A STUDY ON GROUNDWATER ASSESSMENT, DEVELOPMENT AND MANAGEMENT IN THE STATE OF TRIPURA

Thesis Submitted by

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Dedication

"I dedicate my thesis work to my parents and friends. A special feeling of gratitude to my loving and Younger Sister"

CERTIFICATE FROM THE SUPERVISORS

This is to certify that the thesis entitled **"A STUDY ON GROUNDWATER ASSESSMENT, DEVELOPMENT AND MANAGEMENT IN THE STATE OF TRIPURA"** Submitted by **Sri Jayanta DebBarma,** who got his name registered on 02.03.2011 for the award of Ph.D. (Engineering) degree from Jadavpur University is absolutely based upon his own work under the supervision of Prof. (Dr.) Asis Mazumdar, Dr. Pankaj Kumar Roy and Dr. Manish Pal and that neither his thesis nor any part of the thesis has been submitted for any degree/diploma or any academic award anywhere before.

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LIST OF PUBLICATIONS

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SYNOPSIS

TITLE: A STUDY ON GROUNDWATER ASSESSMENT, DEVELOPMENT AND MANAGEMENT IN THE STATE OF TRIPURA

Groundwater has been the mainstay for meeting the domestic needs of more than 80% of rural and 50% of urban population besides, fulfilling the irrigation needs of around 50% of irrigated agriculture. The ease and simplicity of its extraction has played an important role in its development. Recent the problems of decline in water table, contamination of groundwater etc. are being reported at many places.

Total area of Tripura is 10,477 km^2. It receives an annual average Rainfall of 1927 (mm). The hill area is 6400 km^2. The semi-consolidated formations consisting of friable sandstone, sandy shale etc. of Tertiary age forms the main rock types of the area. The unconfined aquifer is mainly tapped through shallow wells with a discharge of 5 to 15 Lps in the valley areas whereas in the sandstone, the yield varies from 2 to 4 Lps. The Annual Replenishable Groundwater Resource is 2.19 BCM and Net Annual Groundwater Availability is 1.97 BCM. The Annual Groundwater Draft is 0.17 BCM and Stage of Groundwater Development is 9%. The entire state has been categorized as Safe. Groundwater development in the deeper aquifers has also been established through construction of deep tube wells, the yield of wells tapping the sandstone areas varies from 25 to 40 Lps. There is no over Exploited, Critical and Semi- critical zone. Exploratory Tube wells Constructed (as on 31.03.2010 (D.W.S.)) are as follows: 948 deep tube well (DTWs) and 26,086 Spot sources. For artificial recharge to Groundwater (AR) the numbers of feasible AR structures are: 300 check dams, 500 weirs, 1000 gabion structures, 240 roof top harvesting, 100 developments of springs. However in districts of Dhalai, North Tripura, South Tripura and West Tripura are affected (in part) by Iron Contaminants (e.g. water having >1.0 mg/l of iron). As on 2009 the total irrigation utilization potential of Tripura is 52616 ha (sources from WR dept, Agriculture dept., ADC, Forest dept. and RD dept. Govt. of Tripura).

Groundwater resource is a replenishable but finite resource. Rainfall is the principal source of recharge, though in some areas, canal seepage and return flow from irrigation also contribute significantly to the groundwater recharge. Groundwater resource comprises of two parts-dynamic which reflects seasonal recharge and discharge of aquifers and static resource below water table.

Aside from the aquifers of the active recharge zone which get charged every year and which constitute the dynamic fresh groundwater resource, there are deeper aquifers below the zone of water level fluctuation. These deeper aquifers of passive recharge zone contain vast quantity of water. The water in these aquifers has accumulated over many years. This water is often called ‘static’ water though in reality it also flows but very slowly. “In the alluvial areas, these resources are renewable and get replenished over long period from recharge areas flanking the mountains. However, in some cases like the “Lathi aquifers” in Rajasthan the in-storage resources comprise fossil water, which is of non-renewable nature” [Romani (2006)]. The tentative estimate of in-storage fresh groundwater in the country is about 10,800 BCM and in Tripura 101 BCM.

The natural reservoir, underlain by unconsolidated alluvial sediments, (sand, gravel, pebbles, etc.) has immense groundwater potential. The water table depth in Tripura of the natural reservoir varies between 2 m and 6 m. In the synclinal valley of Tripura state, aquifers are found in the semi consolidated soft and stones of tertiary age where both shallow (within 20-50 m bgl with yield 5 to 20 m^3/hr) and deep tube wells (50 to 200 m bgl deep with yield varying from 50-200 m^3/hr) are feasible. Potential deep aquifers in the upper tertiary areas of Agartala have been identified in Surma, Tipam and Dupitila parts of the district. The latest estimate of ground water potential of Haora river is 398 MCM/yr but its current utilization is insignificant. Lack of road communication, non availability of flat areas in the hills, high iron content, lack of right type of the equipments for drilling bouldry foundation, huge thickness of clay bodies and over burden of weathered residuum are the dominant problems of ground water development in the area. The existing 70 deep tube well has been found having yield 10,000 to 20,000 gallon per hour.

Since earliest antiquity, humankind has obtained much of its basic requirement of good quality water from subterranean sources. Springs, the surface manifestation of under groundwater, have played a fundamental role in human settlement and social development. But for many millennia, capability to abstract groundwater was tiny compared with the available resource.

To meet the present and future need with currently available surface and groundwater resources, while at the same time preserving terrestrial and aquatic eco-system, will require a sustainable approach to managing water. The industrialized and developing countries should give importance to groundwater resources, so that associated problems of over-abstraction and groundwater pollution is controlled, with the objective of defining sustainable groundwater development. The sustainable groundwater development at a global and local scale is achieved through the maintenance and protection of groundwater resources balanced against economic, environmental, and human (social) benefits.

In recent years, there has been an increasing threat to groundwater quality due to human activities. The adverse effects on groundwater quality are the results of anthropogenic activity at ground surface unintentionally by agriculture, domestic and industrial effluents and unexpectedly by sub-surface or surface disposal of sewage and industrial wastes. Groundwater constitutes about 95 per cent of the freshwater on our planet (discounting that locked in the polar ice caps), making it fundamental to human life and economic development.

Agartala is a developing and growing city which has the capacity to become the gateway of North-East to South East Asia through an international link. However it is already facing some scarcity of water in the area during non-monsoon seasons. Soils of these catchment areas have low retention capacity. These areas have the maximum density of urban population in the whole state (as per population census G.O.I). Earlier Chakraborty, (2009) had estimated the groundwater recharge for west Tripura District and also a study on dynamic groundwater assessment in Agartala city has been carried out by Debbarman, (2010) but there was no rigorous study on entire state of Tripura. But presently Agartala Municipality area has a higher water demand than any other parts in the state due to its higher density of population. Hence, to fill the gap in study and to contribute for sustainable development and management of groundwater resources as well as identification of artificial recharge sites in Tripura State, this area is selected for present research work.

In Chapter 1 highlights an introduction of the selected area along with objective and scope of the work. The comprehensive literature review has been made related to the groundwater development and management in a sustainable manner. The dynamic groundwater potential of Agartala municipality has been estimated using groundwater resources estimation methodology-97 as given in Chapter 1. The methodology uses the rainfall-infiltration method, water-level fluctuation technique and water regression method and the estimated groundwater recharge is validated by using some empirical norms for recharge estimation. The groundwater utilization is also estimated.

In Chapter 2 Groundwater assessment and development of the selected area has been described. Different methods are highlighted and the empirical equations used for static and dynamic groundwater are described in this chapter.

The hydrological cycle with groundwater characteristics are described in Chapter 3 to assess the groundwater balance and also the groundwater scenario of the study area is highlighted.

In Tripura, there are many rivers and most of the rivers are almost dry due to high amount of silt carries from higher altitude and deposits as well at river bed referred in Chapter 4. A critical study is undertaken to assess the groundwater availability in the sub-surface aquifer using vertical electrical sounding (VES) survey at nineteen locations with a total of thirty eight points spread over the area.

Vertical Electrical Sounding (VES) is one such method by which resistivity of earth materials is checked and prospective ground water potential zones are identified along with sub soil stratifications. The resistivity meter (SAR-MP-ATS) was used to collect the VES data by employing Schlumberger electrode configuration and the field data were interpreted in terms of resistivity and the corresponding thickness of various subsurface layers using 'Interpex, IX1D' computer software as given in Chapter 4.

MODFLOW package using groundwater Modeling System (GMS) was applied for this study to find out the volumetric flow budget and hydraulic heads for groundwater under steady state analysis method reflected in Chapter 4.

Results and discussion of all individual data of existing as well as newly added district and block of Tripura are carried out described in Chapter 5. The all calculation for static as well as groundwater scenario of Tripura are made along with water budget components. The sectorial demand and the recharge zone, overflow zone and the development zone of Tripura State are identified as sown in Chapter 5. VES survey could be an alternative method to assess the groundwater potential at present and future scenario by reducing the overall project cost and also to reduce the chances of failure for making borewell in the same or nearby critical areas for all stakeholders as given in Chapter 6. VES study may be used to find the litholog of the terrain without further making boreholes in the regions thus reducing cost incurred and labour required and thus finding groundwater potential zones economically as highlighted in Chapter 6. The results conclude the hydraulic heads decrease against discharge wells and it increases towards recharge wells and this model will help to estimate the groundwater volume for water budgeting as reflected in Chapter 5.

The following concluding remarks to study on groundwater assessment, development and management in Tripura State are highlighted as given below:

- The general geology of the study area is represented by a respective succession of argillaceous and arenaceous sedimentary rocks like sandstone, shale, siltstone and clay belonging to Surma, Tipam and Dupitila Groups. The study area is also found by mottled clay, clayey sandstone, coarse to gritty ferruginous sandstone and pockets of bluish to gray plastic clays with form silica and laterites. The recent alluvium formation is represented by unconsolidated silt, sand, clay, silty clay, etc. and is developed along the rivers streams etc.

- The total river of Tripura state has considered as seventeen having a catchment area of 1.049 Mha. Out of seventeen, eight river are covered by 83% of the total catchment area and the rest 17% of the total catchment area is belonged to the other rivers. These major perennial rivers are all joined by ninety four nallah and Chharas where the total length is covered by approximately 2428 km which in turn forms a part of Meghna sub-basin. The common drainage patterns are sub-parallel to parallel and dendritic up to 4^{th} order streams are found in the study area. The total average river flow of Tripura state is found to be in the tune of 10.89 BCM contributed the base flow of 4.255 BCM. Out of which, a magnitude of 8.92 BCM of river flow is flowing through eight major rivers.

- The highest 39-years average rainfall of Tripura state is found to be 2116 mm. The highest rainfall is observed as 3015 mm in the year of 1997-98 whereas the lowest rainfall is received as 1285 mm in the year of 1994-95. The daily highest rainfall occurred in the month of July in 1993 is recorded as 257 mm. The results also depicted that about 60% of total rainfall is observed during the monsoon period.

- The daily highest temperature is found to be 42.20C in the year of May, 1960 whereas the lowest is observed as 20C in the month of December, 1972. The decade wise a value of 0.2 0C is increased for the last 30-years temperature data.

- Physiographically, the study area is divided by Anticlinal Hill Ranges and Synclinal flat-bottomed valleys. The major hill ranges are Baramura, Atharamura, Longtarai and Shakan. The trend of the hill ranges is almost north-south and the highest peak is recorded as 3066 m in Shakan connected with Manu river. The height of the hill ranges increases from west to east. The broad synclinal valleys are Udaipur- subroom, Amarpur, Agartala, Khowai Dharmanagar, Kamalpur and Kailashahar valley. The valleys are gently undulating with intermittent flood plains of rivers and streams. All the valleys become narrow and constricted towards south and widens towards north. The master slope of the valleys is towards north. The terrain is mostly undulating and hilly with small water streams (Chharas), rivers and fertile valleys intervening. All ephemeral major rivers are originated from top of the hill and flow towards along with valley and ultimately it reaches to Bangladesh. It is true that all rivers are originated in Tripura state which is unique geographical feature.

- Presently in Tripura state eight districts, fifty eight blocks and twenty municipalities/nagar panchayats are recorded. Initially there were four districts, thirty eight blocks and twelve municipalities. However, without further increased the geographical area, all added boundary are redistributed and formed new revenue land structures in the study area.

- There are three hydrogeological units / water bearing formations identified in the state are Alluvial formation, Dupitila formation and Tipam formation. In case of alluvial formation, it occurs along the banks of main rivers and its thickness varies from 0 to 10 m bgl against recent formation and above 10 m bgl found as older formation. In this section, recharge as well as discharge value found are sufficient. Ground water occurs under unconfined condition. Ground water is developed through dug wells and ordinary hand pumps.

- Dupitila formation is nearly horizontal in disposition and its thickness varies from 10 to 30 m. The formation consists of mainly clay and silts with some intercalations of gritty and ferruginous and stones. It is exposed in the central portion of Udaipur valley. In general, it has low permeability and low storage capacity due to high clay content. It has been developed through dugwells and hand pumps. Tipam formation consists of sub-rounded, fine to medium grained, friable sandstone with intercalated clay. Tipam formation is found in the majority of the valley portion. Sandstone of Tipam formation constitutes the principal aquifer in the study area. The permeability of this sandstone is much higher than that of Dupitila sandstone or Surma sandstone. The recharge area of the sandstone is in the anticline hills. Groundwater occurs under semi-confined to confined conditions. This sandstone is developed by deep tubewell sand shallow tubewells.

- The static and dynamic groundwater is calculated using GEC, 09 (Water level fluctuation method) considered overflow zone area for static but not for dynamic condition. The depth ranges from 30-35 m is considered for replenishable dynamic groundwater recharge and storage as well. The specific yield is considered as 0.08 referred by Central Ground Water Board, Govt. of India for estimation of dynamic groundwater recharge. But for static it is considered starting 30 m onwards up to 300 m bgl. So, the total static groundwater storage is estimated as 11.75 BCM with the help of total available boring depth. Again, the dynamic groundwater replenishable as well as storage would be received as 2.03 BCM.

- Nine empirical formulae are used to estimate the replenishable dynamic groundwater and it is validated with the estimated value. The result is also very close to the value found by the Central Ground Water Board (CGWB), Govt. of India considered the period of 1996-2014. The deviated average value of 10.6% is observed compared to CGWB which is a good agreement as close to 20% error prescribed by any past literature.

- The results also showed that the storativity, transmissivity, permeability, hydraulic gradient and yield for confined aquifer of Tripura State are highlighted as given below:

Sl. No.	Storativity	Transmissivity (m^2/day)	Permeability. (m/day)	Hydraulic gradient	Slot
North Tripura valley	$4.2x10^{-4}$ - $2.7x10^{-4}$	4.5-507	0.1-12	$3.13x10^{-3}$ - $1.39x10^{-3}$	3-5
Kailashar valley	$2.2x10^{-3}$ - $5.9x10^{-4}$	26.4-1212	0.4-23.7	$8.42x10^{-4}$ - $4.13x10^{-3}$	4-7
Kamalpur valley	$1.85x10^{-3}$ - $2.85x10^{-4}$	709-1186	26-43	$2.74x10^{-3}$ - $7.4x10^{-4}$	2-7
Khowai valley	$1.0x10^{-2}$ - $5.16x10^{-3}$	1073-1698	15-28		3-6
Agartala valley	$2.06x10^{-3}$ - $4.42x10^{-4}$	86.67-1449	3.62-40.85	$1.01x10^{-2}$ - $8.42x10^{-3}$	2-7
Udipur – Sabroom Valley	$1.36x10^{-3}$ - $4.2x10^{-4}$	246-897	4.6-22.4	$2.4x10^{-2}$ - $7.17x10^{-3}$	2-9
Amarpur valley	-	326-794	7.1 -10.7	$6.28x10^{-4}$ - $2.73x10^{-3}$	3-6

- The above all aquifer parameters are within the limit. Yield test of all individual valleys is conducted for 8 hrs duration with a depth of 300 m and accordingly drawdown data with respect to time are measured and prepared different graphs for all seven valleys. Permeability test is also conducted to estimate the permeability. The groundwater parameters are calculated to assess the static and dynamic groundwater potential and it is reflected in the above table.

- Stations are recorded water levels of eight district during pre and post-monsoon. The minimum and the maximum water level ranges from 1.3 m-5.36 m and 0.68 m-5.34 m during pre-monsoon post-monsoon respectively in North Tripura. The minimum and the maximum water level ranges from 0.93 m-9.32 m and 0.57 m-7.98 m during pre-monsoon post-monsoon respectively in Unokoti. The minimum and the maximum water level ranges from 0.32 m-0.62 and 0.35-5.05 m during pre-monsoon post-monsoon respectively in Dhalai.

- The static water table ranges from 0.3 m to 67.1 m of the study area. There is one place located at Jampui Hill near Mizoram Border under Kanchanpur Block, North Tripura district, the static water level is found to be in the tune of 154.4 m.

The pipe is lowered with a depth of 223 m having a remarkable discharge value of 5.44 m^3/hr. The total filter thickness is given as approximately 48 m.

- Springs/seepage zones are available in the study area. Traditionally tribal people living in the hilly areas are using spring water for drinking and domestic purposes. In the foothill areas people used to arrest the spring water by constructing seasonal/permanent bund on small streamlets/cherras and used this water for irrigation purpose and sometimes used for drinking and domestic purposes also. Artesian zones occur in Tripura State. These wells are mainly used for irrigation purposes but some of the wells are even used for drinking and domestic purposes. The artesian zones found are discontinuous and are localized phenomenon. It is reported that the wells are constructed within a depth range of 5 to 300 mbgl. Discharge of the wells varies from 0.05 to 15 lps during pre-monsoon period and from 0.15 to 7.0 lps during post-monsoon period. It is to be opined that there is one perched aquifer coming hot water which is connected with deep aquifer ranges from 2000 m to 2500 mbgl at Dackmura under Mahara, Amarpur Vally.

- The stage of development is divided into three distinct classes such as high yield, medium yield and low yield based on discharge and drawdown. The values for high, medium and low yield are observed 50-150 m^3/hr, 25-100 m^3/hr and not specified respectively. The drawdown ranges from 0-12 m, 10-45 m and not known for three conditions. As per calculation, 0.2597 BCM (1.16%) is calculated as unaccounted water in water budget which may consider as deep percolation.

CHAPTER 1

DESCRIPTION OF THE RESEARCH STUDY INCLUDING LITERATURE`

1.1. INTRODUCTION

The increasing stress on freshwater resources due to ever-rising demands and profligate uses as well as growing population India is an issue of great concern (Anornu et al., 2009). Sustainable development and efficient management of water is an increasingly complex challenge in India. Increasing population, growing urbanisation and rapid industrialisation combined with the need for raising agricultural production generates competing claims for water. Groundwater has an important role in meeting the water requirements of agriculture, industrial and domestic sectors in India (CGWB, 2014).

Groundwater is the backbone of India's agriculture and drinking water security in urban and rural areas. Nearly 90% of rural domestic water use is based on groundwater while 70% of water used in agriculture is pumped from aquifers. Increasing evidence points to the fact that 50% of urban water usage is groundwater. Groundwater is also important for the industrial sector in a large measure and if left unregulated may lead to serious inter-sectoral conflicts. Hence growth in both agriculture and industry is impingent on how India is able to manage her groundwater resources, particularly the aquifers in different parts of the country. A serious groundwater crisis prevails currently in India due to excessive over-extraction and groundwater contamination covering nearly 60 percent of all districts in India and posing a risk to drinking water security of the population. In addition to over-extraction and biological and chemical contamination, excess groundwater and waterlogging is also a serious problem in many regions, impacting livelihood security of large sections of society. The acute problems relating to groundwater warrant a change in both the perspective on our aquifers as well as the approach in the use and management of groundwater resources. It is necessary to acknowledge the hydrogeological characteristics of groundwater and its integral link to land, vegetation and surface water resources and perceive it as a 'resource' rather than a 'source'. Acknowledging the ubiquity of groundwater usage and its importance to all sections of society, it is necessary to recognize it as a common pool resource and adopt an aquifer-based approach to its management (GEC, 2017).

India is a vast country with diverse geological, geomorphological and hydro meteorological conditions, which give rise to widely varying ground water situations. The hydrogeological units are broadly classified into unconsolidated, consolidated and semi-consolidated formations (CGWB, 2013).

The groundwater behavior in the Indian sub-continent is highly complicated due to the occurrence of diversified geological formations with considerable lithological and chronological variations, complex tectonic framework, climatological dissimilarities and various hydro-chemical conditions. Studies carried out over the years have revealed that aquifer groups in alluvial/soft rocks even transcend the surface basin boundaries. Broadly two groups of rock formations have been identified depending on characteristically different hydraulics of ground water, viz. porous formations and fissured formations (CGWB, 2012).

Groundwater is a dynamic and replenishable resource and monitoring special and temporal changes of this resource is essential for sustainable development and management. The water level data is of paramount importance in development and management of water resources in the country (CGWB, 2015).

Groundwater engineering is the art and science of investigating, developing, and managing ground water for the benefit of man. The technology involves specialized fields of oil science, hydraulics, hydrology, drainage, geophysics, geology, mathematics, agronomy, metallurgy, bacteriology, civil, electrical, mechanical, and chemical engineering. The ever-increasing demand for water will make ground-water engineering increasingly important (Ground Water Manual, 1995).

In addition to the solution of ground-water recovery problems for water supply, ground-water engineering is important in problems concerning seepage from surface reservoirs and canals, the effects of bank storage, stability of slopes, recharging of ground-water reservoirs, controlling of saltwater intrusion, dewatering of excavations, subsurface drainage, and construction, land subsidence, waste disposal, and contamination control.

Ground-water engineering involves the determination of aquifer properties and characteristics and the application of hydraulic principles to ground-water behaviour for the solution of engineering
problems. Determination of aquifer characteristics and the application of those data by appropriate mathematical and other methods are essential to the solution of complex problems in which ground water is a factor. The extent to which the determination of aquifer properties and characteristics must be made depends upon the complexity of the problem involved. It may entail study or consideration of all or only one or two aquifer properties and hydraulic principles. Conditions often may be so complex as to preclude the determination of finite values and the application of available theory to the solution of some problems. Such circumstances require an understanding of the hydrologic cycle developed in the latter part of the 17th century. During the 18th century, fundamentals in geology were established that provided a basis for understanding the occurrence and movement of ground water (Todd, 1980). The French engineer Henry Darcy (1803-58) studied the movement of water through sand and developed the fundamental law of ground-water flow which was largely subjective. The reliability of these principles depends upon the experience and judgment of the ground-water technical specialist.

1.2. General Description of Groundwater

The first use of ground water as a source of supply is lost in antiquity. Ancient man obtained water from springs, but hand-dug wells were widely used in the earliest of Biblical times, and the ancient Chinese are generally regarded as the inventors of drilled and cased wells (McWhorter and Sunada, 1984). For centuries (Tolman, 1957; U.S. Department of

Agriculture, 1956) ground-water use was limited by developmental difficulties and by the absence of a clear understanding of its origin and occurrence. Shallow, hand-dug wells and crude water-lifting devices marked the early exploitation of ground water. The introduction of well drilling machinery and motor-driven pumps allowed the recovery of ground water at increased depths. Expanded knowledge of groundwater hydrology and other sciences added to man's ability to understand and use this resource.

As technology has improved, the benefits of ground-water development have become increasingly important. The use of water for domestic purposes (human and animal consumption) usually has the highest priority, followed by individual requirements and then agricultural usage (irrigation). Development of the ground-water resources of the United States has been increasing in recent years as development of surface water sources approaches the point of full potential.

1.3. Groundwater Components

1.3. 1. Water Supply

The major application of ground-water engineering has been, and probably always will be, the provision of a water supply by means of wells and infiltration galleries. Facilities range from isolated individual small wells yielding a few liters per minute for domestic and stock purposes to well fields consisting of a number of irrigation, municipal, or industrial water supply wells with individual discharges in excess of 20,000 liters per minute (Groundwater Manual, 1995). The small individual well seldom presents a problem if it is designed according to good engineering practice. The larger installations, particularly those with numerous wells, require evaluation of the aquifer characteristics, estimates of well spacing, drawdowns, quality of water, and possibly recharge-discharge relationships. Wells must be designed and pumps selected for economical, long, and trouble-free operation within the capabilities of the aquifer, with the consideration of any possible corrosion and encrustation problems which may be present. Proposed development may be further complicated by restrictions imposed by overlying or underlying saline aquifers, salt-water intrusion, influences on the discharge of adjacent surface water streams, and land subsidence. Some aquifers have little measurable recharge or discharge but contain large quantities of water in storage which have accumulated over long periods. Estimates can be made of the desirability of mining the water and the probable economic life of such aquifers under various degrees of development.

1.3.2. Ground-Water Reservoirs and Artificial Recharge

The storage of surface waters in underground reservoirs and the recharge of depleted ground-water reservoirs are other aspects of ground-water engineering of growing importance and interest. Recharge wells, basins, channels, and waste disposal facilities present special problems of aquifer plugging caused by chemical, biological, and physical factors, and of contamination of overlying or adjacent potable aquifers.

The maintenance of minimum stream flows by supplementing surface water with pumped ground water during low flow periods and recharging the ground-water reservoir during: high runoff is also of growing interest.

1.3.3. Drainage

Drainage may involve the lowering of groundwater levels beneath irrigated lands to permit crop growth, the lowering of water levels or prevention of boils in limited areas to permit excavation and construction activities in the dry, reduction of pressures to maintain stability of slopes, and the reduction of pressures and exit velocities to ensure stability of dams and similar structures incident to reservoir and dam construction. Applications of ground-water hydraulics and engineering are involved in all such problems.

1.3.4. Groundwater Contamination

Finally it is also very much important once the groundwater is contaminated with any toxic substances resulting some technological options are to be adopted at field level. Groundwater modeling is usually a major aspect of predicting direction and rate of contamination potential and mitigation. Situations involving contamination are generally much more complex than those involving water supply or drainage because of complex chemical and biological interactions. In addition, flow of contaminants may not coincide with direction and rate of groundwater flow. The ground-water engineer involved in these projects must work closely with chemists, bio-chemists, and geologists, in evaluating conditions.

1.4. Purpose of Study

In addition to the solution of ground-water recovery problems for water supply, ground-water engineering is important in problems concerning seepage from surface reservoirs and canals, the effects of bank storage, stability of slopes, recharging of ground-water reservoirs, controlling of saltwater intrusion, dewatering of excavations, subsurface drainage, and construction, land subsidence, waste disposal, and contamination control.

Tripura is a picturesque state in the northeastern region of the country. The state is acceded to the Indian Union in 1949 and is bounded on the north, west, south and southeast by the international boundary of Bangladesh. Seven valleys namely Dharmanagar, Kailasahar, Kamalpur, Khowai, Agartala, Udaipur subrum and Amarpur are situated in Tripura and flowing of water from all valleys are sloped towards Bangladesh. Tripura As we know, Tripura is the only state where all major rivers are situated on the top of the hilly area. It is also noted that almost all rivers are in perennial condition but in dry season water scarcity problems occur in most of the hilly areas (approximately 47%). Tripura has got shale zone geologically found in three blocks under north Tripura where yield is insignificant. As per past record reported by Central Ground Water Board that the replenishable net average groundwater availability is found to be 2.27 BCM during the period of 2005-2015.

As per State Govt. reports, around 247 deep tube well with minimum discharge observed as 45.4 m^3/hr. and 3994 shallow tube well are found particularly for irrigation purpose in Tripura State. It is also observed that around 1627 deep tube well and 15583 shallow tube well and 8503 artesian well and 5093 dug well are reported for drinking purpose. Around 1500 private hand pump well with depth varied between 25 m and 45 m are found in general to meet up the water demand. However, most of the available resources are observed in plain area. Keeping in view, shallow tube wells with small command area are most suitable in the state.

The State of Tripura has immense potentialities for ground water development which may be used for green revolution as well as industrial development. The ground water resource so far developed for drinking, agriculture and industrial uses touches only 9% of the dynamic ground water resources. The vast total ground water resources, consisting of dynamic and in-storage ground water resources, remain un-used. For a scientific planning of development of total availability of ground water resource potential, estimation has been done and the total fresh available ground water resource in Tripura has been estimated as 15.88 billion cubic meter (BCM). As if, not only good amount of fresh groundwater is available but also higher amount of rainfall approximately 2116 mm is occurred even though a very less amount of water is available for domestic purpose particularly in hilly area during dry season.

1.5 Objective and Scope of the Present Research Study

The overall objective of the research work is to assess groundwater potential, identification of recharge zone, estimation of sectional groundwater flow and demarcation of overflow zone including management options in the state of Tripura. The details scope of work as different stages are given below:

- Since database on these components like evaporation and evapo-transpiration, inflow and outflow across the assessment boundary, baseflow, etc are not readily available with the state governments at present efforts should be made for the generation of database of these components, so that at micro-level assessment, complete water balance of the assessment unit of Tripura state is attempted.
- Considering the changing groundwater scenario, re-assessment of groundwater resources is to be carried out at regular intervals for further strengthening of the available database. These may include intensified monitoring of the measured data like water level, rainfall, canal discharge, well sensus, baseflow etc. and special studies on estimation of parameters like specific yield, rainfall infiltration factor, canal seepage factor, return flow factor etc.
- For lateral flow in the confined aquifers which are hydro-geologically separate from shallow water table aquifers, the groundwater is to be assessed by resistivity survey for seven valleys to work out the optimum development of the confined aquifers as well as the recharge area may be demarcated in the state of Tripura.
- Deep Tube Well by Rig machine (direct/reverse) is to be drilled for preparation of lithological sheet using collected soil sample at different layer under static groundwater level condition.
- Sub-surface geology of panel diagram is to be made in Tripura for estimation of effective sand bed with all aquifer parameters.
- Recent study done by Debbarman, J in Agartala indicates that with high degree of groundwater development, water levels have not shown a declining trend. It is, therefore, considered that temporary depletion of water table taking place in non-monsoon period is made up in years of high rainfall or in other wards the utilization of static reserves and consequent depletion in water levels in non-monsoon period is made up during years of high rainfall. This may be studied by comparing the long term rainfall and water table hydrograph to establish the periodical recharge. In such areas it would be desirable that the groundwater reservoir be drawn to the optimum limit to provide adequate scope for its recharge during the monsoon period. It is also looked into that the static groundwater resource, basin wise/district wise in each district of Tripura is to be evaluated.
- Recharge zone is to be identified for present and future water uses in different sectors.

- Groundwater potential zones are to be identified for future water allocation at block/village level.

1.6. Road map of the Study Area

1.6.1. Salient Features

Tripura is located in the south-west extreme corner of the north-eastern region. With an area of 10,492 sq km, it is one of the smallest states of the country. It is surrounded by Bangladesh on its north, south and west: the length of its international border is 856 km (84 per cent of its total border). The state is connected with the rest of India by only one road (NH- 44) that runs through the hills to the border of Karimganj District in Assam and then winds through the states of Meghalaya, Assam and North Bengal to Calcutta. The State of Tripura is located between $22^0$56” and 24o 32” North latitude and between 90^0 09” and 92^0 20” East latitude. Tripura is a landlocked State. The total length of its border is 1018 km. It is connected with the mainland through Assam over a small strip of border of 53 km characterized with unfavorable terrain. Nearly 70% of the total area is hilly, leaving very little cultivable land. About 59% of the total area is classified as forest total forest area was reported 6,294.3 sq. km. and TSAC 3666.88 sq km. Reserved forest works out 3588.183 km^2 and unclassified Government forest is 2195.473 km^2 under the ambit of the Forest Conservation Act. The net sown area is approximately 280,000 ha which constitutes about 27% of the state’s total area. The cropping intensity is 172%. The state has many rain-fed, non-perennial rivers and streams draining into Bangladesh.

Tripura comprises picturesque hills, green valleys with the symphony of splashing water and dense forests. The mountain mass that has beautified the landscape 23 of the state thrusts South from the Eastern Himalayan region of Asia between the Brahmaputra and the Chindwin - Irawady river systems. The hills of Tripura rise in a succession of ranges running mainly from the North to the South, each successive ridge to the East rising higher as the spur approaches the main mountain mass. Five major and two minor ranges of hills all around from North-West to South-East and separated from each other by beautiful valleys make the hilly terrain of Tripura. The major hill ranges from West to the East are: Boramura, Atharomura, Longtorai, Sakhantang, Jampui. The highest peak of the state is Betalangshiv, Which is about 1097.28 m. succession of Jampui hill range. Major Tributaries of Tripura: Tripura is fiiH of rivers, tributaries and streams. Most of the places, areas or villages are named after rivers .and tributaries. Some of the important rivers of the state are the Gumoti, the Khowai, the Manu, the Haorah and the Mohuri. Many myths, legends and folk tales also surrounded by these rivers. Among these, the Gumoti is the biggest river and considered as the most sacred by the people of Tripura. It is considered to be as holy as Ganga of North India.

Photo 1.1. Water fall at Sanaiya Reangbasti, Dhalai, Tripura Sandstone

Photo 1.2. Water fall at Dalapati, Gandacharra, Dhalai, Tripura conglomerate and Tripum Sandstone

Photo 1.3. Sandstone formation

Photo 1.4. Thin seepage at Assam Agartala road at Atharamura hill ,in the month of February

Photo 1.5. 0.74 m (bgl) water level at Sipahijala centurion wild forest in the month of March

Photo 1.6. Soil sample for litholog at bishalgarh under Sipahijala

1.6.2. Study Area

1.6.2.1. Geology

The state of Tripura exhibit a wide array of sedimentary rocks characteristics of marine-mixed fluvial type origin ranging age from upper most Oligocene (38 million years from present time) to recent period referred in Table 1.1. These sediments, according to GSI, have been laid down in the Surma basin during Tertiary age (which lasted for 65 million years) in a wide range of environmental conditions governed by local tectonic movement. Tectonically, the region now comprises a series of sub-parallel arquate, elongated, doubly plunging folds arrange in north south direction. These folds for anticlines is separated by wide flat sinclines.

Table 1.1. Groups of sediments during different geological age on litho-stratigraphy

Age	**Group**	**Formation**
Holocene		Khowai Formation
		Ghilatoli Formation
		Teliamura Formation
		Kalyanpur Formation
Quaternary	Dupitila	Dupitila Formation
Upper Pliocene to Pleistocene	Tipam	Upper Tipam Formation
Pliocene		Lower Tipam Formation
Micocene- Lr. Pliocene	Surma	Bokabil Formation
		Upper Bhuban Formation
		Middle Bhuban Formation
Upper most Oligocene		Lower Bhuban Formation (Not exposed in Tripura)

Source: GIS, Govt. of India

Photo 1.7. Surma sand stone, Unokoti Tripura

Photo 1.8. Wanasa Para, Kalayansing Village, Gandacharra Dhalai, Tripura conglomerate

Photo 1.9. Alternate thin layers of Sandstone and Shale, surma formation Atharamura hill

Photo 1.10. Soil and sandstone of Bhuban formation at Assam Agartala road, Ambassa to Atharamura

Photo 1.11. Splintary shale with very thin bands of Sandstone Surma formation at Kalajrt hill Dmburnagr

Photo 1.12. Bhuban Sandstone formation at Amarpur Gandacherra road

1.6.2.2. Topography /Physiography

The topography is immature. The major geomorphic elements observed in the area are both structural and topographic ‘highs’ and ‘depressions’, ‘flats’ and ‘slopes’, sculptured on the topographic surface in a linear and areal fashion. In Tripura the topographic highs and lows are in accordance with the normal first order structural elements. The state is dissected by a number of broad and long valleys, viz.,Agartala-Udaipur-Sabrum, Khowai-Telimura-Amarpur-Silachari, Kamalpur-Ambasa-Candachara, Kailashar-Kumarghat, Dharmanagar-Panisagar, etc. located between the N-S trending parallel to sub-parallel antiformal hill ranges (topographic highs), such as the Baramura-Deotamura Ranges, the Atharamura Ranges, the Langtarai Ranges, the Shakan Ranges, and the anticlinal ranges. There are a few disconnected open and shallow anticlinal ridges, viz. Gazalia-Mamunbhagna anticline, Sonamura anticline, Agartala dome, etc. Besides, small-scale elements like the spurs, keels, and the moderate gorges are the other geomorphic elements formed. Generally, the valleys are broad and flat with low to moderate Bed Relief Index (BRI), which are separated from the adjacent highs with domes and conical peaks. Some of the peaks of the hills are also flat. The RL between the elevations of the peaks and valleys has increased eastwards constantly. The general altitude of the state varies between 16 m to 600 m above MSL. The drainage patterns are of ‘dendritic’, ‘parallel’ to ‘sub-parallel’ and ‘rectangular’ types. The stream channel patterns lie mainly within the ‘piedmont’, ‘straight’ and ‘meandering reaches. The ‘braided reach’ is, however, not noticed along the course of the stream channels. The drainage flows down along north by the Khowai, Dolai, Manu, Juri and Langai Rivers; West by the Gumti River and southwest by the Fenny and Muhari Rivers

1.6.2.3. Soil

The soil types of Tripura can be classified under five major groups, of which Red loam and sandy loam soil occupies 43.07 percent of the total area followed by Reddish yellow brown sandy soils (33.06%), the other three groups occupy less than 10 percent each.

Photo 1.13. Tipam Sandstone near Bgma ,Udaipur valley

Photo 1.14. Recharge zone at Agartala bypass Road

Photo 1.15. Recharge Zone at Takatjala

Photo 1.16. Different soil layer recharge vertically

Table 1.2. Soil type of Tripura

S. No.	Soil Group	Area		Soil taxonomic unit
		sq. km	Percent	
1	Reddish yellow brown sandy soils	3468.17	33.06	(a)UlticHapludalfs
				(b) UdicUstochrepts
				(c) TypicUdorthent
2	Red loam and sandy loam soils	4514.32	43.07	(a) UlticHaplustaIfs
				(b) Typic/UlticHapludalfs
				(c) TypicPaleudaIfs
				(d) TypicUstochrepts
				(e) TypicDrystochrepts
				(f) UdicUstochrepts
				(g) TypicU.stochrepts
3	Older alluvial soils	1019.13	9.71	(a) TypicOchraquaJfs
				(b) TypicHaplaquepts
4	Younger alluvial soils	980	9.34	(a) TypicUdifluvents
5	Lateritic soils	510.07	4.86	(a) TypicPalehumults
				(b) TypicPlinthustults
				(c) TypicPlinthudults
				(d) TypicPaleudults
	Total	10491.69	100	

1.7. Methodology

1.7.1. Validation of the acquired data with the help of GIS and remote sensing

This part of the study tried to compare percentage of error, water spread area and impermeable (construction, road, building, etc) area field data with GIS data of Agartala municipality area in Tripura with the help of remotely sensed imageries.

a) Satellite Data upload and Download

In this regard the first step was to upload latitude longitude (field Survey) data upload on google earth and download the latest imageries of municipality area of Agartala. This imagery has been taken from SPOT image.

b) Radiometric Correction & Contrast enhancement

The downloaded image has been imported in ERDAS IMAGINE 10.1 'Viewer'. After importing Radiometric correction Contrast correction has been applied for improving visual impact of the image. Some trial and error enhancements were expected to find the desired results, and then those enhancement values were applied to the image data file.

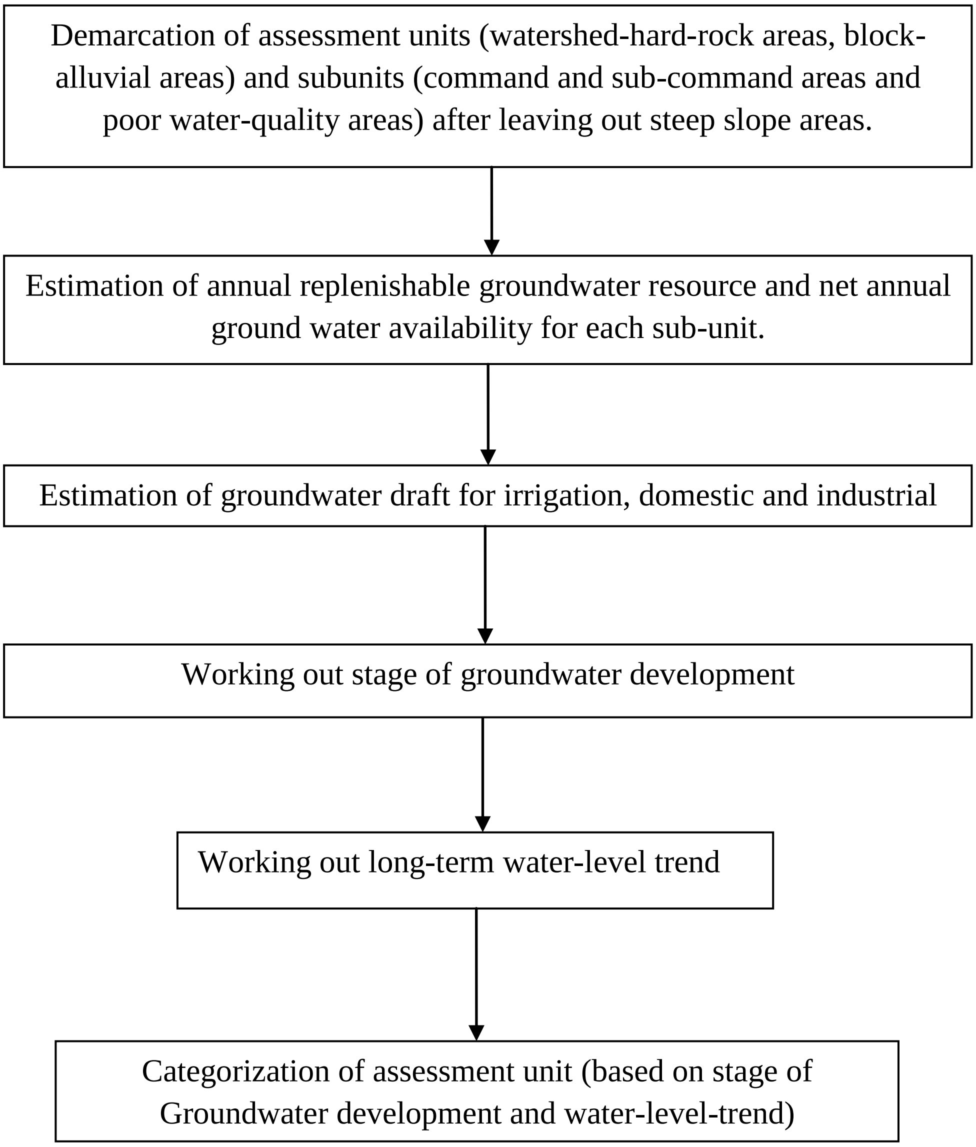
The model input includes

GPS readings were taken at the survey points and along the boundary (as per eye estimation) readings were identified and imported into the MapWindow software along with the satellite imagery of the study area .A polygon was drawn by joining these points to get the catchment or total area of influence of the river basins. The distance between the farthest point were determined in the following method,

- First, the locations of the boundary were identified from Google Earth with the help of GPS data taken from these locations.
- Then, the screen window was captured with the help of some screen capture software and the captured image was imported into the GIS software.
- The coordinate type was changed by going to File > Settings > Project Projection
- A line shape file was created and drawn to connect two points of interest.

1.7.2. Flowchart of Groundwater Development

Groundwater has been assessed using different input of the study area and it has been categorized and accordingly unit is classified based on stage of groundwater development and also to identify the water level as depicted in flow chart.



1.7.3. Groundwater estimation flowchart

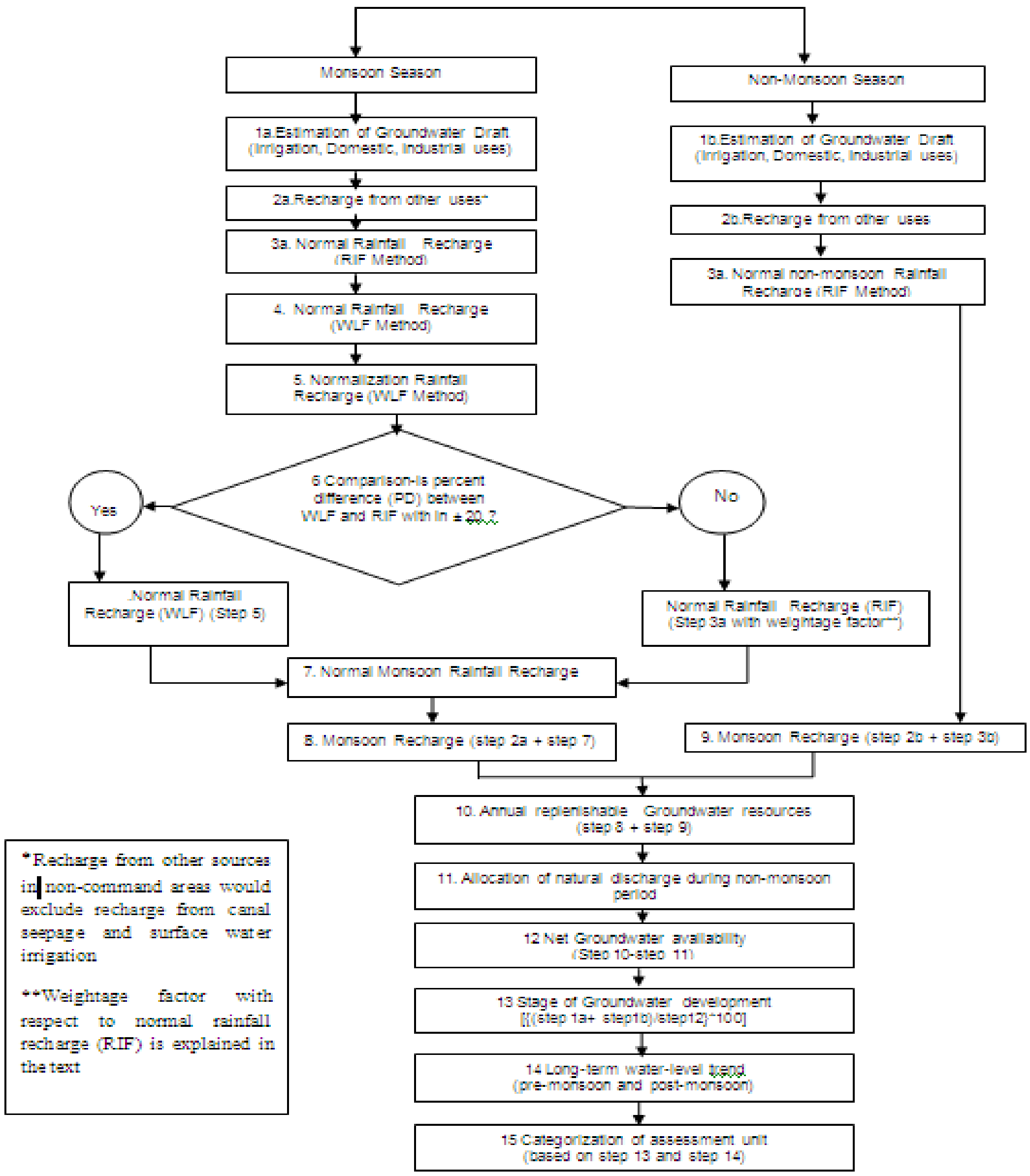


Fig. 1.1: Step for estimation & categorization of annual replenishable groundwater resources [Rajagopalan, 1998]

The groundwater resources in unconfined aquifers can be classified as static and dynamic. The static resources can be defined as the amount of groundwater available in the permeable portion of the aquifer below the zone of water level fluctuation. The dynamic resources can be defined as the amount of groundwater available in the zone of water level fluctuation. The replenishable groundwater resource is essentially a dynamic resource which is replenished annually or periodically by precipitation, irrigation return flow, canal seepage, tank seepage, influent seepage, etc.

Groundwater recharge of Tripura has been computed according to GEC'97 methodology delineated in Fig. 1.1. Steps for the estimation of annual replenishable groundwater resources and categorization of assessment units/sub-units are presented in Fig. 3.1. Several data related to water level data collected from CGWB and observation wells data located in different municipality area were used for groundwater resource assessment. Rainfall data for thirty nine years (1970-2008) were utilized mainly for the assessment of groundwater resource. The rainfall infiltration factor and specific yield were considered 0.16% and 8% respectively for calculation of recharge volume.

There are two methods of recharge volume against rainfall data namely water level fluctuation (WLF) and rainfall infiltration method (RIM). These methods are used to estimate the recharge volume from rainfall during monsoonal season and the equations are described in Table 1. The recharge volume during non-monsoonal period is calculated by using RIM only. The other methods of governing equations are highlighted in Table 1.3 to consider as for calculating the recharge volume for the same study area. The assessment units are categorized according to the status of groundwater utilization and water level trend (Table 1.4). Some established equations were used to validate the calculated results obtained from GEC, 1997. The formulae along with their limitations are highlighted in Table 1.5.

Table 1.3. Governing equations for calculation of recharge volume (Debbarma et al, 2013)

Method/Type	Equation	Remarks
Gross groundwater draft in any season (GGWD)	GGWD=n*unit draft where unit draft=draft per day*no of days the structures are in use	n = no of abstraction structures actually in use
Estimation of Recharge for other uses		
Recharge from canals (R_c in ha-m)	R_c=WA*Days*SF where WA=WP*L WP=(2*ASD)/(sin(side angle)) +BW	WA=wetted area in Mm^2, WP=wetted perimeter in m, L=length of canal segment in km, ASD-average supply depth in m, side angle-side slope in degree, BW=bed width in m.
Recharge from surface water irrigation (R_{swi} in ha-m) same as groundwater irrigation (R_{gwi} in ha-m)	R_{swi} = IWA*RFF where IWA = AD*days	IWA=irrigation water applied in ha-m, RFF=return flow factor as a fraction, AD=average discharge of the outlet in ha-m/d.
Recharge from tanks & ponds (R_T in ha-m)	R_T = AWSA*days*RFact here RFact= 1.4 mm/d	AWSA=avg water spread area, RFact=a recharge factor in mm/d
Recharge from water conservation structures (R_{WCS} in ha-m)	R_{WCS}=GS*RFact where GS=storage capacity* no of fillings	GS=gross storage
Estimation of Recharge for Rainfall		

Recharge from Rainfall, R_{RF} using Rainfall Infiltration factor method (RIF)	R_{RF} = NMR x A x RFIF	NMR=normal monsoon rainfall, RFIF=rainfall infiltration factor, A=total area of the sub unit
Recharge from rainfall using water level fluctuation method (WLF)	R_{RF} = (A x WLF x S_y) + D - R_{other}	A = area suitable for recharge, WLF=water level fluctuation, S_y =specific yield, D=gross draft and Rother=recharge from other sources.
Estimation of Percent Difference (PD)		
Percent Difference	PD=(R_{Rf} (wtfm)-R_{Rf}(rifm))/ (R_{Rf}(rifm)) * 100	R_{Rf} (wtfm) = rainfall recharge for normal monsoon season estimated from WLF, R_{Rf}(rifm)= rainfall recharge for normal monsoon season estimate from RIF
Total groundwater recharge (TGWR)	TGWR=$R_{RF+}R_c+R_{swi}+R_{gwi}+ R_{WCS}+ R_T$	
Total annual groundwater recharge (TAGWR)	TAGWR= TGWR(monsoon)+ TGWR (non-monsoon)	
Net annual groundwater availability (NAGWA)	NAGWA= TAGWR-UND where UND=unavoidable natural discharges	
Stage of development (SD)	SD=(existing gross draft for all uses/NAGWA)*100	
Allocation of groundwater for domestic and industrial needs (AFDIWR in mm/year)	AFDIWR =22 * N*L_g where $L_g \leq 1.0$	N=projected population density in the sub unit in thousands per km^2
Net annual groundwater availability for future irrigation use (NAGWAFFIU)	NAGWAFFIU=NAGWA-(CGGWDFI+AFDIWR)	CGGWDFI=current gross groundwater draft for irrigation
Static groundwater resources (SGWR)	SGWR=A*(Z2-Z1)*Sy	Z_2=max depth of the bottom of the unconfined aquifer, Z_1=max. Extension of zone of water table fluctuation,

Table 1.4. Criteria for categorization of assessment units [Chatterjee and Purohit, 2009]

sl. no.	Stage of groundwater development	Significant long term decline		Categorization
		Pre-monsoon	Post-monsoon	
1	<=70%	No	No	Safe
2	> 70% and <= 90%	No	No	Safe
		Yes/No	Yes/No	Semi- Critical
3	> 90% and <= 100%	Yes/No	Yes/No	Semi- Critical

		Yes	Yes	Critical
4	> 100%	Yes/No	Yes/No	Over- Exploited
		Yes	Yes	Over- Exploited

Table 1.5. Empirical equations for various regions in India

Name of the formula	Equation	Remarks
Chaturvedi formula	$R_{ef} = 2.0\,(P - 15)^{0.4}$	R_{ef} = net recharge due to precipitation during the year, in inches; and P= annual precipitation, in inches.
U.P. Irrigation Research Institute, Roorkee	$R_{ef} = 1.35\,(P - 14)^{0.5}$	
Kumar and Seethapathi (2002)	$R_{ef} = 0.63(P - 15.28)^{0.76}$	R_{ef} = Groundwater recharge from rainfall in monsoon season (inch); P = Mean rainfall in monsoon season (inch).
Amritsar formula	$R_{ef} = 2.5\,(P - 16)^{0.5}$	Where, R_{ef} and P are measured in inches
Krishna Rao	$R_{ef} = 0.35\,(P - 600)$	Areas with P above 2000 mm

1.7.4. Estimation Methodology of Dynamic Groundwater Resources

Groundwater recharge usually considered a process of water movement downward through the saturated zone under the forces of gravity or in a direction determined by the hydraulic conditions. Total recharge to Groundwater has several components, rainfall being the major one. The other components include return flow from surface water irrigation, return flow from Groundwater irrigation, seepage from tanks ponds etc. Recharge from various sources has been calculated for monsoon as well as non-monsoon periods.

Estimation of Groundwater Recharge is a complexity of factors - hydrogeological, hydrological and climatological, control the Groundwater occurrence and movement. The precise assessment of recharge and discharge is rather difficult, as no techniques are currently available for their direct measurements. Hence, the methods employed for Groundwater resource estimation are all indirect. Groundwater being a dynamic and replenish able resource, is generally estimated based on the component of annual recharge, which could be subjected to development by means of suitable Groundwater structures.

For quantification of Groundwater resources proper understanding of the behaviour and characteristics of the water bearing rock formation known as Aquifer is essential. An aquifer has two main functions - (i) to transit water (conduit function) and (ii) to store it (storage function). The Groundwater resources in unconfined aquifers can be classified as Static and Dynamic. The static resources can be defined as the amount of Groundwater available in the permeable portion of the aquifer below the zone of water level fluctuation. The dynamic resources can be defined as the amount of Groundwater available in the zone of water level fluctuation. The replenishable Groundwater resource is essentially a dynamic resource which is replenished annually or periodically by precipitation, irrigation return flow, canal seepage, tank seepage, influent seepage, etc.

The methodologies adopted for computing Groundwater resources based on the hydrological budget techniques. The hydrologic equation for Groundwater regime is a specialized form of water balance equation that requires quantification of the items of inflow to and outflow from a Groundwater reservoir, as well as of changes in storage there in. A few of these are directly measurable, some may be determined by differences between measured volumes or rates of flow of surface water and some require indirect methods of estimation. These items are,

I. Items of supply to Groundwater reservoir

1. Precipitation infiltration to the water table.
2. Natural recharge from stream, lakes and ponds.
3. Groundwater inflow into the area under consideration.
4. Recharge from irrigation, reservoirs, and other schemes especially designed for artificial recharge.

II. Items of disposal from ground' water reservoir

1. Evaporation from capillary fringe in areas of shallow water table, and transpiration by phreatophytes and other plants / vegetation.
2. Natural discharge by seepage and spring flow to streams, lakes and ponds.
3. Groundwater outflow.
4. Artificial discharge by pumping or flowing wells or drains.

Over the years the Groundwater assessment techniques have evolved from progressive understanding of Groundwater occurrence and movement, recharge and discharge processes.

Groundwater recharge of Agartala Municipality under West Tripura district has been computed according to GEC'97 methodology (hilly area in Agartala Municipality area is zero). Three rain gauge stations and fifteen (3 dug well, 12 nos. shallow tube well) 5 years water level data from CGWB and five (public, one year's data) observation wells data in the Agartala Municipality area were used for Groundwater resource assessment. Rainfall data for 39 years (1970-2008) were utilized mainly for the assessment. The rainfall infiltration factor and specific yield used in the recharge calculation is 0.16% and 8% respectively. Recharge from surface or Groundwater irrigation during monsoon period has not been considered as there is enough rainfall during monsoon and irrigation not practiced.

Recharge from monsoon Rainfall, RMR

Recharge from monsoon rainfall is a function of geographical area of the district and the normal monsoon rainfall. In GES'97 methodology, two approaches are recommended for calculation of recharge from monsoon rainfall – water level fluctuation method (WLFM) and rainfall infiltration method (RIFM). In the present study both the approaches were worked out. The equation used for computation of recharge from monsoon rainfall by RIFM is

$$\mathbf{RMR = NMR \times A \times RIF}$$

Where, RMR is recharge from monsoon rainfall, NMR is normal monsoon rainfall, A is area suitable for recharge and RIF is rainfall infiltration factor.

Recharge from rainfall using water level fluctuation method has been estimated using the following relation.

$$\mathbf{R_{ef} = (A \times WLF \times S_y) + D - R_{other}}$$

Where, $\mathbf{R_{ef}}$ is recharge from rainfall, A is area suitable for recharge, **WLF** is water level fluctuation, $\mathbf{S_y}$ is specific yield, **D** is gross draft and $\mathbf{R_{other}}$ is recharge from other sources.

The results from the above two methods (WLFM & RIFM) have been compared using percent deviation **(PD)** and recharge from rainfall has been computed as per the criterions recommended by the methodology (GEC'97).

- Recharge from non-monsoon rainfall **(RNMR)**
  Recharge from rainfall during non-monsoon period has been computed using rainfall infiltration method only.

- Recharge from ponds and tanks **(R P/T)**
  Recharge from tanks is taken as 0.00144m/day for the period in which the tank has water. Here the period considered is 100 days

- Recharge from Groundwater irrigation **(RGW)**
  Recharge from Groundwater irrigation during non-monsoon period has been estimated based on types of crop, crop water requirement and irrigated area. For paddy 45% of total water applied for irrigation and for non-paddy 25% of total water applied for irrigation has been considered.

- Recharge from surface water irrigation**,(RSWI)**
  Recharge from surface water irrigation during non-monsoon period has been estimated based on the same conditions as for RGWI. For paddy 50% of total water applied for irrigation and for non-paddy 30% of total water applied for irrigation has been considered.

Net Annual Groundwater Availability, NAGA

Net annual Groundwater availability has been computed by deducting the unaccounted natural discharge from the total annual recharge. Unaccounted natural discharge has been taken as 5 to 10% as per the criteria recommended by GEC'97 methodology.

For validation water bodies and impermeable (Road building) data compare with GIS

Return flow from irrigation

The recharge due to return flow from irrigation may be estimated, based on the source of irrigation (Groundwater or surface water), the type of crop (paddy, non-paddy) and the depth of water table below ground level, using the norms provided below.

Recharge from storage tanks and ponds:
1.4 mm/day for the period in which the tank has water, based on the average area of water spread. If data on the average area of water spread is not available, 60% of the maximum water spread area may be used instead of average area of the water spread.

Recharge from percolation tanks:
50% of gross storage, considering the number of fillings, with half of this recharge occurring in the monsoon season, and the balance in the non-monsoon season.

Recharge due to check dams and nala bunds:
50% of gross storage (assuming annual desilting maintenance exists) with half of this recharge occurring in the monsoon season, and the balance in the non-monsoon season.

1.7.5. Advantages and Limitation Groundwater Estimation

Advantages

- The method is a lumped approach and therefore relatively simple to use.
- It is suitable with regard to the data normally available from Groundwater level monitoring programmes of State and Central agencies.
- Application of water-level fluctuation (WLF) method for recharge estimation during monsoon season. The WLF method which is more commonly referred to in the International literature as water table fluctuations (WTF) method, provides actual field evidence of recharge to Groundwater. The area represented by recharge rates (fluxes) arrived through the WLF method ranges from tens of square meters to several hundreds or thousands square meters. These recharge fluxes can be spatially integrated over large areas, which is important for large scale water resources assessment. Thus this method is suitable for regional estimates. The time period is represented by the recharge estimates using the WLF method ranges from event (short time) scale to the length of the hydrographic record. Thus there scope for assessment both at short time intervals as well as longer periodical intervals using WLF method.

- Since monsoon rainfall is the most significant contributor to Groundwater recharge in our country, rain fall recharge during the monsoon season is estimated using two methods- WLF method and rain fall infiltration factor (RIF) method.

Limitation:

- A field survey is required for hand pump (shallow tube well) for exact quantity estimation of Groundwater withdrawal.
- A field survey is required for land use pattern data (Irrigation area type of crop sources of water etc., constructed area road building etc. Department wise data, Water Resources, R.D. Forest, agriculture PWD) for exact quantity estimation of Groundwater recharge.
- Groundwater estimation committee 1997 by CGWB recommended 1.44 for pond and tank recharge factor which is based on Maharastra, the factor is appropriate or not for this area proper research work is required
- And also CGWB recommended in rainfall infiltration method considering area for recharge and again a portion(water logged pond, tank, lake, river) of the area which was recommended for accounting in recharge from pond/tank but in our estimation we are not considering here same area in several time in a period
- For water table fluctuation method specific yield considered 8% it may be more as per soil structure for that a proper research work is required
- Here we consider unaccounted natural discharge is 10% in rainfall infiltration method it may be more as per soil structure and slope of the area therefore a detailed research study is required.
- In the end of the non-monsoon period (last 3 month March, April, May) water level dropped 5-10 m in deep tube well therefore rate and trend of groundwater flow identification is required.

1.8. Literature Review

Groundwater resources estimation methodology report was recommended under the Groundwater resources estimation committee under Ministry of Water Resources Government of India, New Delhi in June 1997.

Due to the rapid expansion of urban, industry and agriculture, the water requirement of the country and groundwater utilization is of fundamental importance now. Reliable estimation of groundwater resources is therefore, a prime necessity. Quantification of the groundwater recharge is a basic pre-requisite for efficient groundwater resource development and this is particularly vital for India which has widely prevalent semiarid and arid climate. The soil and water resources are limited. They are often in a delicate balance. Quantification of groundwater resources is often critical and no single comprehensive technique is yet identified which is capable of estimating accurate groundwater assessment.

Attempts have been made from time to time by various Working Groups/ Committees /Task Force, constituted under the Government of India, to estimate the Groundwater resources of the country based on status of available data and in response to developmental needs. But, due to paucity of scientific data and incomplete understanding of the parameters involved in recharge and discharge processes, all these early estimation were not accurate but tentative and best approximations.

In 1972, guidelines for an approximate evaluation of groundwater potential were circulated by the Ministry of Agriculture (Government of India) to all the State Governments and financial institutions. The first attempt to estimate the Groundwater resources on a scientific basis was made in 1979. In the year 1982, Government of India constituted "Groundwater Estimation Committee" (GEC). In 1984 this committee, after reviewing the data collected by central and state agencies, research organizations, universities etc. recommended the methods for Groundwater recharge estimation. The GEC (1984) recommended two approaches for Groundwater resource assessment, namely (1) Groundwater level fluctuation and specific yield method and (2) rainfall infiltration method.

But there were some basic merits as well as few limitations of the existing methodology. Several issues have been raised on the GEC-1984 Report. These reviews were required for improvement in the existing methodology. Evaluation and utilization of the case studies of Groundwater assessment in the recent years in different parts of the country was carried out. While going through such a review process, one had to keep in view the status of data on groundwater resource evaluation, as available in the country. The methodology as recommended by the GEC-1984 is reviewed here, both on its merits and limitations.

The two approaches recommended by the GEC-1984 are: groundwater level fluctuation method and rainfall infiltration method. Several improvements were made in the basic approaches on the a) limitations of the existing methodology b) Improvements of the existing methodology c) revision of norms for Groundwater assessment. In the proposed methodology, discussions such as hard rock areas and alluvial areas, canal command areas and non-command areas and recharge in monsoon season and non-monsoon season are kept in view. It was recommended that the recharge due to rainfall in the monsoon season was to be estimated by groundwater level fluctuation method, unless adequate data is not available, for which case rainfall infiltration method may be used. The groundwater recharge assessment is essentially for unconfined aquifers. The usable groundwater resource is essentially the dynamic resource which is recharged annually by rainfall and other sources.

The methodology for groundwater resource estimation is based on relatively sound scientific method. It also meets adequately well the practical requirements for formulating rational groundwater development strategies. It is also commensurate with available human resources, their level of technical skill and available infrastructure facilities with the state level groundwater organizations which have to actually apply the methodology. However, it is to be also recognized that the methodology has considerable scope for refinements and improvements which can be planned to be achieved in a time bound and phased manner for future assessment.

Kumar (2002) discussed that groundwater assessment methodology on the basis of The 'National Water Policy' adopted by the Government of India in 1987 and revised in 2002. It regards water as one of the most crucial elements in developmental planning with regard to Groundwater, by Water Balance Concept. The estimation of groundwater balance of a region, requires quantification of all individual inflows to or outflows from a groundwater system and change in groundwater storage over a given time period.

The basic concept of water balance is:

Input to the system - outflow from the system = change in storage of the system (over a period of time).

The general methodology of computing Groundwater balance consists of the following:

- Identification of significant components,
- Quantifying individual components and
- Presentation in the form of water balance equation

The groundwater balance study of an area may serve the following purposes: As a check on whether all flow components involved in the system have been quantitatively accounted for, and what components has the greatest bearing on the problem under study. To calculate one unknown component of the groundwater balance equation provided all other components are quantitatively known with sufficient accuracy. Groundwater balance equation considers the various inflow and outflow components in a given study area.

Preferably, all elements of the groundwater balance equation should be computed using independent methods. Computations of various components usually involve errors, due to shortcomings in the estimation techniques. The goundwater balance equation therefore generally does not balance, even if all its components are computed by independent methods. The resultant discrepancy in Groundwater balance is defined as a residual term in the balance equation, which includes errors in the quantitative determination of various components as well as values of the components which have not been accounted in the equation. The water balance may be computed for any time interval. The complexity of the computation of the water balance tends to increase with increase in area. This is due to a related increase in the technical difficulty of accurately computing the numerous important water balance components.

The various inflow/outflow components of the groundwater balance equation may be estimated through - Appropriate empirical relationships suitable for a region, Groundwater Estimation Committee norms (1997), Analytical methods, field experiments or other methods, such as sample survey etc.

- Recharge from Rainfall Empirical Methods: Several empirical formulae have been worked out for various regions in India on the basis of detailed studies. Some of the commonly used formulae are: (a) Chaturvedi formula: (b) Kumar and Seethapathi (2002): (c) Amritsar formula: (d) Krishna Rao:
- Soil Moisture Data Based Methods a).Soil Moisture Balance b).Monthly water balancing by Thornthwaite method c).Nuclear Methods
- Recharge from Canal Seepage: The various guidelines for estimating losses in the canal system are only approximate. The seepage losses may best be estimated by conducting actual tests in the field. Inflow - outflow method. The total losses from the canal system generally consist of the evaporation losses and the seepage losses.
- Recharge from Field Irrigation: Drum-Culture Method
- Recharge from Tanks
- Influent and Effluent Seepage
- Inflow from and Outflow to Other Basins
- Evapotranspiration from Groundwater
- Draft from Groundwater
- Change in Groundwater Storage
- Establishment of Recharge Coefficient

Kumar and Seethapathi (1998) discussed quantification of the rate of natural groundwater recharge is a pre-requisite for efficient groundwater resource management. It is particularly important in regions with large demands for groundwater supplies, where such resources are the key to economic development. However, the rate of aquifer recharge is one of the most difficult factors to measure in the evaluation of groundwater resources. Estimation of recharge, by whatever method, is normally subjected to large uncertainties and errors. In this paper, an attempt has been made to derive an empirical relationship to determine Groundwater recharge from rainfall in Upper Ganga Canal command area based upon seasonal groundwater balance study carried out for a number of years.

Chakraborty (2008) describe in his paper groundwater assessment estimation procedure of West Tripura District in Tripura. In India dynamic groundwater recharge is calculated following the GEC' 97 methodology advocated by the Groundwater Estimation Committee,1997.For assessing the groundwater potential it's recharge is required to properly tackle the rapid increase in urban, rural, industrial and agricultural water requirements. Hence proper assessment of groundwater potential is warranted. West Tripura is a highly agrarian district of Tripura where both groundwater and surface water resources are utilized for irrigation. For tapping the entire utilizable Groundwater, the resource assessment was highly necessitated. Most of the inputs were derived from the field studies and norms / factors considered (as per GEC'97 methodology) wherever necessary. Rainfall data from five rain gauge stations and water level fluctuation data from eleven observation wells spread throughout the district were used for recharge assessment. Total recharge to groundwater has several components, like monsoon rainfall, surface water irrigation, groundwater irrigation, seepage from surface water bodies etc. Net annual groundwater available has been arrived by deducting unaccounted natural discharge from total groundwater recharge.

Mohan. and Ramani Bai (2000) discussed in their paper how to estimate groundwater potential by a comparative analysis on the basis of the hydro-geological features such as sub-soil structure, rock formation, lithology. Location of water plays a crucial role in determining the potential of water storage in groundwater reservoirs. To assess the groundwater potential, a suitable and accurate technique is required for a meaningful objective analysis. A critical study is carried out on the different methods of estimating the groundwater potential and compared to arriving at the most suitable technique for practical utility. In this work, four methods of estimating groundwater recharge where studied viz., yearly water level fluctuation, 10 years average water level fluctuation, fluctuation between the lowest and highest water levels over 10 years and fluctuation in monsoon season. The result of this study helps in accurate prediction of groundwater availability, which in turn may avoid groundwater over exploitation and help restore the aquatic –ecosystem.

Chatterjee and Purohit (2009) told in their findings that the dynamic groundwater resources of India have been estimated using groundwater resource estimation methodology-1997. The methodology uses the water-level fluctuation technique and empirical norms for recharge estimation. The groundwater utilization is also estimated. The stage of groundwater development is worked out and assessment units are categorized based on the stage of groundwater development and long-term water-level trend. The annual replenishable groundwater resources of India and net annual groundwater availability were also estimated resulting in the annual groundwater draft and thus the overall stage of Groundwater development. In the year of 2004, out of 5723 assessment units in the country, 4078 are ‘safe’ and 839 are ‘overexploited’. The rest are fallen under ‘semi-critical’ and ‘critical’ category. Over-exploitation is more prevalent in North-western, Western and Peninsular India. Eastern India has good potential for future groundwater development. Considering the changing groundwater scenario, re-assessment of groundwater resources needs to be carried out at regular intervals. This would require further strengthening of the available database.

Singhal.et.al.(2010) in their study attempted to delineate aquifers in the piedmont zone of Himalayan foot hill region in Pathri Rao watershed, district Haridwar, Uttarakhand, India. They used integrated hydrologic and geophysical techniques. The geophysical techniques included vertical resistivity soundings, two dimensional resistivity image profiling and electromagnetic surveys. Nuclear isotope studies have been carried out to estimate the groundwater recharge and its relative age. An assessment of groundwater availability and stage of groundwater development has also been made from the available and generated field data on the basis of the study, it was found that the rate of recharge in to the aquifers. And the stage of groundwater development in the watershed indicated critical over-exploration of the ground water. Based on the findings, possibilities of artificial recharge of the groundwater have been looked in the study area for augmentation of groundwater resources by proposing a few check dam at the suitable site in the upstream areas of the watershed.

Pendke (2009) studied on Pimpri watershed located in Hingoli district, Maharashtra, which was treated with various soil and water conservation measures like nala bunding, loose boulder dams, earthen plugs, vegetative hedges and contour trenches during the year 1992 to 1993. Four open wells in treated and two open wells in untreated areas of the watershed were selected for monitoring Groundwater table fluctuations to study the effect of watershed management on increase in groundwater potential. Meteorological data, namely, rainfall and evaporation were collected. The hydrologic budget equation (Walton) was used for assessing the gravity yield, which is the change in Groundwater storage per unit difference in Groundwater elevation at each well. The gravity yield of 2.2% and 1.2% were observed in treated and untreated watersheds respectively indicating 86.5% increase. Monthly change of 0.22 ha-m/ha and 0.19 ha-m/ha in Groundwater storage per unit area was calculated for treated and untreated areas respectively. The monthly cumulative Groundwater potential in both treated and untreated area was calculated. An increase of 40% to 45% in accumulated groundwater potential due to watershed management practices was observed in the treated area after a period of four years showing clearly the impact of watershed management.

Briz-Kishore (1983) used a sophisticated method of measuring water levels. Researchers tried to determine the groundwater potentialities in a typical weathered and fractured environment by storage method. In his findings the frequency of the rainfall had shown a direct bearing on recharging the groundwater system compared to the intensity of the rainfall. The Thiessen polygon method was used to determine the weighted average of the rainfall over the basin area to estimate the groundwater infiltration rates. The long term average infiltration to the medium is established as 15% of the total rainfall.

Bhattacharjee (1982) told that the macro-level water balance and its correlation with rainfall can be used to calculate groundwater recharge to an unconfined aquifer. For his research the hydrographs of 15 observation wells in the Hooghly district of West Bengal for the years 1978 to 1980 were analyzed. A good correlation was found between seasonal rainfall and changes in water level. By evaluating the increment in Groundwater reserve, and checking the specific yield of the aquifer by pumping tests, the potential Groundwater for the area was calculated.

ANCD, (2004) stated that applicability in the use of groundwater monitoring wells to identify and also to estimate canal seepage based on the principle that water introduced to a soil profile that reaches the water table can change the hydraulic and chemical conditions within the aquifer. In the areas where the canal water level is above the level of Groundwater, there is a hydraulic gradient between the canal and the aquifer, which provides a driving head for seepage to migrate away from the canal. Conversely, if the groundwater level is very high and above the canal water level, Groundwater will discharge into the canal.

Seepage from a channel into an aquifer results in an increase in the water stored in the aquifer and therefore a rise in Groundwater level. Groundwater observation bores allow the water table (piezometric level) to be measured and monitored. Trends in the Groundwater levels in relation to channel running times can provide an indication of seepage, and it may be possible to estimate seepage rates in some circumstances. In addition, chemical analysis can provide information on chemical changes in the Groundwater in the aquifer resulting from the introduction of channel water. Groundwater observation bores provide a permanent record of the response of the aquifer to seepage from canals, and this can be useful for post-remediation seepage analysis in analytical calculation, Numerical analysis, and Hydro chemical Methods.

Rangarajan and Athavale (2000) estimated that the natural recharge is a vital parameter to be known for groundwater budgeting, management and modeling. Percolation of a portion of the rainfall, through the vadose zone, is the principal source of natural recharge to the aquifer systems in India. The tritium injection method, based on piston flow model, is particularly suitable for quantifying the downward flux of moisture in the vadose zone and for measuring natural recharge in Indian climatic condition, where about 80% of the annual rainfall is received as pulses and occurs during the four monsoon months from June to September. Natural recharge measurements, using the tritium injection method, have been carried out in India during the last 25 years, in several basins and watersheds, located in varying climatic and hydro geological situations. The mean natural recharge values for 35 study areas, well distributed over 17 major river basins are presented. The recharge rates range from 24 to 198 mm yr^{-1} or 4.1 to 19.7% of the local average seasonal rainfall.

The natural recharge data were grouped into four main hydro geological provinces, namely granitic, basaltic, sedimentary and alluvial and the regression equations between rainfall and natural recharge are derived for each province. These equations enable one to determine the approximate value of natural recharge in any watershed/basin from the rainfall data for any year. The regression equations are used to compute the total annual replenishment of Groundwater reserves of the country, for an average rainfall year. The calculated annual input is about $476 \times 10^9\ m^3\ yr^{-1}$. This can be considered as a minimal quantity, as it represents the natural recharge due to precipitation alone and does not account for seepage from ponds, lakes, stream bed, canals and return flow from surface water irrigation.

Sharda et.al., (2006) suggested that **g**roundwater recharge from water storage structures under semi-arid conditions of western India has been estimated by employing water table fluctuation (WTF) and chloride mass balance (CMB) methods. Groundwater recharge was estimated as 7.3% and 9.7% of the annual rainfall by WTF method for the years 2003 and 2004, respectively while the two years average recharge was estimated as 7.5% using CMB method. A Recharge function depicting the relationship between potential recharge from storage structures and successive day averaged storage depths was better exhibited by a power function. A diagnostic relationship correlating the rainfall to the potential recharge from water storage structures has been developed to explain the characteristics of the storage structures for a given geographical location. The study has revealed that a minimum of 104.3 mm cumulative rainfall is required to generate 1 mm of recharge from the water storage structures. It was also inferred that the storage structures have limited capacity to induce maximum recharge irrespective of the amount of rainfall and maximum recharge to rainfall ratio is achieved at a lower rainfall than the average annual rainfall of the area. An empirical linear relationship was found to reasonably correlate the changes in chloride concentration with water table rise or fall in the study area.

Jha et.al., (2009) described that RS (remote sensing), GIS (geographic information System) and MCDM (Multi Criteria Decision Making) could be a tool in identifying groundwater potential zones in the Bankura district of West Bengal, Eastern India. Remote sensing data and available conventional maps have been used to generate thematic layers for: geology, geomorphology, land use/land cover, drainage density, soil, slope, lineament density and proximity to surface water bodies, using GIS software. All these thematic layers were standardized using fuzzy logic, and weights were assigned to thematic layers according to their relative influence on Groundwater occurrence. The assigned weights were normalized using Saaty's Analytic Hierarchy Process (AHP). Finally, all thematic layers were integrated in a GIS environment to generate a Groundwater potential map. Thus, four Groundwater potential zones were identified, viz., "good" (23% of study area), "moderate" (29%), "poor" (20%) and "very poor" (28%). It is concluded that RS, GIS and MCDM are very useful tools for delineating Groundwater potential zones in an area/basin, especially under data-scarce conditions.

Chandrashekar et.al., (2000) suggested that Groundwater pollution potential has been assessed through Remote Sensing and GIS technique**.** DRASTIC index methodology helps in the assessment of Groundwater pollution potential. DRASTIC index uses a set of seven hydrogeological parameters viz., D-depth to Groundwater table; R-recharge due to rainfall; A-aquifer media; S-soil media; T-topography; I-impact of vadose zone; C-hydraulic conductivity. These parameters are weighed with respect to their relative importance. All the DRASTIC parameter layers in spatial formats are put into GIS. The layers were assigned weights and ratings and they are combined interactively in the computer system. The DRASTIC index map was generated on a minute grid and seven categories of Groundwater pollution potential zones were identified. The Drastic Index represents the relative measure of Groundwater pollution potential, which helps planners and administrators in broadly screening areas for waste disposal sites. Pollution potential map also helps in evaluating alternatives for directing the financial resources and land use activities to the appropriate areas.

Sikdar et.al., (2004) described in their paper the study of land use /land cover conversions in Raniganj area from 1972 to 1998 and Groundwater potential zoning for future Groundwater development has been delineated using the techniques of Remote Sensing and Geographic Information System (GIS). The study indicates that land covered by vegetation and settlement has decreased at the expense of mining activity, which was reflected in the increase in area of overburden dump, barren land, waste land and abandoned quarry filled with water. Land use/land cover conversion has taken place in about 99.6 sq km, which accounts for 34.9 % of the total area, over 26 year period. Overlay analysis using multi-criteria such as drainage texture, geomorphology, lithology, current land use and steepness of slope and frequency of lineaments has been utilized to understand the potentiality of Groundwater for future development. The analysis indicated that the Groundwater potentiality of Raniganj area is medium (yield: 25 –50 m3/hr) with high potential (yield: >50 m3/hr) in the stretch along the Damodar River and in small pockets in the northern part of the study area. The Groundwater abstractions structures was feasible in the each of the various potential zones have also been suggested.

Whid et.al., (2007) described how to estimate the potential of Groundwater use as investigated in the Teesta barrage project in which large-scale Groundwater development for dry season irrigation has taken place in the recent past. Several technique and tools have been applied, such as the combination of analysis of Groundwater hydrographs and mathematical modelling to derived key hydrological variables, calculations of net irrigation requirement and the use of geographical systems. The results showed that the economically attractive high yielding variety boro (dry season) rice cultivation during the Groundwater irrigation season may not be sustainable in large parts of the project area if the current trends in abstraction are continued. However, due to special variation in abstraction of Groundwater in few areas, a structured approach, based on zoning of potential areas is recommended for groundwater development and use.

Ndubuisi (2007) described in his paper, how to assess Groundwater recharge into the water table aquifers in semi-arid reasons of Northern-Nigeria as estimated using soil moisture deficit method. Three sides representing the major geological basins of the area were used based on available data. The results show that the average annual value of range and drought effect was evaluated by a comparison with the results during the drought period. The study provides information that can be used for modelling and management of Groundwater in the area.

Shahid (2010) estimated and described assessment of Groundwater demand in North West Bangladesh. It was carried out as part of sustainable water resources management in North West Bangladesh. ASTER image were synthesized for extracting the extent of irrigated land. The Penman-Monteith method was used for calculation of reference evapotranspiration for climate data, soil information is used for estimation of water requirement for land preparation and seepage loss. The domestic water demand was calculated from population census data.

Zagana et.al (2006) mentioned in their paper that groundwater recharge in semi-arid areas are fundamental because Groundwater is often the only water resource of importance. This paper described the water balance method of Groundwater recharge estimation in three different hydro-climatic environments in eastern Mediterranean, in northwest Greece (Aliakmonas basin/Koromilia basin), in Cyprus (Kouris basin and Larnaka area) and in Jordan (northern part of Jordan). For the Aliakmonas basin, Groundwater recharge was calculated for different sub-catchments. For the Upper Aliakmonas basin (Koromilia basin), a watershed-distributed model was developed and recharge maps were generated on a daily basis. The mean annual recharge varied between 50 and 75 mm/year (mean annual rainfall 800 mm/year). In Cyprus, the mean Groundwater recharge estimates yielded 70 mm/year in the Kouris basin. In the Larnaka area, Groundwater recharge ranged from 30 mm/year (lowland) to 200 mm/year (mountains). In Jordan, the results indicated recharge rates ranging from 80 mm/year for very permeable karstified surfaces in the upper part of the Salt basin, where rainfall reaches 500 mm/year to less than 10 mm/year and to only about 1 mm/year in the southernmost part of the basin. For the north part of Jordan, a watershed-distributed model was developed and recharge maps were generated. This water balance model was used for Groundwater recharge estimations in many regions with different climatic conditions and has provided reliable results. It turned out to be an important tool for the management of the limited natural water resources, which required a detailed understanding of regional hydrogeological processes.

Chen et.al., (2008) discussed in their paper the estimation of water fluxes, such as Groundwater recharge and loss. It is vital for water resources assessment and planning. In this study, lysimeter measurements at the Wudaogou Hydrological Experiment Station in the Huaihe River plain region were used for analyzing characteristics of Groundwater recharge from precipitation and Groundwater loss due to evapotranspiration. A multilayer soil moisture model integrating water fluxes between vegetation, soil, and aquifer was used for simulating soil moisture dynamics and Groundwater recharge and loss. The model was calibrated against observed soil moisture content from 1994 to 2000. Model validation was conducted by comparing model simulated Groundwater recharge and loss with the corresponding lysimeter-measured values. Statistical results from lysimeter measurements reveal influences of vegetation, depth to Groundwater, and soil moisture content on Groundwater recharge and loss. Modeling results proved that the model is able to reliably simulate soil moisture content and water fluxes. Water budget analysis showed that the multiyear mean of Groundwater recharge is approximately 25% of the mean of potential evapotranspiration and the multiyear mean Groundwater evapotranspiration loss is 22% of the precipitation amount.

The Assessment and Estimation Report of Dynamic Groundwater resources of India based on GEC'97 (base year as 2004) by Government of India 2006, identifies the areas where Groundwater development is at low key and the areas, where Groundwater development is alarmingly high. The estimation for the individual state was jointly carried out by the Groundwater Wing of the State Govt., and the concerned Regional Office of Central Groundwater Board. The technical guidance for the state level estimate and national level compilation was given by R&D Advisory Committee.

CHAPTER 2

GROUNDWATER ASSESSMENT AND DEVELOPMENT

2.1. Ground-Water Development, Sustainability, and Water Budgets

A ground-water system consists of a mass of water flowing through the pores or cracks below the Earth‘s surface. This mass of water is in motion. Water is constantly added to the system by recharge from precipitation, and water is constantly leaving the system as discharge to surface water and as evapotranspiration. Each ground-water system is unique in that the source and amount of water flowing through the system is dependent upon external factors such as rate of precipitation, location of streams and other surface-water bodies, and rate of evapotranspiration. The one common factor for all ground-water systems, however, is that the total amount of water entering, leaving, and being stored in the system must be conserved. An accounting of all the inflows, outflows, and changes in storage is called a water budget. Human activities, such as ground-water withdrawals and irrigation, change the natural flow patterns, and these changes must be accounted for in the calculation of the water budget. Because any water that is used must come from somewhere, human activities affect the amount and rate of movement of water in the system, entering the system, and leaving the system. Some hydrologists believe that a predevelopment water budget for a ground-water system (that is, a water budget for the natural conditions before humans used the water) can be used to calculate the amount of water available for consumption (or the safe yield). In this case, the development of a ground-water system is considered to be "safe" if the rate of ground-water withdrawal does not exceed the rate of natural recharge. This concept has been referred to as the "Water-Budget Myth" (Bredehoeft and others, 1982). It is a myth because it is an oversimplification of the information that is needed to understand the effects of developing a ground-water system. As human activities change the system, the components of the water budget (inflows, outflows, and changes in storage) also will change and must be accounted for in any management decision. Understanding water budgets and how they change in response to human activities is an important aspect of ground-water hydrology; however, as we shall see, a predevelopment water budget by itself is of limited value in determining the amount of ground water that can be withdrawn on a sustained basis.

Some hydrologists believe that a predevelopment water budget for a ground-water system (that is, a water budget for the natural conditions before humans used the water) can be used to calculate the amount of water available for consumption (or the safe yield). This concept has been referred to as the "Water-Budget Myth".

2.1.1. National Water Policy

The "National Water Policy" (2012) adopted by the Government of India regards water as a scarce natural resource, fundamental to life, livelihood, food security and sustainable development. It emphasizes that the efforts to develop, conserve, utilise and manage this resource have to be guided by national perspective. The concerns related to water are generally the skewed accessibility to safe water for drinking and other domestic needs, general perception that groundwater is an individual‘s property rather than community resource, encroachment of river channels, blockage of recharge zones and inter regional disputes in sharing water etc. Safe water for drinking and sanitation should be considered as pre-emptive needs, followed by high priority allocation for other basic domestic needs including needs of animals, achieving food security, supporting sustenance agriculture and minimum eco-system needs. The National Water Policy enunciates the following guidelines for ground water in particular.

The availability of water resources and its use by various sectors in various basins and states in the country need to be assessed scientifically and reviewed at periodic intervals, say every five years. Water is essential for sustenance of eco-system and therefore, minimum ecological needs should be given due consideration. The anticipated increase in variability in availability of water because of climate change should be dealt with by increasing water storage in its various forms, namely soil moisture, ponds, ground water, small and large reservoirs and their combination. There is a need to map the aquifers so as to know the quantum and quality of ground water resources replenishable as well as non replenishable in the country. Quality conservation and improvement is very important for ground water since cleaning of it is very difficult. Declining ground water levels in over exploited areas need to be arrested by introducing improved technologies of water use, incentivizing efficient water use and encouraging community based management of aquifers.

Watershed development activities with ground water perspectives need to be taken in a comprehensive manner to increase soil moisture reduce sediment yield and increase overall land and water productivity. The present action of revising the ground water estimation methodology is a sequel to the tenets of the National Water Policy for periodic reassessment of ground water potential on scientific basis. "If sustainable development is to mean anything, such development must be based on an appropriate understanding of the environment—an environment where knowledge of water resources is basic to virtually all endeavours" (WMO/UNESCO, 1991)

2.1.2. Ground Water Development Scenario

During the past four-five decades, there has been a phenomenal increase in the growth of ground water abstraction structures due to implementation of technically viable schemes for development of the resource, backed by liberal funding from institutional finance agencies, improvement in availability of electric power and diesel, good quality seeds, fertilisers, government subsidies, etc. The net irrigated area tripled from 21 million hectares in 1950–51 to 63 million hectares in 2008–9; the share of groundwater irrigation through wells rose substantially from 28 per cent to 61 per cent. The main contribution in this came from rapid growth in tube well irrigation, the share of which rose from zero in 1950–51 to over 41 per cent by 2008–9. This shows that groundwater irrigation with the advent of tube well irrigation technology has made a huge contribution to irrigation growth in India. This could also be assessed from the facts that during the period 1951-92, the number of dug wells increased from 3.86 million to 10.12 million that of shallow tube wells from 3000 to 5.38 million and public bore/tube wells from negligible to 68000. The number of electric pump 16 sets has increased from negligible to 9.34 million and the diesel pump sets from 66,000 to about 4.59 million. Such a magnitude of ground water development requires realistic assessment of ground water resources to avoid any deleterious effects on ground water regime and to provide sustainability to the ground water development process.

2.2. Ground Water Resources Assessment

There are several techniques for estimation of ground water recharge, which can be broadly classified into methods based on physical parameters, chemical and isotopic methods and numerical modelling and empirical methods. All the methods of recharge estimate have inherent uncertainties and therefore it is advisable to use more than one method since these techniques generally complement each other. The choice of technique depends upon the objective of the study and hydrological and hydro-meteorological conditions of the area. Regional scale assessment forms the foundation of country scale assessment since it studies the ground water flow system of the entire aquifer system as a unique identity. In some countries, the regional scale implies Regional Aquifer systems like USA whereas in case of countries like Australia and South Africa, regional scale assessment is at basin/ catchment level. In Kansas High plain alluvial aquifers, total availability, ground water accessibility and ground water recharge are estimated. While Availability is estimated based on Storage properties of the aquifer, Accessibility is determined based on Hydraulic Conductivity and Ground Water Level. The Ground Water Recharge is determined based on Water Budget, Soil Moisture Balance and Ground Water Flow modelling technique. Kansas State is divided into five GMD – each GMD has its own ground water management policy. Based on hydrologic conditions and demand considerations, the ground water management policies (Safe/ Sustainable Yield policy, Planned Depletion Policy) are decided. The existing practices of ground water resource estimation in India are comparable to the International Practices. There are many commonalities in the methodology used in India and in countries like South Africa and Australia. Gradual Refinements in methodology were brought in the South African Practice as in India. Guiding principles, outputs and forms of outputs are also comparable. However, in view of the international best practices, a refined methodology has been proposed. The methodology is based on Sustainable Yield Policy. Assessment unit would be aquifer based, alternatively hydrologic unit like micro-watershed (hard rock), doab (alluvium) and catchment area (hilly terrain). Separate assessment to be done for phreatic and confined aquifers. Assessment would be carried out in GIS based approach. Proposed methodology is based on water balance approach. Exploitable groundwater resources would be calculated taking into consideration the minimum flow in the river. The Stage of Exploitation (SOE) would be estimated and validated with the water level data. A Significance Index has been introduced to check the reliability the assessment. The Categorization of assessment unit would be done for the purpose of groundwater resources management. Categorization would involve following criteria – SOE, Extractability Factor (depending on average yield of wells), Temporal Availability Factor (based on dissipation rate during non-monsoon period) and Quality Factor. The total Availability of groundwater resources in the phreatic aquifer would also be assessed incorporating – Replenishable Resource in storage Resource. Assessment of groundwater resources in Confined aquifer involves estimation of groundwater storage under pressure condition and ground water draft. GIS based classification is recommended to bring out spatial variation in groundwater condition in confined aquifer.

2.2.1. *Water Balance Equation*

The following equation is a generalised form of water balance equation, which applies to any assessment unit irrespective of it being an administrative unit, a watershed or an aquifer. This water balance equation (eq. 2.1) holds good for any part of the year and for the annual water balance as well.

$\Delta S = R_{rainfall} + R_{other} - B - GE_{all} - ET \pm L \pm O_{\ inflow\ /outflow}$ (2.1)
Where ΔS = Change in storage in ground water reservoir
$R_{rainfall}$ =Recharge from rainfall
$Rother$=Recharge from other sources
B = Baseflow
GE_{all} = Ground water draft for all uses
ET = Evapotranspiration losses
L =Leakage to or from deeper aquifers
$Oinflow\ /outflow$ =Net inflow/outflow across the boundary of the assessment unit
The above equation can be rewritten as
$\Delta S = R_{rainfall} + R_{other} - GE_{all} \pm V_{out\ net}$ (2.2)

Where the new term introduced $V_{out\ net}$ is the net inflow/ outflow from the unit which is the resultant of baseflow, evapotranspiration losses, leakage from or to the deeper aquifers, net flow across the boundaries etc. One of the major limitations of the existing methodology (GEC'97) is that in an attempt to simplify the water balance equation it completely ignores the net inflow/outflow term. A complete assessment of ground water resources should include assessment of all the components of the above water balance equation (eq. 2.2). However, if the unit chosen is a watershed in a hard rock area with a single aquifer system, the components like L and O inflow /outflow can be neglected. However, there cannot be a generalised assumption. It is left to the judgement of the professional doing the assessment to include or neglect any component based on field conditions and to formulate the water balance equation accordingly.

2.2.2. Water Table Fluctuation (WTF)

2.2.2.1. Ground water level fluctuation method

The water level fluctuation method is applied for the monsoon season to estimate the recharge using Ground water balance equation. The ground water balance equation for the monsoon season is expressed as,

RG- DG -B+IS+I= ΔS

Where RG = gross recharge due to rainfall and other sources including recycled water DG = gross ground water draft B = base flow into streams from the area IS = recharge from streams into ground water body

I = net ground water inflow into the area across the boundary (inflow - outflow) ΔS = increase in ground water storage in the above equation, if the area under consideration is a watershed, the net ground water inflow (I) may be taken as zero. If there is inflow and outflow across the boundary, theoretically, the net inflow may be calculated using Darcy law, by delineating the inflow and outflow sections of the boundary. Besides such delineation, the calculation also requires estimate of transmissivity and hydraulic gradient across the inflow and outflow sections. For the present ground water assessment as prescribed in these recommendations, the net inflow may be dropped. There are similar difficulties in estimating the base flow and recharge from streams in the above equation. Hence, it is recommended that the base flow and recharge from stream in the above equation may also be dropped. After deleting net inflow and base flow the equation is now rewritten as, $R=\Delta S + DG = h \times S_y \times A + DG$ Where R= Possible recharge, which is gross recharge minus the natural discharges in the area in the monsoon season (RG - B + I +IS) h = rise in water level in the monsoon season A = area for computation of recharge S_y = specific yield ΔS = increase in ground water storage DG = gross ground water draft The recharge calculated from the above equation gives the available recharge from rainfall and other sources for the particular monsoon season. For non-command areas, the recharge from other sources may be recharge from recycled water from ground water irrigation, recharge from tanks and ponds and recharge from water conservation structures. The recharge from rainfall is given by,

$$R_{rf} = R - R_{gw} - R_{wc} - R_t = h \times S_y \times A + DG - R_{gw} - R_{wc} - R_t$$

Where R_{rf}= recharge from rainfall R_{gw}= recharge from ground water irrigation in the area R_{wc}= recharge from water conservation structures R_t= Recharge from tanks and ponds

In command areas there are two more components in recharge due to other sources viz. recharge due to canals and return flow from surface water irrigation. Hence the rainfall recharge can be estimated using the following formula as given below

$$R_{rf} = h \times S_y \times A + DG - R_c - R_{sw} - R_t - R_{gw} - R_{wc}$$

Where, R_{rf} = rainfall recharge h = rise in water level in the monsoon season S_y = specific yield A = area for computation of recharge DG = gross ground water draft in the monsoon season R_c= recharge due to seepage from canals R_{sw}= recharge from surface water irrigation R_t= recharge from tanks and ponds R_{gw}= recharge from ground water irrigation R_{wc}= recharge from water conservation structures

2.2.3. Empirical Methods.

For Recharge Assessment several empirical formulae have been worked out for various regions in India on the basis of detailed studies. Some of the commonly used formulae are:

(**a) Chaturvedi formula:** Based on the water level fluctuations and rainfall amounts in Ganga-Yamuna doab, Chaturvedi in 1936, derived an empirical relationship to arrive at the recharge as a function of annual precipitation.

$$\mathbf{R_{ef} = 2.0\,(P - 15)^{0.4}}$$

where, $\mathbf{R_{ef}}$ = net recharge due to precipitation during the year, in inches; and
P = annual precipitation, in inches.
This formula was later modified by further work at the U.P. Irrigation Research Institute, **Roorkee and the modified form of the formula is**

$$\mathbf{R_{ef} = 1.35\,(P - 14)^{0.5}}$$

The Chaturvedi formula has been widely used for preliminary estimations of groundwater recharge due to rainfall. It may be noted that there is a lower limit of the rainfall below which the recharge due to rainfall is zero. The percentage of rainfall recharged commences from zero at P = 14 inches, increases up to 18% at P = 28 inches, and again decreases. The lower limit of rainfall in the formula may account for the soil moisture deficit, the interception losses and potential evaporation. These factors being site specific, one generalized formula may not be applicable to all the alluvial areas.

Tritium tracer studies on Groundwater recharge in the alluvial deposits of Indo-Gangetic plains of western U.P., Punjab, Haryana and alluvium in Gujarat state have indicated variations with respect to Chaturvedi formula.

(b) Kumar and Seethapathi (2002): They conducted a detailed seasonal groundwater balance study in Upper Ganga Canal command area for the period 1972-73 to 1983-84 to determine groundwater recharge from rainfall. It was observed that as the rainfall increases, the quantity of recharge also increases but the increase is not linearly proportional. The recharge coefficient (based upon the rainfall in monsoon season) was found to vary between 0.05 and 0.19 for the study area. The following empirical relationship (similar to Chaturvedi formula) was derived by fitting the estimated values of rainfall recharge and the corresponding values of rainfall in the monsoon season through the non-linear regression technique.

$$\mathbf{Ref = 0.63\ (P - 15.28)^{0.76}}$$

where, $\mathbf{R_{ef}}$ = Groundwater recharge from rainfall in monsoon season (inch);
P = Mean rainfall in monsoon season (inch).
The relative errors (%) in the estimation of rainfall recharge is computed from the proposed empirical relationship was compared with Groundwater balance study. In almost all the years, the relative error was found to be less than 8%. On the other hand, relative errors (%) computed from Chaturvedi formula were found to be quite high. Therefore conveniently be used for better and quick assessment of natural Groundwater recharge in Upper Ganga Canal command area.

(c) Amritsar formula: Using regression analysis for certain doabs in Punjab, the Irrigation and Power Research Institute, Amritsar, developed the following formula in 1973.

$$\mathbf{R_{ef} = 2.5\ (P - 16)^{0.5}}$$

where, **Ref** and **P** are measured in inches.

(d) Krishna Rao: Krishna Rao gave the following empirical relationship in 1970 to determine the Groundwater recharge in limited climatological homogeneous areas:

Ref = K (P - X)

The following relation is stated to hold good for different parts of Karnataka:
Ref = 0.20 (P - 400) for areas with annual normal rainfall (P) between 400 and 600 mm
Ref = 0.25 (P - 400) for areas with P between 600 and 1000 mm
Ref = 0.35 (P - 600) for areas with P above 2000 mm
where, Rr and P are expressed in millimeters.

(e) Chandra and Saxena (1975):the empirical formula Recharge from rainfall was suggested **(1975)**was given as follows:

$$\mathbf{Rr = 3.984\ (P - 40.64)^{0.5}}$$

Where, **Rr** = Recharge to the groundwater (cms), **P** = Monthly precipitation (cms). recharge was estimated using the five years monthly rainfall data of different ranging station.

(f) (Bredenkamp,(1990): This relationship yields a recharge equation as follows:

$$\mathbf{RE = A\ (RF - B)}$$

Where, RE is recharge, RF is rainfall, and A and B are simulated parameters.

Considering the general applicability of this method and the soil types, together with the range of annual rainfall, the following simulated parameters were applied, the factors that influence precipitation in northern Nigeria: **A** = 0.2 and **B** = 395. The relation becomes:

$$\mathbf{RE = 0.2\ (RF - 395)}$$

where RF is rainfall (in mm/year). This mathematical relation was used in the estimation of recharge From Equation it is important to note that **A** = 0.2 is the optimized lumped parameter representing threshold rainfall that has to be exceeded to effect recharge while **B** = 395 is aconstant representing integrated accumulated soil moisture deficit for a non-dolomitic area. In the simulation of these parameters an aquifer porosity of 0.028 was assumed.

(g) Sinha and Sharma,(1988): $\mathbf{= 50.8((p/25.4)-15)^{0.4}}$, Where, **P**= precipitation is greater than 380 mm/year.

(h)The Water 2010 Modelling Approach*:* The Water 2010 project provides a national coverage of modelled data for surface water runoffand deep drainage to groundwater. Water balance components derived from Water 2010 were given reliability ratings from A to F based on the source of data and the type of analysis the data had undertaken. In general, the Water 2010 data used has a reliability category of C (+/- 50 %)A national catchment water balance model was developed by the Bureau of Rural Sciences that estimates average monthly and annual evapotranspiration, runoff, drainage, and irrigation demand in one kilometer pixels over the Australian continent and its nearby islands. Outputs are routinely aggregated to river basin
level using the 245 basins defined by the Australian Water Resources Council in 1985.A steady-state catchment water balance modelling approach used. Under this approach, precipitation is
equal to total evaporation (soil evaporation and transpiration) plus runoff (as surface and sub-surface runoff) and drainage to below the root zone.

$$P = E + R + D$$

Where ***P***= precipitation, ***E***= actual evapotranspiration, ***R***= surface/ sub-surface runoff, and ***D***= deep drainage.

(I) Groundwater storage change (Ws): Change in groundwater storage was estimated by the following relationship. $\mathbf{\Delta S = \Delta\ H.\ A.\ Y}$

Where, **ΔS** = Change in groundwater storage. **ΔH** = Water table fluctuation**.** **A** = area under consideration

(j)Slope method (based on slope of terrain) (Rama Rao and Rao, 1985)

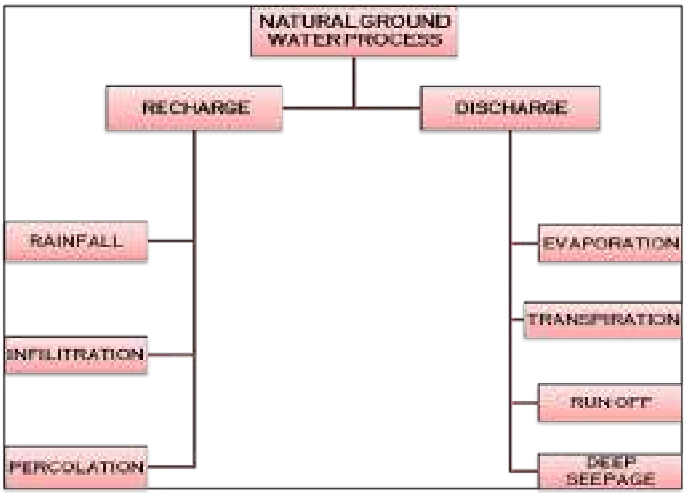
If the slope is greater than 2°, **G = 5/100 x P,** If the slope is less than 2° ,**G = 20/100 x P,**

Where, G is the groundwater recharge in mm, P is precipitation in mm.

The relationships indicated above, which were tentatively proposed for specific hydrogeological conditions, have to be examined and established or suitably altered for application to other areas.

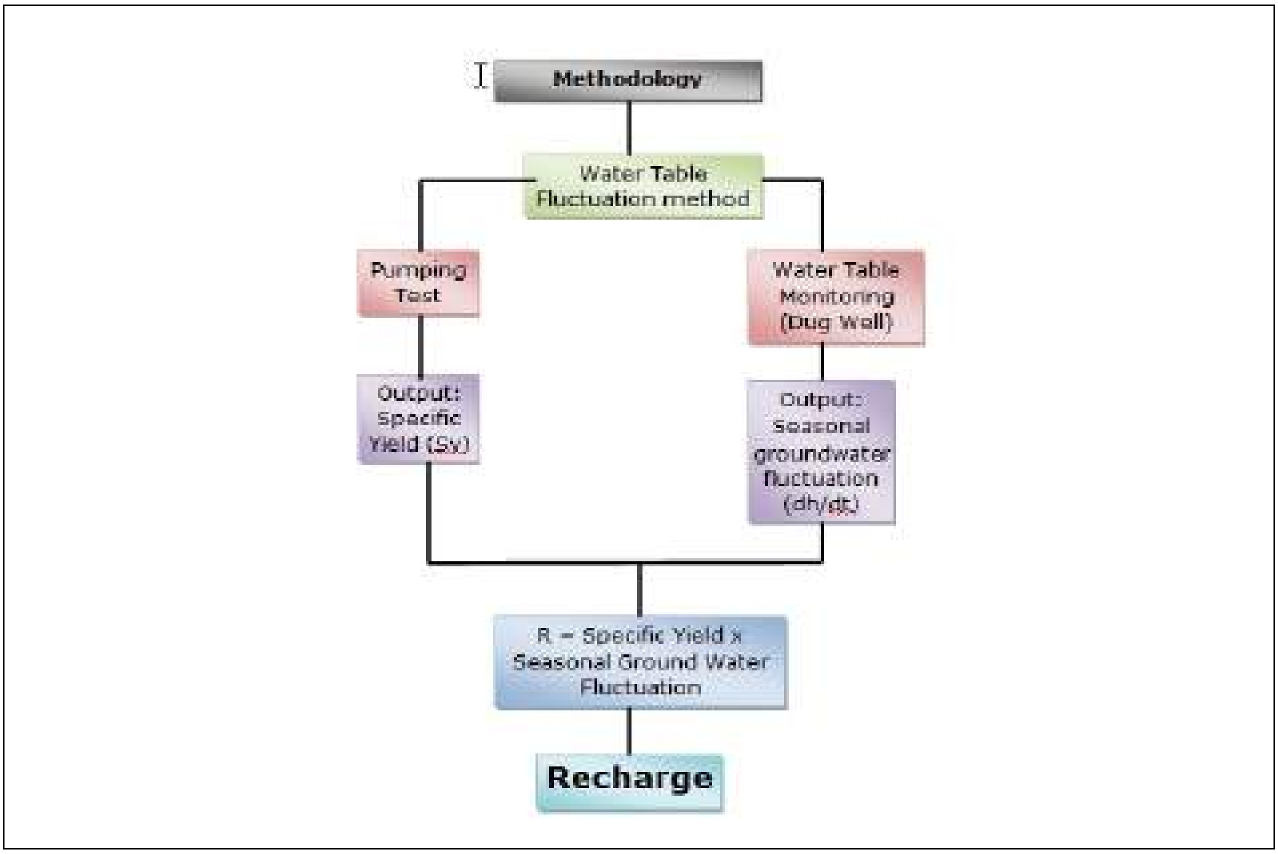
2.2.3.Components of Groundwater

As we know natural ground water process is divided into two zones names ad recharge and discharge. The recharge component is basically followed by rainfall, infiltration and percolation. Again, the discharge component is fallen under four categories such as evaporation, transpiration, runoff and deep seepage as given in flow chart. The basic difference between infiltration, percolation and seepage are water moves into the soil, water percolates through the soil by gravity and water comes over the surface by pressure respectively.



2.2.4. Groundwater Estimation flow chart

The groundwater is estimated by different technique available in the literature. The WTFM is an important method for unconfined aquifer used to estimate the groundwater and most of the related Govt. Dept. is using this method. There are two steps namely pumping test and water table monitoring to determine the aquifer parameters such as specific yield and groundwater fluctuation rate. Using these two parameters the recharge component is evaluated referred in flow sheet diagram.



2.2.5. Static Ground Water Resource (SGWR)

The quantum of groundwater available for development is usually restricted to long term average recharge or dynamic resources. Presently there is no fine demarcation to distinguish the dynamic resources from the static resources. While water table hydrograph could be an indicator to distinguish dynamic resources, at times it is difficult when water tables are deep. For a sustainable groundwater development, it is necessary to restrict it to the dynamic resources. Static groundwater resources could be considered only during the eventuality of extreme drought conditions, that also for drinking water purposes. It is also recommended that no irrigation development schemes based on static Groundwater resources be taken up at this stage. The computation of static Groundwater resources may be done after delineating the aquifer thickness and specific yield of the aquifer material. The computations can be done as follows:

$$SGWR = B \text{ x } A \text{ x } S_y$$

Where B = Thickness of the aquifer below the zone of water level fluctuation down to exploitable limit
A = Areal extent of the aquifer
S_y = Specific yield of the aquifer

Deep percolation is the fraction of percolation that reaches the deep Groundwater. In terms of volume, deep percolation is about 1/20 of streamflow **(L'vovich, 1979).** Therefore, on an annual global basis, deep percolation constitutes (0.05 × 0.40) × 100 = 2% of precipitation this value varies as a function of scale, from local to regional; furthermore, it has a tendency to decrease from coastal to inland regions.

2.3. Water logging: definition, causes, effects (with statistics)

When the conditions are so created that the crop root-zone gets deprived of proper aeration due to the presence of excessive moisture or water content, the tract is said to be waterlogged. To create such conditions it is not always necessary that under ground water table should enter the crop root-zone. Sometimes even if water table is below the root-zone depth the capillary water zone may extend in the root-zone depth and makes the air circulation impossible by filling the pores in the soil.
The waterlogging may be defined as rendering the soil unproductive and infertile due to excessive moisture and creation of anaerobic conditions. The phenomenon of waterlogging can be best understood with the help of a hydrologic equation, which states that

Inflow = Outflow -I- Storage

Here inflow represents that amount of water which enters the subsoil in various processes. It includes seepage from the canals, infiltration of rainwater, percolation from irrigated fields and subsoil flow. Thus although it is loss or us, it represents the amount of water flowing into the soil. The term outflow represents mainly evaporation from soil, transpiration from plants and underground drainage of the tract. The term storage represents the change in the groundwater reservoir.

Causes of Waterlogging:

After studying the phenomenon of waterlogging in the light of hydrologic equation main factors which help in raising the water-table may be recognised correctly as given below:

i. Inadequate drainage of over-land run-off increases the rate of percolation and in turn helps in raising the water table.
ii. The water from rivers may infiltrate into the soil.
iii. Seepage of water from earthen canals also adds significant quantity of water to the underground reservoir continuously.
iv. Sometimes subsoil does not permit free flow of subsoil water which may accentuate the process of raising the water table.
v. Irrigation water is used to flood the fields. If it is used in excess it may help appreciably in raising the water table. Good drainage facility is very essential.

Effects of Waterlogging:
The waterlogging affects the land in various ways. The various after effects are the following:

Creation of Anaerobic Condition in the Crop Root-Zone:

When the aeration of the soil is satisfactory bacteriological activities produce the required nitrates from the nitrogenous compounds present in the soil. It helps the crop growth. Excessive moisture content creates anaerobic condition in the soil. The plant roots do not get the required nourishing food or nutrients. As a result crop growth is badly affected.

Growth of Water Loving Wild Plants:

When the soil is waterlogged water loving wild plant life grows abundantly. The growth of wild plants totally prevents the growth of useful crops.

Impossibility of Tillage Operations:

Waterlogged fields cannot be tilled properly. The reason is that the soil contains excessive moisture content and it does not give proper tilth.

Accumulation of Harmful Salts:

The upward water movement brings the toxic salts in the crop root-zone. Excess accumulation of these salts may turn the soil alkaline. It may hamper the crop growth.

Lowering of Soil Temperature:

The presence of excessive moisture content lowers the temperature of the soil. In low temperature the bacteriological activities are retarded which affects the crop growth badly.

Reduction in Time of Maturity:

Untimely maturity of the crops is the characteristic of waterlogged lands. Due to this shortening of crop period the crop yield is reduced considerably.

Detection of Water logging:

From the subject matter discussed above it is clear that the waterlogging is indicated when the ground water reservoir goes on building up continuously. When the storage starts building up in the initial stages the crop growth is actually increased because more water is made available for the crop growth. But after some time the waters table rises very high and the land gets waterlogged. Finally the land is rendered unproductive and infertile.

The problem of waterlogging develops in its full form slowly. Therefore its early detection is possible by keeping a close watch over the yields and also on the variations in the groundwater level. A comparative reduction in crop yields in spite of irrigation and fertilisation and early maturity of crops indicate the symptoms of water logging. Also when harmful salts start appearing on the fields as white incrustation or deposit it indicates that waterlogging is likely to follow. In worst cases the water-table rises so high and close to the ground surface that the fields turn into swamps and marshes.

The best way of keeping watch over the problem of waterlogging is by observing variations in the groundwater level. It can be done by measuring the depth of water levels at regular interval in the wells dug in the area. Continuous high water levels indicate that the groundwater storage is building up which may create waterlogging in the area.

Solution to the Problem of Water logging:

The problem of waterlogging may be attacked on two fronts. First is preventive measures, which keep the land free from water logging. Secondly curative measures may be adopted to reclaim the waterlogged area. But in principle both measures aim at reducing the inflow and augmenting the outflow from the underground reservoir.

Preventive Measures:

Preventive measures include the following:

(a) Controlling the loss of water due to seepage from the canals:

The seepage loss may be reduced by adopting various measures for example

i. **By lowering the FSL of the canal:**

Loss may be due to percolation or absorption but when FSL is lowered the loss is reduced to sufficient extent. It is course essential to see that while lowering the FSL command is not sacrificed.

ii. By lining the canal section:

When the canal section is made fairly watertight by providing lining the seepage loss is reduced to quite a good extent.

iii. By introducing intercepting drains:

They are generally constructed parallel to the canal. They give exceptionally good results for the reach where the canal runs in high embankments.

(b) Preventing the loss of water due to percolation from field channels and fields:

The percolation loss can be removed by using water more economically. It may also be affected by keeping intensity of irrigation low. Then only small portion of the irrigable tract is flooded and consequently the percolation loss takes place only on the limited area. It keeps the water-table sufficiently low.

(c) Augmentation of outflow and prevention of inflow:

It may be accomplished by introducing artificial open and underground drainage grid. It may also be achieved by improving the flow conditions of existing natural drainages.

(d) Quick disposal of rainwater:

Quick removal of rainwater by surface or open drains is a very effective method of preventing the rise in water table and consequent waterlogging of the tract. It is needless to state that the rainwater removed is net reduction in inflow.

Curative Measures:

Curative measures include the following:

(a) Installation of lift irrigation systems:

When a lift irrigation project in the form of a tube well irrigation system is introduced in the waterlogged area the water table gets lowered sufficiently. It is found to be very successful method of reclaiming waterlogged land. Thus a combination of a canal system and a supplementary tube well irrigation system may be considered to be most successful and efficient irrigation scheme.

Of course it is true that it will create some complications while assessing the charges for irrigation water (The canal water being cheaper than tube well water). Implementation of drainage schemes: The waterlogged area may be reclaimed by introducing overland and underground drainage schemes.

(b) Implementation of Drainage Schemes:

The waterlogged area may be reclaimed by introducing overland and underground drainage schemes.

CHAPTER 3

HYDROLOGICAL CYCLE WITH GROUNDWATER CHRACTERISTICS

3.1. Hydrological cycle: General Description

Precipitation, storage, runoff, and evaporation of the earth's water follow an unending sequence known as the hydrologic cycle (Meinzer, 1949; Todd, 1980;U .S. Department of Agriculture, 1956). During this cycle, the total amount of water in the atmosphere and in or on the earth remains the same; however, its form may change. Although minor quantities of water from other deeper region may find its way to the surface so results all water is assumed to be part of the hydrologic cycle. The movement of water keeping all components within the hydrologic cycle is shown in Fig. 3.1. Water vapor in the atmosphere is condensed into ice crystals or water droplets that fall to the earth as rain or snow. A portion evaporates and returns to the atmosphere. Another portion flows across the ground surface until it reaches a stream and then flows to the ocean. The remaining portion infiltrates directly into the ground and seeps downward. Some of this portion may be transported by the roots of plants or moved back to the ground surface by capillarity action and finally it gets evaporated. The rest of the portion of water gets seeped towards downward to attach with the ground-water body by gravity system. Groundwater returns to the ground surface through springs and seepage to streams where it is subject to evaporation or is directly evaporated from the ground surface or transported through vegetation. The water vapor rises into the atmosphere. The elements of the hydrologic cycle for any area can be quantified using water budget equation. For ground-water investigations, the equation can be expressed in terms of ground-water components referred in Fig. 3.1.

3.2. Major Components of Hydrological Cycle: Portion of Groundwater

There are two components namely recharge and discharge of groundwater. The groundwater component with respect to all other components is found to be 10.8 Mkm3 referred in Fig. 3.2. It is also estimated that the groundwater volume and aquifer depth are observed 60 Mkm3 and 120 m respectively shown in Table 3.1.Mean residence times of deeper aquifer were observed ranged between 1700 years and 10,000 years found by two renowned researchers given in Table 3.1. The recharge from natural sources includes the following:

Deep percolation from precipitation

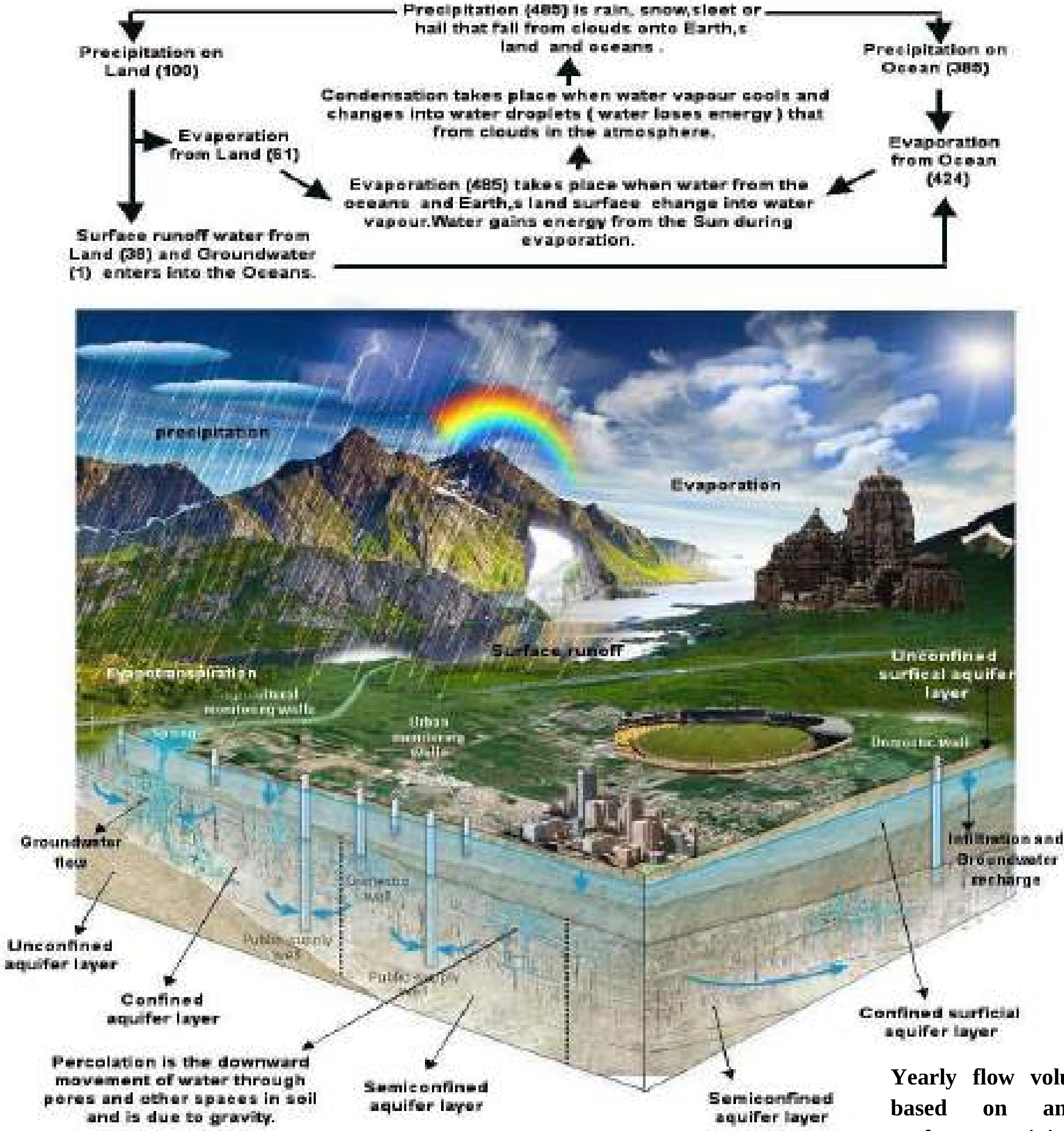
Deep percolation of precipitation is one of the most important sources of ground-water recharge. The amount of recharge in a particular area is influenced by vegetative cover, topography, nature of soils, as well as the type, intensity, and frequency of precipitation.

Seepage from streams and lakes

Seepage from streams, lakes, and other water bodies is another important source of recharge. In humid and sub-humid areas where groundwater levels may be high, the influence of seepage may be limited in extent and may be seasonal. However, in regions where the entire flow of streams may be lost to an aquifer.

Under flow from another aquifer

An aquifer may be recharged by underflow from a nearby, hydraulically connected aquifer. The amount of this recharge depends on the head differential, the nature of the connection, and the hydraulic properties of aquifers.



Yearly flow volumes based on annual surface precipitation on earth, ~119,000km^3/year.

Source:Groundwater Hydrology, Prof.Charles Harvey
LecturePacket,CourseIntroduction,Water

Fig. 3.1.Hydrologiccycle with water budget including groundwater recharge system

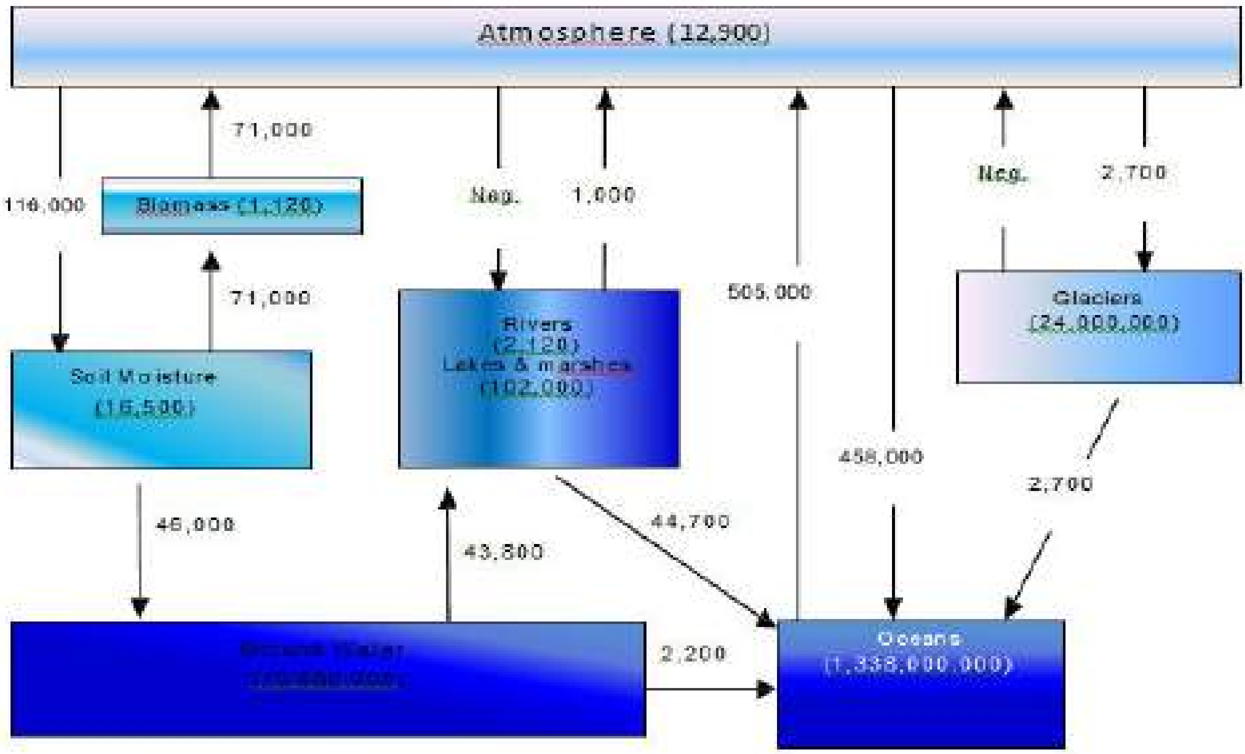


Fig.3.2. World water distribution (in km^3) showing all items of hydrological cycle

Table 3.1. Estimate of the World Water Balance and Mean Residence Time

Parameter	**Surface area(km^2) x10^6**	**Volume(km^3) x 10^6**	**Volume %**	**Equivalent depth (m)**	**MeanResidence Time**	
					Langmuir,1997	**Freeze andCherry,1979**
Oceansand seas	361	1370	94	2500	3550years	~ 4000years
Lakesand reservoirs	1.55	0.13	<0.01	0.25	10years	~ 10years
Swamps	<0.1	<0.01	<0.01	0.007		1-10years
River channels	<0.1	<0.01	<0.01	0.003	2 weeks	~ 2 weeks
Soil moisture	130	0.07	<0.01	0.13		2 weeks – 1year
Groundwater	130	60	4	120	1700years	2 weeks – 10,000years
Ice caps andglaciers	17.8	30	2	60	10-1000	10-1000years
Atmospheric water	504	0.01	<0.01	0.025	11 days	~ 10 days
Biospheres water	<0.1	<0.01	<0.01	0.001		~ 1 week

Sources: Harvey

Artificial recharge

Artificial recharge to the groundwater may be achieved through planned systems, or may be unforeseen or unintentional. Planned major contributions to the ground-water reservoir may be made through spreading grounds, infiltration ponds, and recharge wells. Irrigation applications, sewage effluent spreading grounds, septic tank seepage fields, and other activities have a similar, but usually unintentional effect. Seepage from reservoirs, canals, drainage ditches, ponds, and similar water impounding and conveyance structures may serve as local sources of major ground-water recharge. Recharge from such sources can completely change the groundwater regimen over a considerable area.
The discharge components of groundwater sources include the following:

Seepage to streams

In certain reaches of streams and in certain seasons of the year, groundwater may discharge into streams and maintain their base flows. This condition is more prevalent in humid areas than in semiarid areas.

Flow from springs and seeps

Springs and seeps exist where the water table intersects the land surface or a confined aquifer outlets to the surface.

Evaporation and transpiration

Ground water may be lost by evaporation if the water table is near enough to the land surface to maintain flow by capillary rise. Also, plants may transpire ground water from the capillary fringe or the saturated zone.

Artificial discharge

Wells and drains are imposed artificial withdrawals on groundwater storage and in some areas are responsible for the major depletion. Groundwater moves in response to a hydraulic gradient in the same manner as water flowing in an open channel or pipe. However, the flow of groundwater is appreciably restricted by friction with the porous medium through which it flows. This friction results in low velocities and high head losses compared to open channel or pipe flow.

3.3. Groundwater Balance

A basic groundwater equation (Meinzer, 1949; Todd, 1980), which will permit an approach to a quantitative estimate of groundwater availability, can be established for an area to account for those factors of the hydrologic cycle that directly affect flow and storage of groundwater. The equation can be stated as:

$$\Delta S_{gw} = \textbf{recharge-discharge}$$

Where, **ΔSgw** is the change in ground-water storage during the period of study. Theoretically, under natural conditions and over along period of time, which includes both wet and dry cycles, **ΔSgw** will be zero and inflow (recharge) will equal outflow (discharge). However, man's activities can significantly affect the equation, resulting in long-term increases or decreases in groundwater storage. The natural recharge to the groundwater body includes deep percolation from precipitation, seepage from streams and lakes, and subsurface underflow. Artificial recharge includes deep percolation from irrigation and water spreading, seepage from canals and reservoirs, and recharge from recharge wells. The natural discharge or outflow from the groundwater body consists of seepage to streams, flow from springs, subsurface underflow, transpiration, and evaporation. Artificial discharge occurs by wells or drains. If groundwater storage in an area is less at the end of the selected period of time than at the beginning, discharge is indicated as having exceeded recharge. Conversely, recharge may exceed discharge

Water may occur in several recognizable subsurface zones under different conditions, as shown in Table 3.2 (Meinzer, 1949). Aquifer classified as confined and unconfined showing flowing and non-flowing artesian well of overflow zone reflected in Fig. 3.3.

Table 3.2. Status of groundwater in soil zones

Zone	Horizon	Condition of water	Condition of Soil
Aeration (above water table)			
Saturation (below water table)	Unconfined ground water		Under pressure but upper surface at atmospheric pressure
Saturated			
Confined or artisan ground water		Under pressure but upper surface above atmospheric pressure	

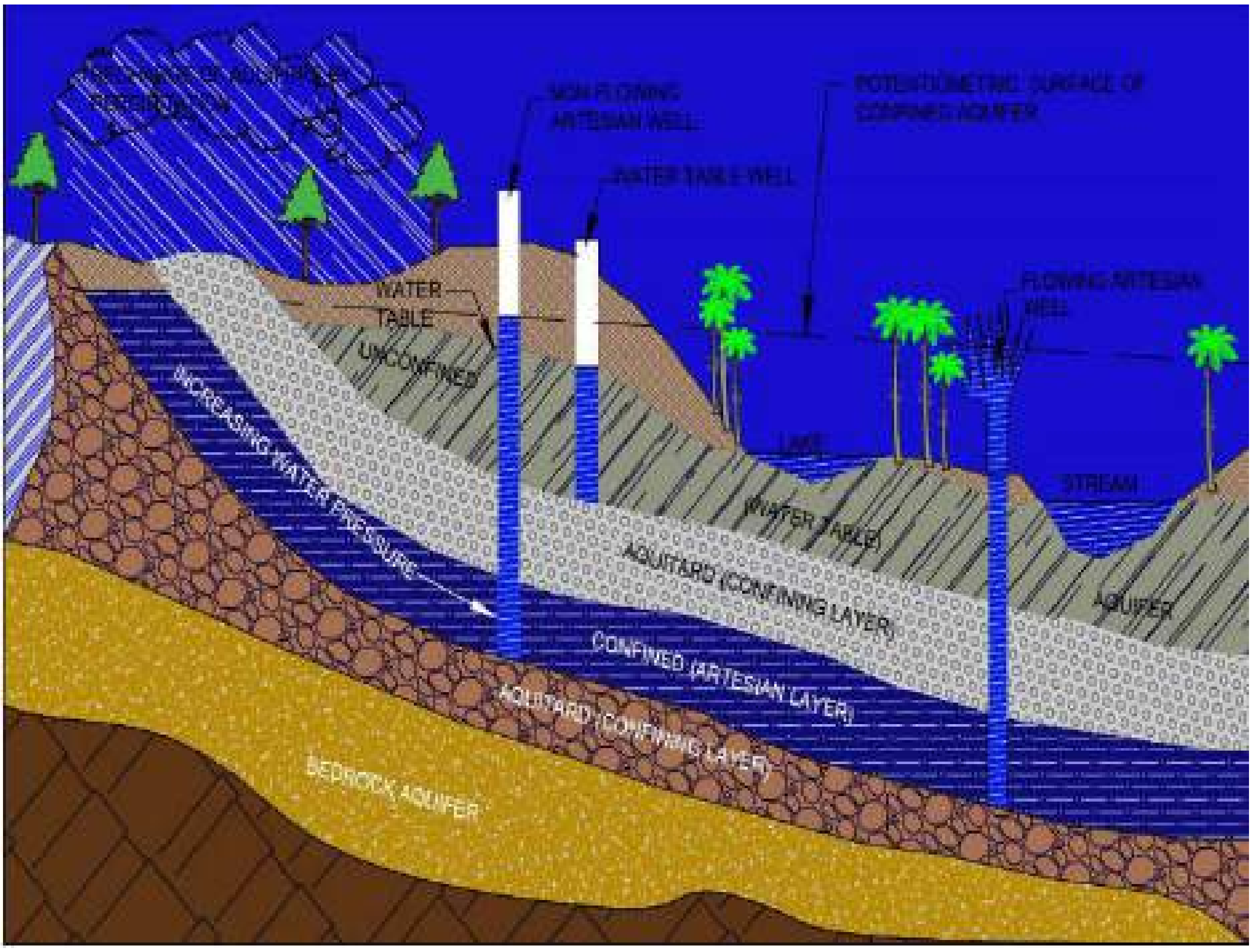


Fig. 3.3.A typical flow diagram showing overflow zone under different aquifer condition

3.4. Groundwater Scenario of the Study Area

In Tripura, ground water occurs under unconfined condition in Dupitila formation, Recent formation and in Tipam formation (in shallow depths, wherever exposed). Besides it also occur under confined to semi-confined conditions in Tipam formation at considerable depth. Recharge areas for the deeper aquifer lies in the adjacent anticlinal hills. Wherever a good thickness of impermeable clay beds underlie & overlie the saturated granular zones, auto flow artesian conditions have been found in the valleys, which are the discharge area. In fact, the geology as well as geomorphology of the state is favourable for such artesian conditions within synclinal valleys. The artesian flowing conditions occur in patches both at shallow depth and at deeper depths. The auto discharge of the flowing wells in the State ranges from 100 to 6000 lph, the maximum auto discharge from deep tube well to the extent of 54000 lph has been found in Khowai valley near Khowai town, where the piezometric head rose up to 7m above ground level.

Central Groundwater Water Board (CGWB), Govt. of India has constructed 58 tube wells in Tripura. In West Tripura district tube wells constructed between 42 and 255 mbgl, tapping 24 – 66 m of granular zones yielded 4 – 165 m3/hr. In South Tripura district tube wells constructed between 35 and 212 mbgl, tapping 18 – 60 m of granular zones yielded 12 – 158 m3/hr. In North Tripura district tube wells constructed between 45 and 262 mbgl, tapping 15 – 63 m of granular zones yielded 4 – 95 m3/hr. In Dhalai district tube wells constructed between 53 and 255 mbgl, tapping 32 – 57 m of granular zones yielded 38 – 211 m3/hr.

Photo 3.1.Water scarcity at Kalanjoy Sing para under Dumbur Nagar, Dhalai , 24th December ,2016

3.5. Geomorphology, Geology and Soil Structures of the Study Area

Geomorphology

Geomorphologically, the state of Tripura represents the western fringe of typical "ridge and valley" province of the late Tertiary fold mountain belt, commonly known as Indo-Burman ranges. The general elevation varies between 780 m in the north eastern part to 15 m in the western part above mean sea level. Five prominent roughly north south trending anticlinal strike ridges traverse the state from east to west; these are Jampui, Sakhantlang, Longtarai, Athramura and Baramura. This strike ridges form the watershed of the Meghna basin of Bangladesh fed by

Khowai, Haora, Juri, Manu, Dhalai, Deo, Longai, Muhuri, Feni and Gomoti rivers. Ten physiographic units have been identified by the Geological Survey of India (1999) in the State of Tripura which is given below.

Geology

The state of Tripura exhibits a wide array of sedimentary rock characteristics of marine-mixed-fluvia type origin ranging in age from upper most Oligocene (38 million years from present time) to Recent period. These sediments, according to GSI, have been laid down in the Surma basin during Tertiary age (which lasted for 65 million years) in a wide range of environmental conditions governed by local tectonic movement. Tectonically, the region now comprises a series of sub-parallel arcuate, elongated, doubly plunging folds arranged in north south direction. These folds are anticlines separated by wide flat synclines. The group of sediments belonging to different geological age on litho-stratigraphy are shown in Table 3.3.

Table 3.3. A generalized stratigraphy of Tripura accretionary belt, Surma Basin (Karunakaran, 1974; Ganju,1975)

Ichnofossil assemblage of Bhuban formation (Surma group) of Tripura.

Age	Group	Formation	Unit	Generalised lithology	Depositional Environment
Recent	Alluvium			Silt, clay and gravel	River deposits
'''''''''''''''''''''''''''''''''''''' **Unconformity** ''					
Early Pliocene to Late Pliocene	Tipam (+900 m)			Friable sandstone with occasional clay bands	Stream deposits
''''''''''''''''''''''' **Conformable and transitional contact** ''''''''''''''''''''''					
Miocene to Upper Oligocene	**Surma (+5950 M)**	Bokabil (+950 m)		Shales with siltstones and sandstones	Shallow marine
		''''''''''''' **Conformable and transitional contact** ''''''''''''			
		Bhuban (5000 m)	Upper Bhuban (1100 m)	Arenaceous with sandstones, shales and siltstones	Shallow marine, near shore to lagoonal
			'''''''' **Conformable and transitional contact** ''''''''		
			Middle Bhuban (3000 m)	Argillaceous with shales, siltstones	Deltaic complex
			''''''' **Conformable and transitional contact** ''''''''		
			Lower Bhuban (900 m)	Arenaceous with sandstones and silty shales	Shallow marine
'''''''''''''''''''''''''''' **Unconformity obliterated by faults** ''''''''''''''''''''''''''					
Oligocene	Barail (+3000 m)			Shales, siltstones and sandstones	Shallow marine
'''''''''''''''''''''''''''' **Lower contact not seen** ''''''''''''''''''''''''''''''''					
Data source	Modified after Karunakaran, 1974; Ganju,1975			Tiwari and Kachhara, 2003;Mandaokar, 2000	

A generalized stratigraphy of Tripura accretionary belt, Surma Basin(Modified after Karunakaran, 1974; Ganju,1975)

Tripura state in general, and investigated areas in particular is underlain by the geological formations ranging from Upper Tertiary to Quaternary. Subsurface formations are characterized by a succession of argillaceous and arenaceous sedimentary rocks like sand stone, shale, silt stone, silt and clay belonging to Surma, Tipam and Dupitila groups. The Surma group occurs at the core of anticline and mostly comprises of shale, siltstone and sandstone and is broadly considered to be not so promising for ground water. The Tipam group is represented by sandstone, sandy shale and siltstone represented in Figs. 3.4, 3.5, 3.6 and 3.7.

Dupitilla group occurs in the form of disconnected mounds and occurs in valleys. This group comprises of coarse to gritty ferruginous sandstone, clay, clayey sandstone and laterites. The recent sediments mostly developed along rivers, comprises of silt, sand, silty clay etc.

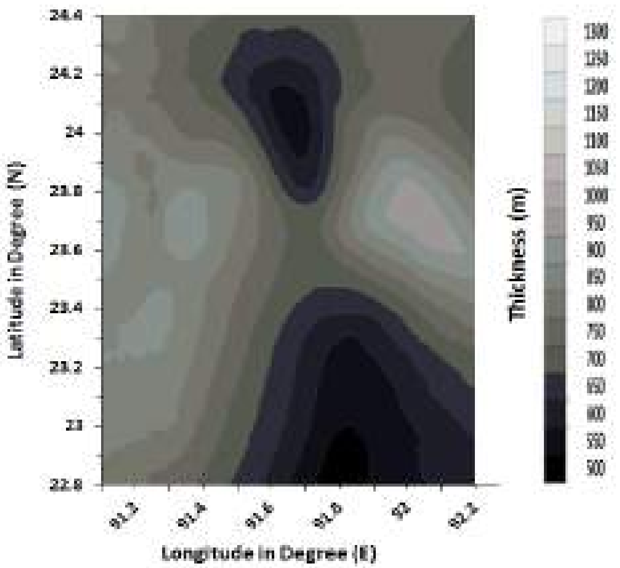


Fig.3.4.Isopachmap of Upper Bhuban formation in Tripura,(Western boundary with Assam and Bangladesh)

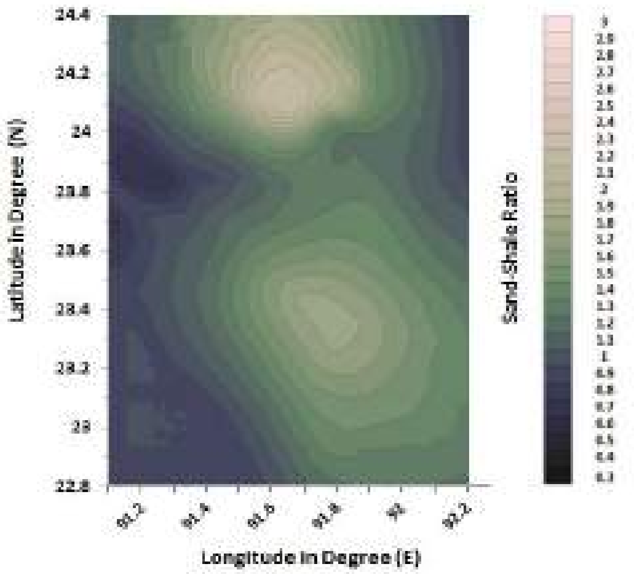


Fig.3.5.Sand Shale ratio map of Upper Bhuban formation in Tripura

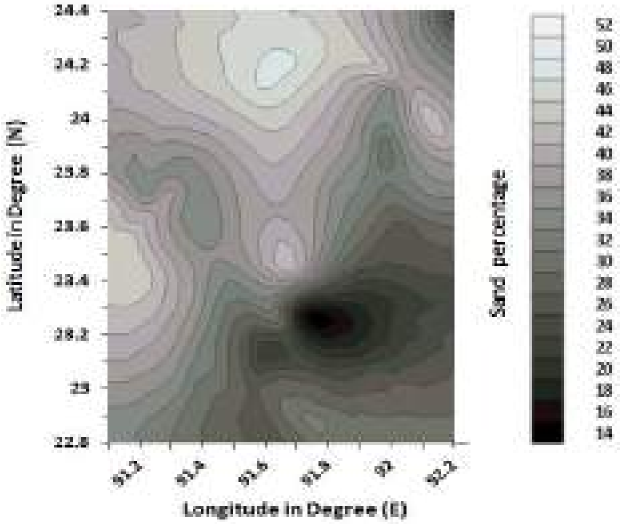


Fig.3.6. Sand percentage map of Bokabil formation in Tripura

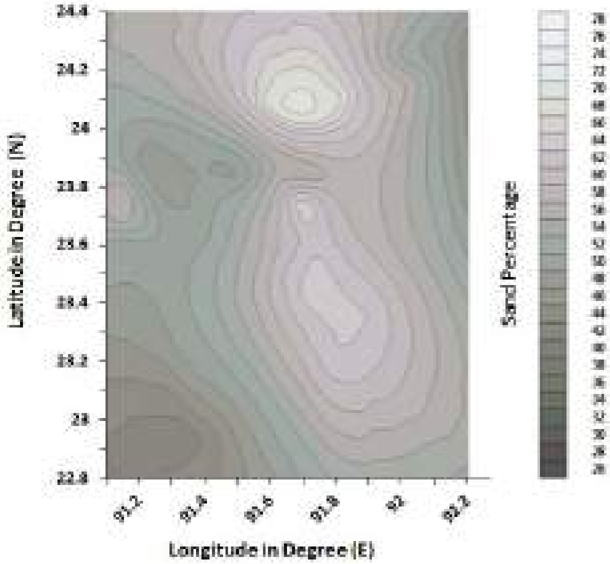


Fig.3.7.Sand percentage map of Upper Bhuban formation in Tripura

Seismic surveys in the region reveal the presence of sub-surface flatus. The part of Surma basin in Tripura Mizoram area lies in close proximity to the Shillong plateau in the north and Arakan Yoma belt to the east. Tripura is therefore located in a seismically active zone. Because of inherent character of sediments of these areas even a minor shock during earthquake may cause devastating effects like landslides etc. (Mukherjee et.al., GSI, 1999).

Soil Strata

Lithological strata are prepared based on soil samples at different depth collected from different location as given in Fig. 3.8 and Fig. 3.9. The lithological chart is made using boring soil samples used drilling tool to assess the effective sand depth for the aquifer zone referred in Fig. 3.10 and Fig. 3.11.

Fig. 3.8. Soil sample for litholog at KamalaCherra, under Ambassa,Dhalai

Fig.3.9.Soil sample for litholog at Bilascherra Cherra, Durga Chowmohani under Dhalai (Inearinter national border Bangladesh)

Fig.3.10.Soil Drilling tool used at site

Fig.3.11.Soil Strata analysis at Bishalgarh

Photo 3.2. Water collection at Sabual under Kanchanpur block,North Tripura

Photo 3.3.Drilling at Bilascherra, Durgachowmohani, Dhalai

CHAPTER 4

GROUND-WATER INVESTIGATIONS BY DIFFERENT TECHNIQUE

4.1. Groundwater Investigations

As we know, groundwater investigation is an important study to assess the optimum yield by keeping the optimum depletion at groundwater and ultimately it is not affected the safe water storage at present scenario as well as future scenario. It has been divided into four stages as given below:

- ✓ Planning
- ✓ Data collection and field work
- ✓ Data analysis
- ✓ Report preparation

Planning a ground-water investigation or project requires athorough appreciation of the purpose, the scopeof the workrequired, the areal extent and geologic complexity of the areainvolved, and the limitations imposed by available financing andallotted time. Ground-water hydrology is a dynamic and inexactscience. The accuracy and reliability of acquired data usuallyincrease with the time available for observation and interpretation,and much of the successand value of such an investigationdepends on the imagination, experience, and judgment of theground-water technical specialists involved. Ground-waterinvestigations generally are costly because of the time factor andthe need for extensive subsurface and data collection.

Ground-water data based on short-term investigations may bemore indicative than substantive. When reliable! Quantitativeinformation is required. Provision should be made for refinement ofdata by continued observation and data collection.

In the planning of an investigation, a review of previous workprovides a basis for planning additional work, and reconnaissancefield surveys provide the information needed to determine fieldconditions, obstacles, limits, and possible alternative methods forcompleting any additional work contemplated.

When the required field work has been tentatively determined ,the minimum number and typeof field personal,cooperativearrangements with other offices, necessary equipment, and thetime and fund requirements can be estimated. Adjustments canthen be made to conform to the requirements of the overall project.The program and plan should be kept flexible, allowing forcurtailment or expansion as determined from information acquiredas the investigation progresses.

Uponcompletion of the field investigations and data collection, afinal review of the data should be conducted and a writtensummary of the field investigations should be prepared. The finalreport, which presents the results of the investigation, shouldcontain a compilation of the data, the results of the analysis of thedata, and the supporting maps, figures, and tables.

4.2. Resistivity Survey Concept and Application: Part of Tripura (District Wise)

Electrical resistivity surveying methods have been widely used to determine the thickness and resistivity of layered media for the purpose of assessing groundwater potential and sitting boreholes in fractured unconfined aquifers. Traditionally, this has been done using one-dimensional (1D) vertical electrical sounding (VES) surveys. However, 1D VES surveys only model layered structures of the subsurface and do not provide comprehensive information for interpreting the structure and extent of subsurface hydro-geological features.

In this case four districts referred in Fig. 4.1 have been considered to identify the effective sand bed in aquifer zone using resistivity survey.

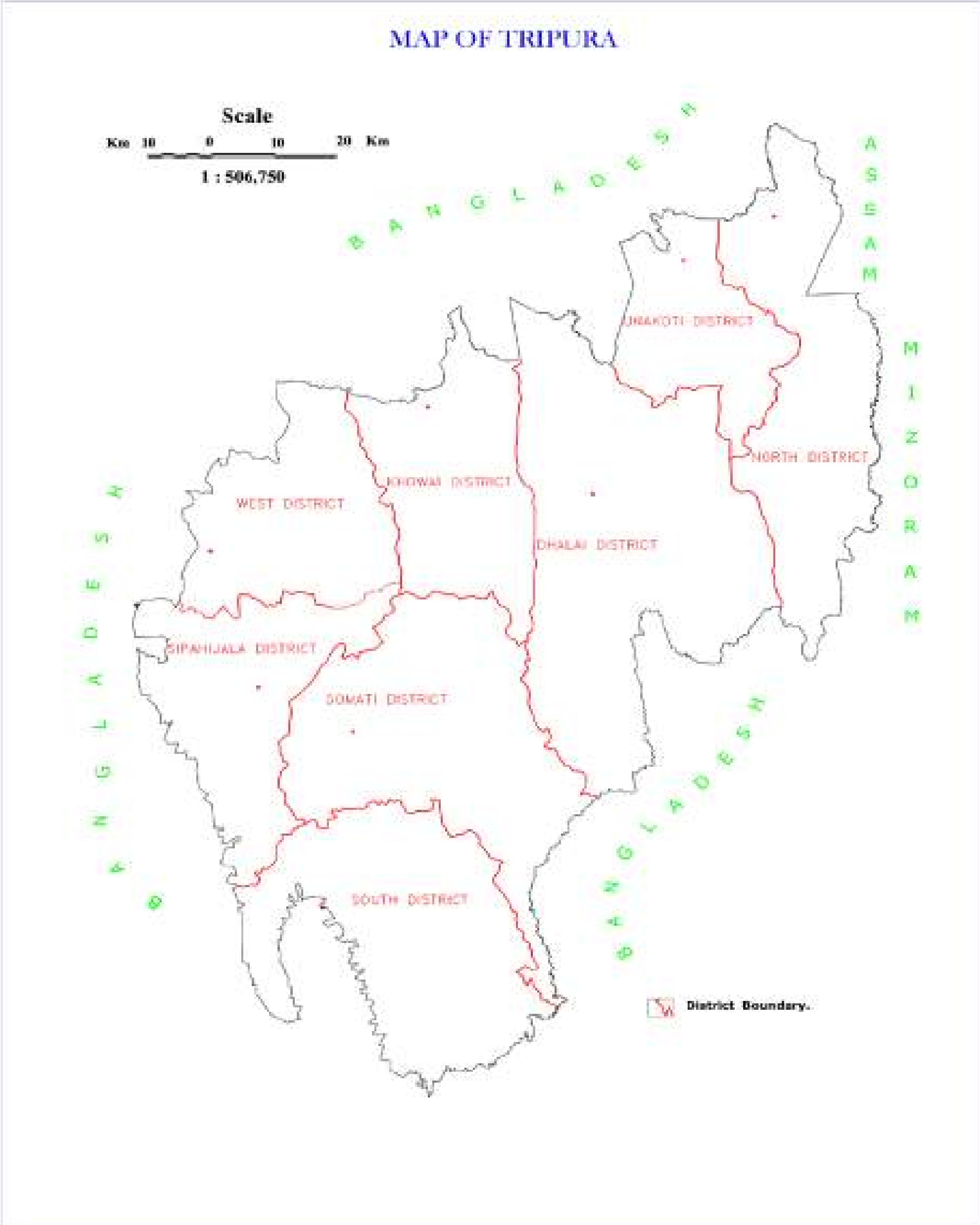


Fig 4.1. Location map of Tripura

To examine the geoelectrical properties of the area, electrical resistivity survey has been carried out using the SSR-MP-ATS resistivity meter with the Schlumberger configuration at 4 locations (Teliamura, Kalyanpur, Padmabil, Khowai) in Khowai district, Tripura. A GPS receiver is used in the field to get the position data of each VES site at the study area. All the survey points are shown in Fig.4.2(a) using Google Earth image.

To examine the geo-electrical properties of the area, electrical resistivity survey has been carried out using the SSR-MP-ATS resistivity meter with the Schlumberger configuration at 2 locations (Jirania, Hezamara) in West Tripura district, Tripura. A GPS receiver is used in the field to get the position data of each VES site at the study area. All the survey points are shown in Fig.4.2 (b) using Google Earth image.

To examine the geoelectrical properties of the area, electrical resistivity survey has been carried out using the SSR-MP-ATS resistivity meter with the Schlumberger configuration at 5 locations (Maheshpur, Kathalia, Paharpur, Sonamura, Boxanagar) in Sepahijala district, Tripura. A GPS receiver is used in the field to get the position data of each VES site at the study area. All the survey points are shown in Fig.4.2(c) using Google Earth image.

Fig.4.2 (a) Location of VES survey points at Khowai district, Tripura

Fig.4.2(b): Location of VES survey points at West Tripura district, Tripura

Fig.4.2(c). Location of VES survey points at Sepahijala district, Tripura

Fig.4.2(d).Location of VES survey points at Gomati district, Tripura

To examine the geoelectrical properties of the area, electrical resistivity survey has been carried out using the SSR-MP-ATS resistivity meter with the Schlumberger configuration at 5 locations (Tepania, Matabari, Amarpur, South Karbook, EastKarbook) in Gomati district, Tripura. A GPS receiver is used in the field to get the position data of each VES site at the study area. All the survey points are shown in Fig.4.2 (d) using Google Earth image.

a) Khowai District

Khowai district lies in the northern part of Tripura state. The district is bounded on the north by the country Bangladesh, on the south by Gomati district, on the west by Dhalai district and on the east by West Tripura district. The district has total area of 1377.28 sq. km. and it lies between the Latitude 23°42' N to 24°14'N and Longitude 91°39' E to 91°46' E. The district is divided into 2 sub- divisions and 6 administrative blocks. The district comprises of 3 numbers of revenue circles, 2 numbers of nagar panchayats, 79 numbers of muja107 numbers of villages. The total population of the Khowai district as per the 2011 census is 327564 persons. The district headquarter is located at Khowai**(Ghosh, 2014).**

b)*West Tripura District*

West Tripura district lies in the western part of Tripura state. The district is bounded on the north by the country Bangladesh, on the south by Sepahijala district, on the west by the country Bangladesh and on the east by Khowai district. The district has total area of 983.63 sq. km. and it lies between the Latitude 23°16' N to 24°14' N and Longitude 91°47' E to 92°20' E. The district is divided into 3 sub-divisions and 9 administrative blocks. The district comprises of 1 number of Municipal Corporation, 1 number of Nagar Panchayat. The total population of the West Tripura district as per the 2011 census is 918200 persons. The density of population is 576 persons per sq. km. The district headquarter is located at Agartala, which is also the capital of the stateTripura.

b) ***Sepahijala District***

Sepahijala district lies in the western part of Tripura state. The district is bounded on the north by West Tripura district, on the south by the country Bangladesh, on the west by the country Bangladesh and on the east by Gomati district. The district has total area of 1043.58 sq. km. and it lies between the Latitude 23°16' N to 24°14' N and Longitude 91°47' E to 92°20' E. The district is divided into 3 sub-divisions and 5 administrative blocks. The district comprises of 2 numbers of Nagar Panchayat. The total population of the Sepahijala district as per the 2011 census is 483687 persons. The density of population is 576 persons per sq. km. The district headquarter is located at Bishramganj.

d)*Gomati District*

Gomati district lies in the southern part of Tripura state. The district is bounded on the north by the West Tripura district and Khowai district, on the south by South Tripura district and Bangladesh, on the west by Sepahijala district and on the east by Dhalai district. The district has total area of 2624.35 sq. km., which is about 25% of the total state area. It lies between the Latitude 22°56' N to 24°32' N and Longitude 91°59' E to92°22' E. The district is divided into 3 sub-divisions and 8 administrative blocks. The district comprisesof 7 numbers of revenue circles, 1 number of Municipal Corporation, 1 number of Nagar Panchayat and 157numbers of villages. The total population of the Gomati district as per the 2011 census is 442336 persons. Thedistrict headquarter is located at Udaipur.

4.2.1. Software: Interpretation of VES survey data

The subsurface layering was derived based on the distinct resistivity values of the upper layer ($\rho 1$), second layer ($\rho 2$), third layer ($\rho 3$) and so on. The distinctive characteristics features in the apparent resistivity curves were characterized by the considerable spatial variability of the groundwater quality and inhomogeneity of the subsurface aquifer conditions. Therefore, depending upon the shape of the curve, different layer earth data were classified into different types. The shape of the VES curve at any location is controlled by the underlined formation distribution i.e. the resistivity (ρi) and thickness (hi) of the geoelectric layers and the total depth investigated.

Two layer sections in resistivity method mean the first layer thickness is finite while that of the second layer is infinite. The only two situations that can occur for a two layer section are either the resistivity of the first layer is greater than the second ($\rho 1 > \rho 2$) or less than the second ($\rho 1 < \rho 2$); the former case is 'Ascending Type' curve and the later is 'Descending Type' curve.

Orellana and Mooney (1966) presented 4 types of interpreted curves based on the 3 layered earth model as given in Table 4.1. Accordingly, the 3 layered earth can be classified into 'Q', 'H', 'K' and 'A' Type curves based on their shapes. The distribution of resistivities associated with different subsurface layers with different settings is described below (Srinavasa, 2004):

Table4.1. Details of curve types for three layer case

Sl. No.	Curve Type	Resistivity Details
1	Q type	$\rho 1 > \rho 2 > \rho 3$
2	H type	$\rho 1 > \rho 2 < \rho 3$
3	K type	$\rho 1 < \rho 2 > \rho 3$
4	A type	$\rho 1 < \rho 2 < \rho 3$

A total 8 types of 4 layer curves are possible depending upon the resistivity distribution of the various layers as highlighted in Table 4.2.

Table 4.2. Details of curve types for four layer case

Sl. No.	Curve Type	Resistivity Details
1	QQ type	$\rho 1 > \rho 2 > \rho 3 > \rho 4$
2	QH type	$\rho 1 > \rho 2 > \rho 3 < \rho 4$
3	AA type	$\rho 1 < \rho 2 < \rho 3 < \rho 4$
4	AK type	$\rho 1 < \rho 2 < \rho 3 > \rho 4$
5	HA type	$\rho 1 > \rho 2 < \rho 3 < \rho 4$
6	HK type	$\rho 1 > \rho 2 < \rho 3 > \rho 4$
7	KH type	$\rho 1 < \rho 2 > \rho 3 < \rho 4$
8	KQ type	$\rho 1 < \rho 2 > \rho 3 > \rho 4$

Similarly a five layer section can yield 16 possible types of curves and so on. A geological formation may be comprised of more than one geoelectric layers and vice versa.

The apparent resistivity values collected from the study areas are to be plotted against half of the current electrode spacing on a transparent log-log paper at the same scale as of two and three layers standard curves. The interpretation by curve matching technique of VES data is to use the curve of apparent resistivity versus electrode spacing, plotted from field measurements, to obtain the parameters of the geoelectrical section, the layer resistivities and thicknesses. The use of standard curves matching technique requires an identification of the curve type followed by a comparison with standard curves of that type to obtain the best match. Two-layer and three-layer curves can be used for complete interpretation of VES curves of more layers by the Auxiliary Point Method, which requires the use of a small set of auxiliary curves and some constructions. This is the early method of interpreting sounding curves which used curve-matching techniques. A set of standard curves developed by Orellana and Mooney (1966) and Zohdy (1969) is shown in Fig. 4.3. This technique has also been used by many researchers such as Shankar (1994), Lashkaripour (2003), Lashkaripour et al. (2005) and Oseji et al. (2006). Based on this preliminary interpretation, initial estimates of the resistivities and thickness (layer parameters) of the various geoelectric layers were obtained.

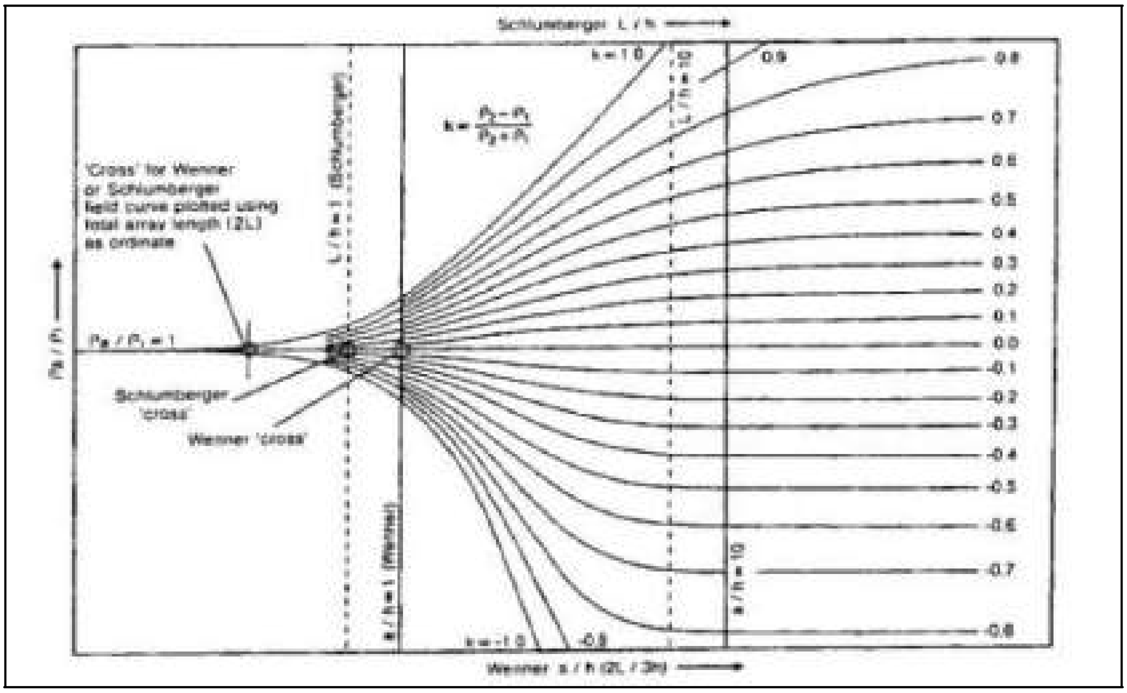


Fig.4. 3. Master curve for two layered system (Source: Bernard, 2003)

In the second analysis, the layered parameters derived from the graphical curve matching were then matched with the interpreted sounding data in terms of the final layer parameters through 1-D inversion technique software (IX1D v3.0, Interpex, USA). This software produces the resistivity model, fitting the acquired field data with the least root mean square (RMS) error between the synthetic data generated from the model and the actual data themselves. The method of iteration was performed until the fitting errors between field data and synthetic model curve became least and constant. The output of true resistivities (or simply resistivities) values of the subsurface layer, their thickness and depth from the ground surface after interpreting field data (apparent resistivities) by fitting curve to input data using IX1D computer software. The electrical resistivity of sediments depends on lithology, water content, clay content and salinity (Bernard, 2003; Choudhury and Saha, 2004). Some interpretation problems for VES can occur when mapping subsurface salinity, since resistivities for salt water, saturated clay and sand overlaps. It is therefore important to correlate the VES results with the lithological and hydrological information of the same sites.

4.2.2. Data Interpretation and Discussion

Since the study area falls on sedimentary tract, the water prospect here is by the saturated water present in the sand aquifers below. The tract is alluvial and water availability here is good, the aquifers zones are unconfined and are very prospectful zones for groundwater development by deep tubewells.

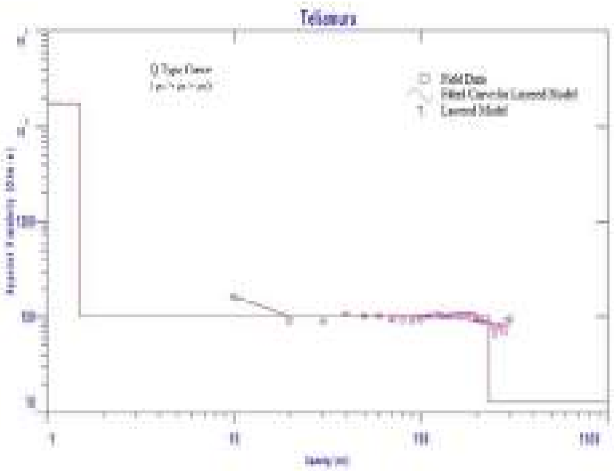


Fig. 4.4a. VES curve for location Teliamura

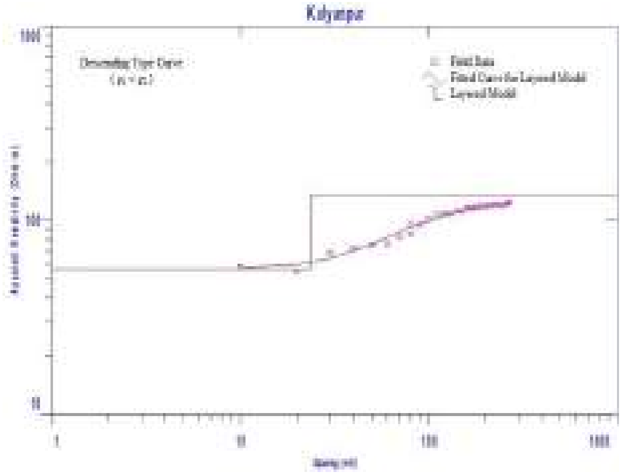


Fig. 4.4b. VES curve for location Kalyanpur

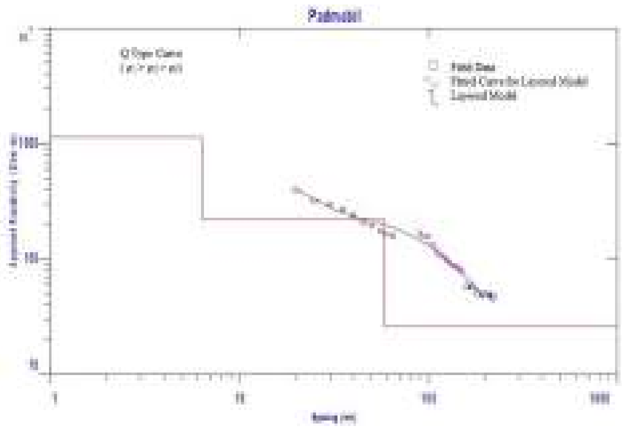


Fig. 4.4c. VES curve for location Padmabil

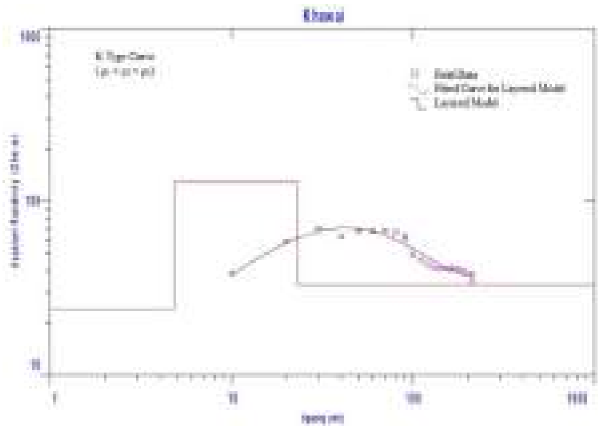


Fig. 4.4d. VES curve for location Khowai

Khowai District

VES curve at Teliamura and Padmabil is classified as Type Q Curve reflecting the presence of three subsurface layers which gives the resistivity relationship of $\rho1 > \rho2 > \rho3$. VES curve at Kalyanpur is classified as Descending Type Curve reflecting the presence of two subsurface layers which gives the resistivity relationship of $\rho1 < \rho2$. VES curve at Khowai is classified as Type K Curve reflecting the presence of three subsurface layers which gives the resistivity relationship of $\rho1 < \rho2 > \rho3$. All the VES curves are presented in Fig. 4.4 (Fig. 4.4a to Fig. 4.4d).

From the interpreted true resistivities at Khowai district, Tripura, we can see that subsurface formations are highly variable. At Teliamura we can see three subsurface layers out of which the top layer is generally formed with very coarse sand particles with gravel, the second layer is generally formed with clay mixed with fine sand particles and the bottom layer is generally formed with clay. At Kalyanpur we can see two subsurface layers out of which the top layer is generally formed with clay with conserved moisture contents and the bottom layer is generally formed with clay mixed with fine sand particles. At Padmabil we can see three subsurface layers out of which the top layer is generally formed with very coarse sand particles, the second layer is generally formed with dry silty clay and the bottom layer is generally formed with clay. At Khowai we can see three subsurface layers out of which the top layer is generally formed with clay, the second layer is generally formed with clay mixed with fine sand particles and the bottom layer is generally formed with clay with conserved moisture contents.

West Tripura district

VES curve at Jirania is classified as Type KH Curve reflecting the presence of three subsurface layers which gave the resistivity relationship of ρ1 < ρ2 > ρ3 < ρ4. VES curve at Hezamara is classified as Ascending Type Curve reflecting the presence of two subsurface layers which gave the resistivity relationship of ρ1 > ρ2. All the VES curves are presented in Fig. 4.5 (Fig. 4.5a and Fig. 4.5b).

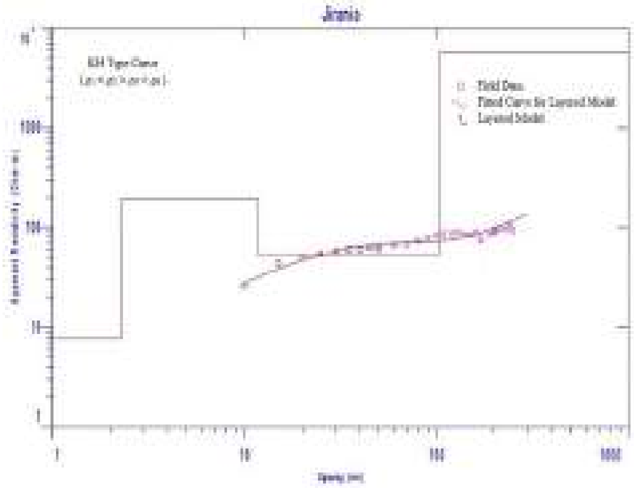


Fig. 4.5a. VES curve for location Jirania

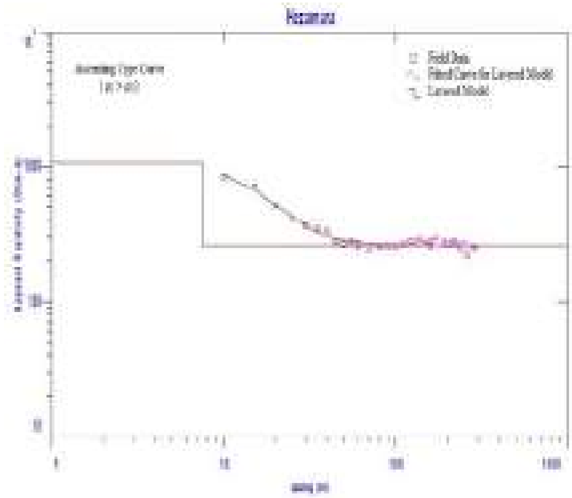


Fig. 4.5b. VES curve for location Hezamara

From the interpreted true resistivities at West Tripura district, Tripura, we can see that subsurface formations are highly variable. At Jirania we can see four subsurface layers out of which the top layer is generally formed with impervious type clay, the second layer is generally formed with clay mixed with fine sand particles, the third layer is generally formed with clay with conserved moisture contents and the bottom layer is generally formed with very coarse sand particles with gravel. At Hezamara we can see two subsurface layers out of which the top layer is generally formed with very coarse sand particles and the bottom layer is generally formed with silty clay.

Sepahijala district

VES curve at Maheshpur and Kathalia is classified as Descending Type Curve reflecting the presence of two subsurface layers which gives the resistivity relationship of ρ1 < ρ2. VES curve at Paharpur is classified as Type Q Curve reflecting the presence of three subsurface layers which gives the resistivity relationship of ρ1>ρ2 > ρ3. VES curve at Sonamura is classified as K Type Curve reflecting the presence of three subsurface layers which gives the resistivity relationship of ρ1 < ρ2 > ρ3. VES curve at Boxanagar is classified as KHK Type Curve reflecting the presence of five subsurface layers which gives the resistivity relationship of ρ1 < ρ2 > ρ3 < ρ4 > ρ5. All the VES curves are presented in Fig. 4.6 (Fig. 4.6a to Fig. 4.6e).

From the interpreted true resistivities at Sepahijala district, Tripura, we can see that subsurface formations are highly variable. At Maheshpur we can see two subsurface layers out of which the top layer is generally formed with hard impervious type clay and the bottom layer is generally formed with clay with conserved moisture contents. At Kathalia we can see two subsurface layers out of which the top layer is generally formed with hard impervious type clay and the bottom layer is generally formed with clay mixed with fine sand particles.

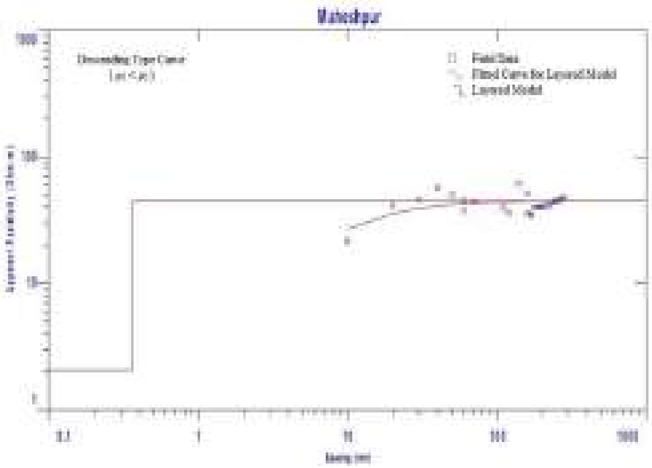


Fig. 4.6a. VES curve for location Maheshpur

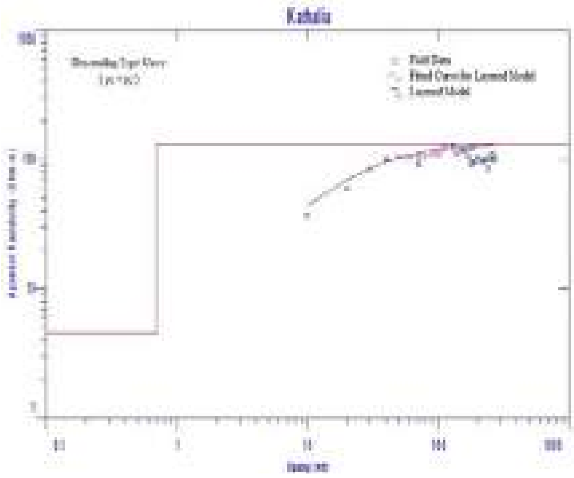


Fig. 4.6b. VES curve for location Kathalia

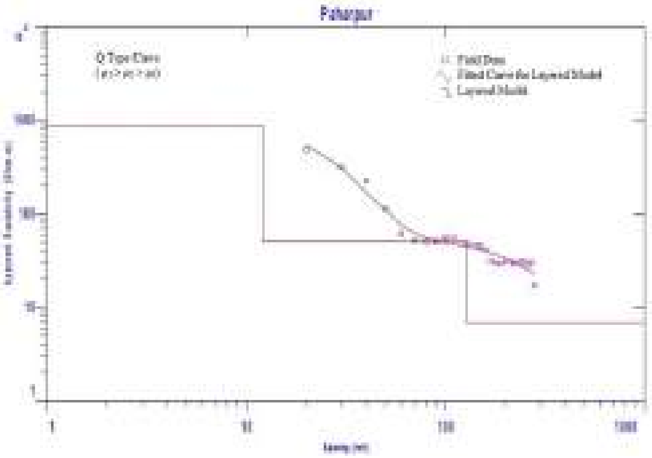


Fig 4.6c. VES curve for location Paharpur

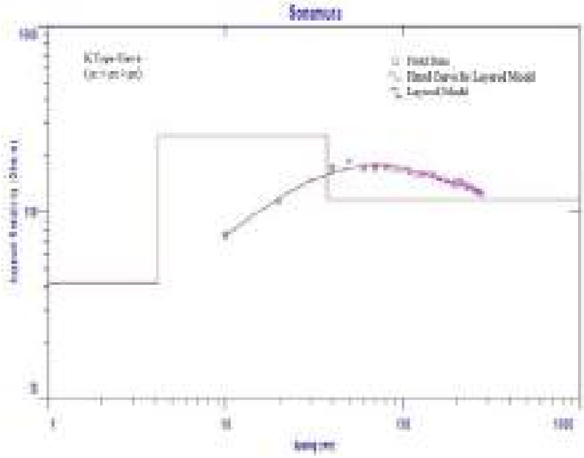


Fig. 4.6d. VES curve for location Sonamura

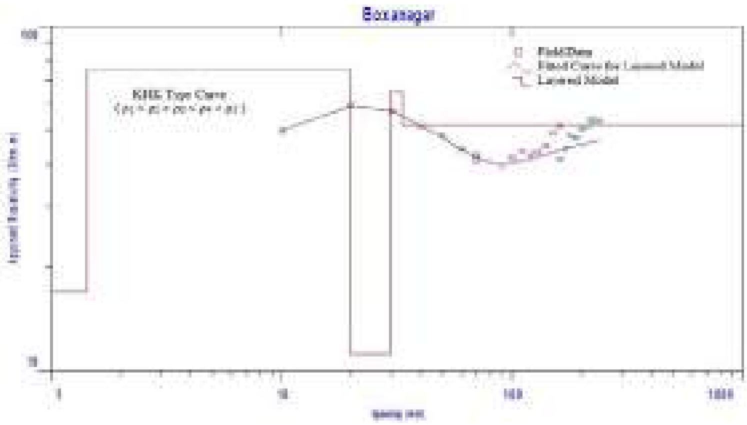


Fig. 4.6e. VES curve for location Boxanagar

At Paharpur we can see three subsurface layers out of which the top layer is generally formed with very coarse sand particles, the second layer is generally formed with clay with conserved moisture contents and the bottom layer is generally formed hard impervious type clay. At Sonamura we can see three subsurface layers out of which the top layer is generally formed with clay with conserved moisture contents, the second layer is generally formed with dry silty clay and the bottom layer is generally formed with clay mixed with fine sand particles. At Boxanagar we can see five subsurface layers out of which the top layer is generally formed with clay, the second layer is generally formed with clay mixed with fine sand particles, the third layer is generally formed with impervious type clay, the fourth layer is generally formed with clay mixed with very fine sand particles and the bottom layer is generally formed with clay with conserved moisture contents.

Gomati district

VES curve at Tepania is classified as Type QH Curve reflecting the presence of four subsurface layers which gives the resistivity relationship of $\rho1 > \rho2 > \rho3 < \rho4$. VES curve at Matabari and Amarpur is classified as Type Q Curve reflecting the presence of three subsurface layers which gives the resistivity relationship of $\rho1>\rho2 > \rho3$. VES curve at South Karbook is classified as Type K Curve reflecting the presence of three subsurface layers which gives the resistivity relationship of $\rho1 < \rho2 > \rho3$. VES curve at East Karbook is classified as Ascending Type Curve reflecting the presence of two subsurface layers which gives the resistivity relationship of $\rho1 > \rho2$. All the VES curves are presented in Fig. 4.7 (Fig. 4.7a to Fig. 4.7e).

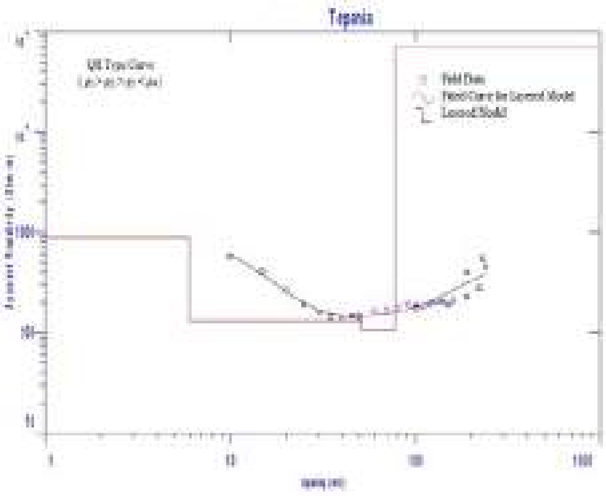


Fig. 4.7a. VES curve for location Tepania

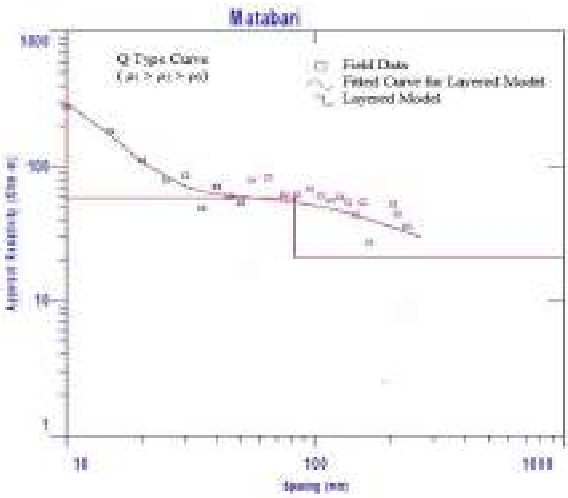


Fig. 4.7b. VES curve for location Matabari

From the interpreted true resistivities at Gomati district, Tripura, we can see that subsurface formations are highly variable. At Tepania we can see four subsurface layers out of which the top layer is generally formed with coarse sand particles, the second layer is generally formed with clay mixed with fine sand particles, the third layer is generally formed with clay mixed with very fine sand particles and the bottom layer is generally formed with very coarse sand particles with gravel. At Matabari we can see three subsurface layers out of which the top layer is generally formed with coarse sand particles, the second layer is generally formed with clay with conserved moisture contents and the bottom layer is generally formed with clay. At Amarpur we can see three subsurface layers out of which the top layer is generally formed with silty clay, the second layer is generally formed with clay mixed with fine sand particles and the bottom layer is generally formed with clay with conserved moisture contents. At South Karbook we can see three subsurface layers out of which the top layer is generally formed with clay with conserved moisture contents, the second layer is generally formed with clay mixed with fine sand particles and the bottom layer is generally formed with clay. At East Karbook we can see two subsurface layers out of which the top layer is generally formed with coarse sand particles and the bottom layer is generally formed with clay.

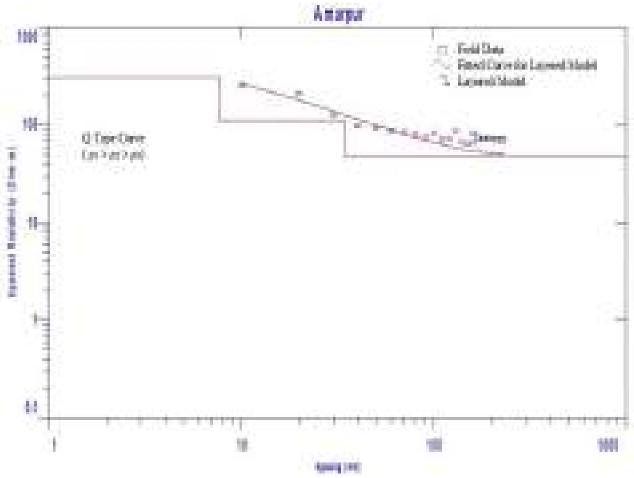


Fig. 4.7c. VES curve for location Amarpur

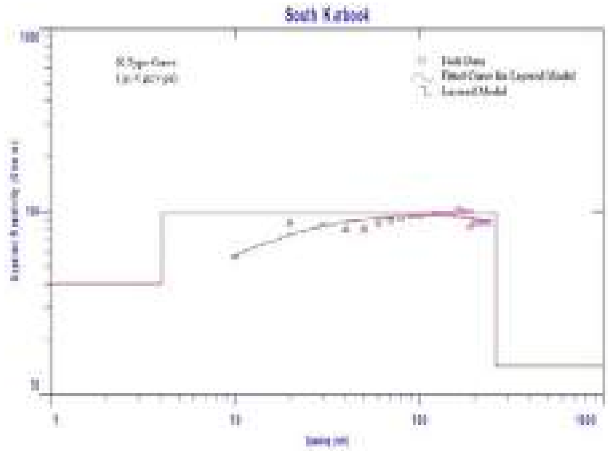


Fig. 4.7d. VES curve for location South Karbook

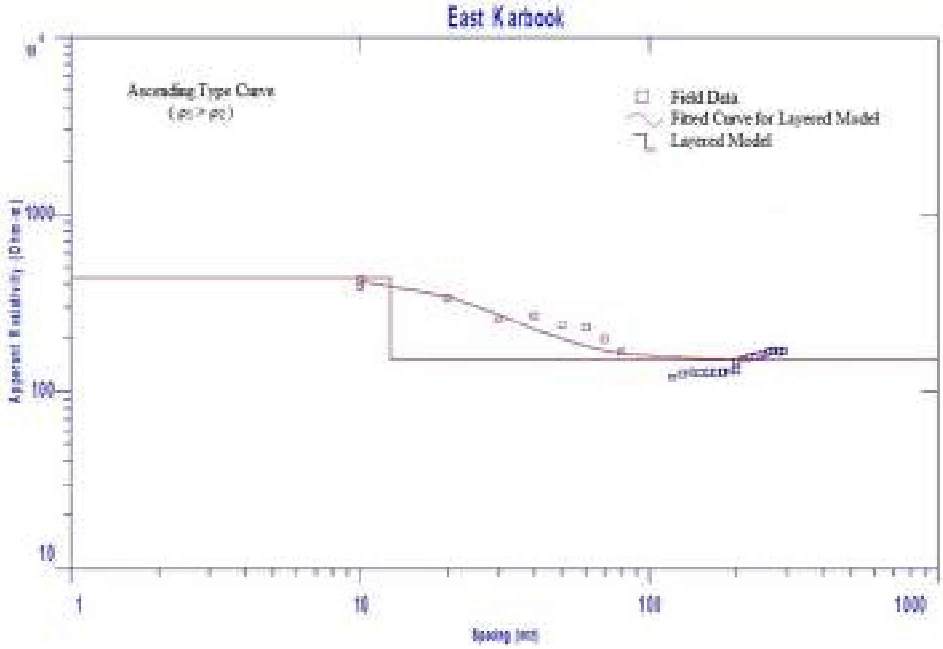


Fig. 4.7e. VES curve for location East Karbook

The two important Dar Zarouk parameters viz. Total Transverse Resistance and Total Longitudinal Conductance calculated for each VES point for this study area varies within 0.747 ohm-m^2 to 46293.1 ohm-m^2 and 0.00713 Siemens to 2.7599 Siemens respectively. From the values it can be seen that Teliamura, Paharpur and South Karbook are the locations which have both the above said parameters value near the maximum i.e., these are the locations having good groundwater potential and Maheshpur and Kathalia are the locations which have both the above said parameters value near the minimum i.e., these are the locations having poor groundwater potential.

4.3.Resistivity Survey Concept and Application: Part of Tripura (Valley Wise)

Schlumberger sounding array was used in the area to know the vertical variation of resistivity along depth and to locate the aquifer zone and proper bore well sites. In this method, all4 electrodes are kept in one line as shown in Fig. 4.8. Current is sent into the ground through two outer current electrodes and the resulting potential difference is measured between two inner electrodes comprising carbon pots. The current electrode spacing is gradually increased. Resistance of the ground is measured for different set s of elect rode spacing. As the separation between the current electrodes is increased, current penetrates deeper and the observed resistance pertains to resistivity of the deeper bodies. Depth of investigation depends on the resistivity structure in the subsurface; the higher the resistivity, the more is the depth of investigation. Maximum current electrode spread of 800 m was used in the investigation. Corresponding toeach spacing of electrodes, apparent resistivity is calculated at the centre of the spread using the following formula.

$\rho a = \Pi n(n+1)a. (\Delta V/I)$,

Where ‘a’ is distance between two potential electrodes in m, na = distance between the centre of the electrodes and one extreme current electrode in m. Resistance ($\Delta V/I$) has been measured by the resistivity meter. In the present investigation, depth of probing was about200-300m. Thus, data for a sounding curve is generated for each sounding point (location). These data (apparent resistivity vs half the current elect rode separation) have been plotted on a Log-Log scale. These curves are first interpreted by curve matching technique with a set of master curves of Orellena and Mooney and then interpretation was refined by using 1-D software IPI2WIN. The interpreted parameters, thus obtained are the resistivitty and thickness of each subsurface layer upto the depth of investigation. Finally, these resistivity values of the layers are interpreted in terms of geological format ions and aquifer zone. Interpreted parameters, namely resistivity and thickness of different subsurface layers are given in Table 4.3. It may be pointed out that resistivity survey technique is indicative and works well under the assumed conditions.

Table 4.3. General guideline of litholog strata with resistivity values of different subsurface layer

Lithology	Resistivity (Ohm.m)
Compactrock(sandstone)	>350ohm-m
Semicompacthardsand/rock/carbonateconcretion	200 ohm-m -350 ohm.m
Coarsesandwith/withoutpebbles(aquifer)	46 ohm-m – 150 ohm.m
Medium sand (aquifer)	30 ohm-m – 45 ohm.m
Finesand/veryfinesand(occasionallyaquiferzone)	20 ohm-m – 30 ohm.m
Clay, sandy clay	<15 ohm-m

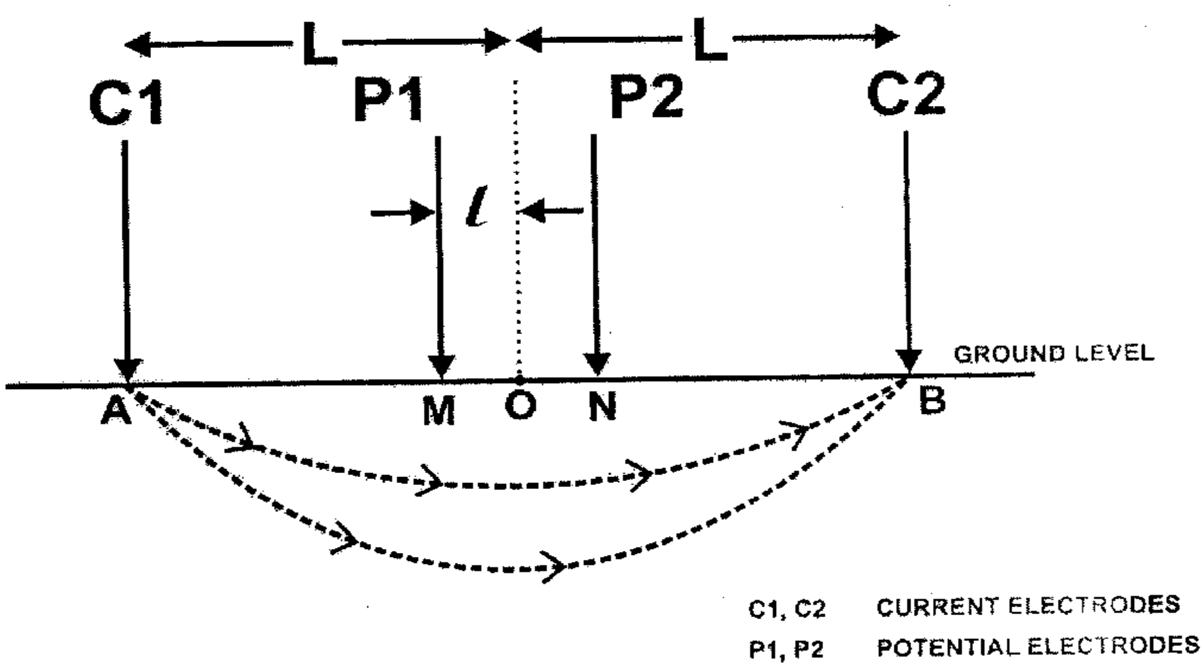


Fig 4.8.ElectrodeconfigurationinSchlumbergermethod(assume, a=1)

4.3.1. Data Analysis using Resistivity Survey and Interpretation with Borehole Litholog

Agartala valley

Based on the known geology of the area in borehole lithology, our past experience and present vertical electrical sounding investigation, correlation has been made between the various lithological units including groundwater zone and the true resistivity values interpreted in the area. These are generally as follows:

Details ofinterpreted vertical electrical soundings (VES) in the 4 valleys are givenbelow depicted in Fig. 4.9.

AgartalathecapitalofTripuraissituatedatthewestern corneroftheState.It is connectedwithmainlandbyNationalHighwayno.44viatheStateofAssam.Globallyitissituated between23^{0}45’and23^{0}55’Nlatitudeand91^{0}15’to91^{0}20’ElongitudeinthefloodplainsoftheHaorariver.Historicallythecityhasbeenanimportantborder-tradingtownhavingtrading linkageswithBangladesh.TotalareaofTripurais10,491.69 km^2. It receives an annual average rainfall of 2115 mm. Thehill area is 6400 km^2. The semi- consolidated formations consisting of friablesandstone, sandy shale, etc of tertiary ageforms the main rock types of the area have been found. The unconfined aquifer is mainly tapped through shallow wells with a discharge of 5 to 15 Lps in the valley areas whereas in the sandstone, the yield varies from 2 to 4 Lps. The annual replenish ablegroundwater resource is 2.19 BCM and netannual groundwater availability is 1.97 BCM. The annual groundwater draft is 0.17 BCM and stage of groundwater development is 9%. The entire state has been categorized as safe. Groundwater development in the deeper aquifers has also been established through construction of deep tubewells, the yield of wells tapping the sandstone areas varies from 25 to 40 Lps. There is no over exploited, critical and semi- critical zone. Exploratory tubewells constructedcollected from Drinking Water Sanitation, are as follows : 94 8 deep tube well (DTWs) and 26 ,086 spot sources. For artificial recharge to groundwater (AR) the numbers of feasible artificial recharge structure are: 300 check dams, 500 weirs, 1000 gabion structures, 240 roof top harvesting and 100 developments of springs. However, in districts of Dhalai, north Tripura, south Tripura and west Tripura are affected (in part) by iron contaminants (for example water having> 1.0 mg/L of iron). As on 2009 the total irrigation utilization potential of Tripura is 52616 ha (MOWR, 2009).

The naturalreservoir,underlainbyunconsolidatedalluvialsediments(sand,gravel,pebblesetc.)hasimmensegroundwaterpotential. ThewatertabledepthinAgartalacityofthenaturalreservoirvariesbetween2mand6m.Inthesynclinalvalleyof Agartatladistrict,aquifersarefoundinthesemi-consolidatedsoftandstonesoftertiaryage wherebothshallow(within30-50mbelowgroundlevelwithyield5to20m^3/hr)anddeeptubewells(50to200mbelowground leveldeepwithyieldvaryingfrom50-200m^3/hr)anddeeptubewells(50 to200m belowgroundleveldeepwithyieldvaryingfrom50-200m^3/hr)arefeasible.Potentialdeep aquifersintheuppertertiaryareasofAgartalahavebeenidentifiedinSurma,TipamandDupitila partsofthedistrict.ThelateststimateofgroundwaterpotentialofHaorariveris353MCM/yearbutitscurrentutilizationisinsignificant(Datta*etal.*,2008).Lackofroadcommunication,non-availabilityofflatareasinthehills, highironcontent,lackofrighttypeoftheequipmentsfordrillingbouldryfoundation,hugethicknessofclaybodiesandoverburdenofweatheredresiduum arethedominantproblemsofgroundwaterdevelopmentinthearea.Theexisting70deeptube wellhasbeenfoundhavingyield10,000 to20,000GPH.

Tripurastateingeneralandinvestigatedareasinparticularisunderlainby thegeologicalformationsrangingfromuppertertiarytoquaternarySubsurfaceformationsarecharacterizedbyasuccessionofargillaceousandarenaceoussedimentaryrocks,likesandstone, shale,siltstone,siltandclaybelongingtoSurma,TipamandDupitialagroups.TheSurmagroupoccursat thecoreofanticlineandmostlycomprisesofshale,siltstoneandsandstoneandisbroadlyconsideredtobe notsopromisingforgroundwater.TheTipamgroup isrepresentedbysandstone,sandyshaleandsiltstone.Dupitillagroupoccursintheformofdisconnectedmoundsandoccursinvalleys.Thisgroupcomprisesofcoarsetogrittyferruginoussandstone,clay,clayeysandstoneandlaterites.Therecentsedimentsmostly developedalongrivers,comprises ofsilt,sandsilty clay,etc. Seismicsurveysintheregionrevealthepresenceofsub-surfaceflatus. ThepartofSurmabasin in TripuraMizoramarealiesincloseproximitytotheShillongplateauinthenorthandArakanYomabelttotheeast.Tripurais,therefore,locatedinaseismicallyactivezone.Becauseofinherentcharacterofsedimentsoftheseareasevenaminorshockduringearthquakemaycausedevastatingeffects,likelandslides,etc.(Mukherjee*etal.*,1998).

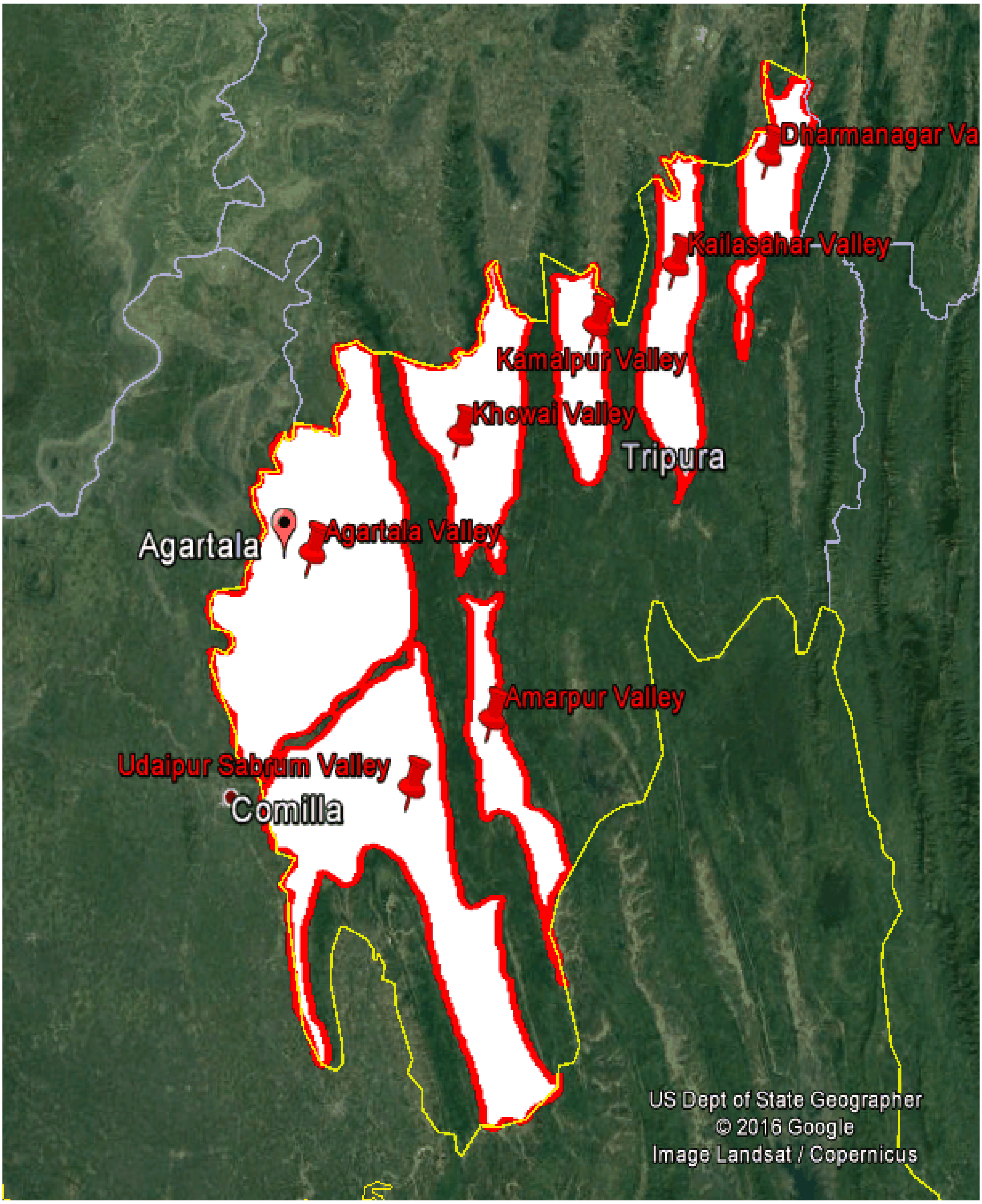


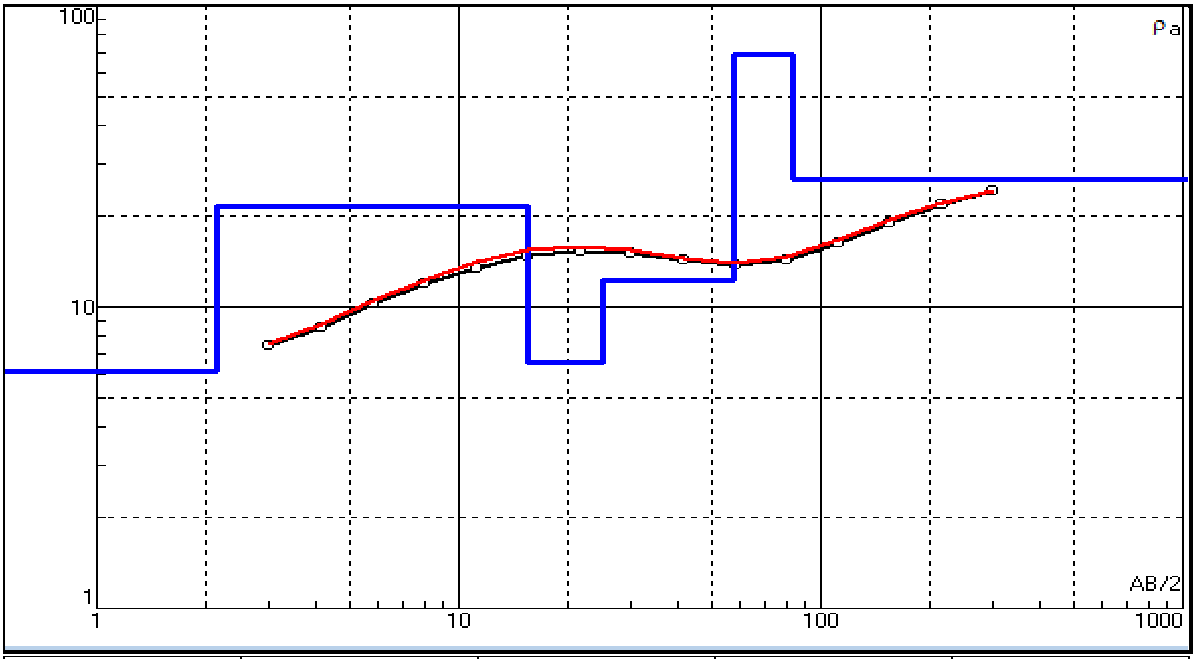
Fig 4.9. Map of Tripura against Valley

4.3.2. Resistivity Survey using Vertical Electrical Sounding (VES): Blocks of Tripura

Based on the known geology of the area in borehole litholog, our past experience and present VES investigation, correlation has been made between the various litho logical units including ground water zone and the true resistivity values interpreted in the area. These are generally as follows:

Details of Interpreted Vertical Electrical Soundings (VES) in the four valleys are given below:

VES-1(MaddyaBoxanagar,Boxnagarblock): Clayandveryfinesandoccurfromsurfacetoadepthof 57.5m,belowwhichagood aquiferzonecomprisingcoarsesandisinterpretedupto83.8mfollowedbyanotherfinesandlayeratdeeperlevel.Consideringthatgroundwaterintheareaisabstractedfromthedepthrange60m-200m,totalthicknessofaquiferzonehasbeenestimatedinthatdepthintervalandfoundtobe23.8 m as given in Fig. 4.10a.

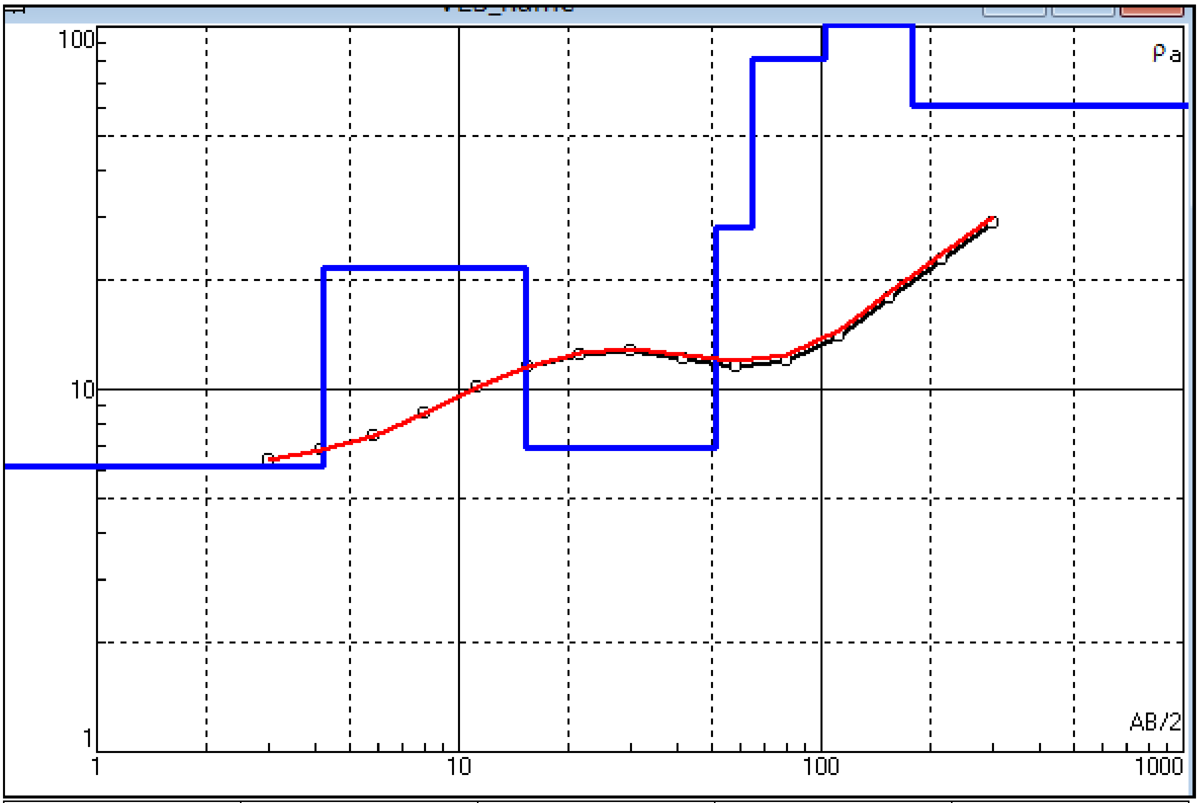


No.	ρ	h	d	Alt
1	6.1	2.14	2.14	-2.14
2	21.6	13.26	15.4	-15.4
3	6.54	9.6	25	-25
4	12.3	32.5	57.5	-57.5
5	69.2	26.3	83.8	-83.8
6	26.6			

Fig. 4.10a. VES-1(MaddyaBoxnagar,Boxnagarblock)

VES-2(Bhabanipur,Kataliablock): Clayandveryfinesandoccurupto51.5mbelowwhich,finesandis inferredupto64.7m.Belowthis,anexcellentaquiferzonecomprisingcoarsesandisinterpreted upto179mormore.Totalthicknessofaquiferzoneinthedepthrange60m-

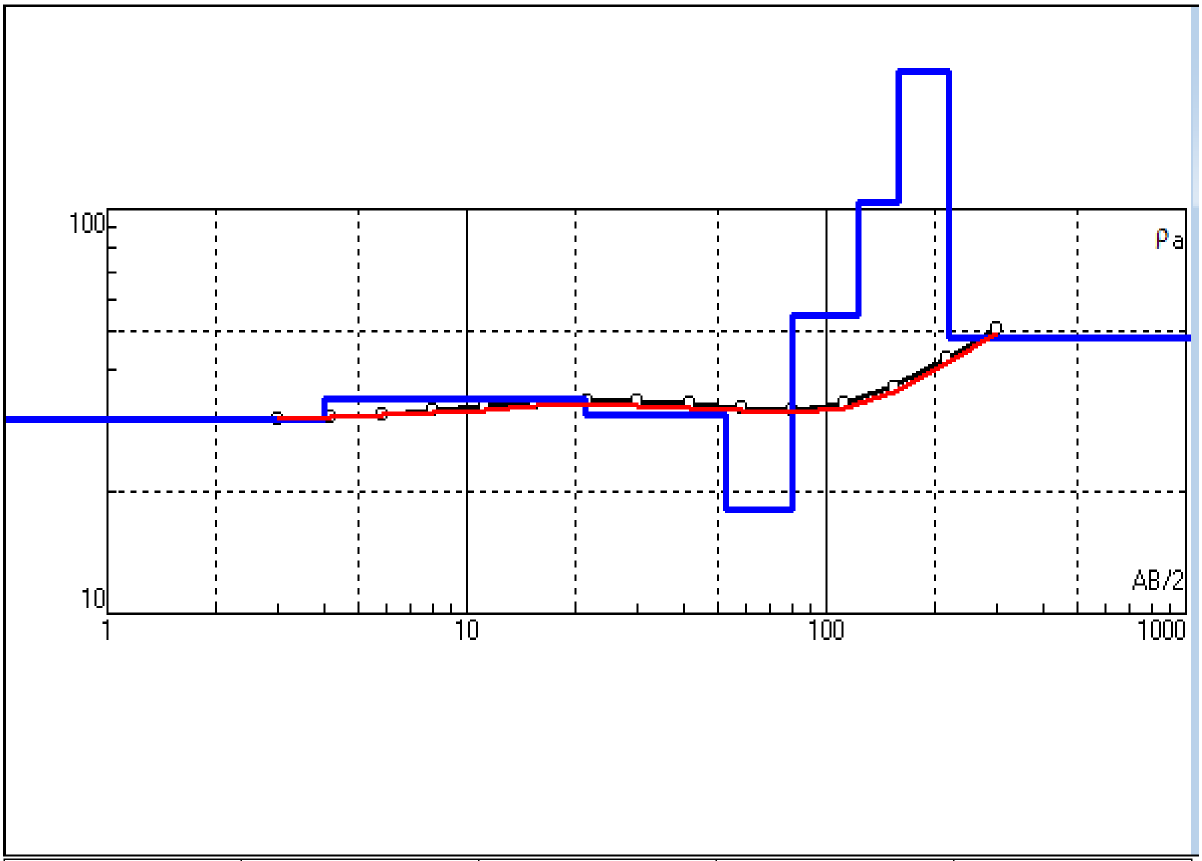
200misestimatedas135.3m as depicted in Fig. 4.10b.



no	ρ	h	d	Alt
1	6.14	4.25	4.25	-4.25
2	21.6	11.05	15.3	-15.3
3	6.89	36.2	51.5	-51.5
4	28	13.20	64.72	-64.7
5	81.4	37.9	102.6	-103
6	101	75.9	178.5	-179
7	60.5			

Fig. 4.10b. VES-2(Bhabanipur,Kataliablock)

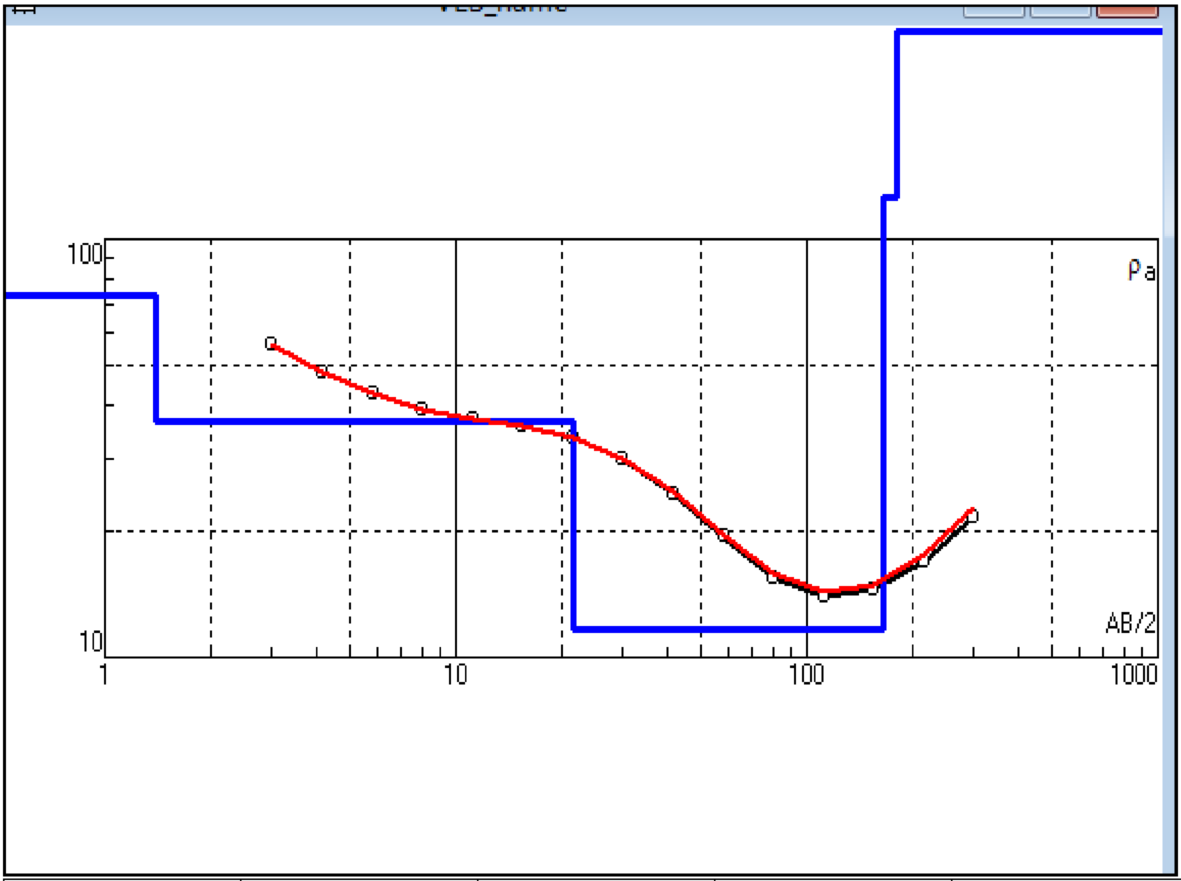
VES-3(UmraiOldMarket,Mohanbugblock): Finesandispredominantupto80.6mbelowwhichanexcellentaquiferzonecomprisingcoarsesandoccursupto158.4m ormore.Totalthicknessofaquiferzoneinthedepthrangeof60m-200misestimatedas69.4m referred in Fig. 4.10c.



no	ρ	h	d	Alt
1	30.12	4	4	-4
2	33.87	17.4	21.4	-21.4
3	30.88	31	52.4	-52.4
4	18.1	28.2	80.6	-80.6
5	54.63	42.8	123.4	-123.4
6	104.6	35	158.4	-158.4
7	218.7	60	218.4	-218.4
8	47.9			

Fig. 4.10c. VES-3(UmraiOldMarket,Mohanvugblock)

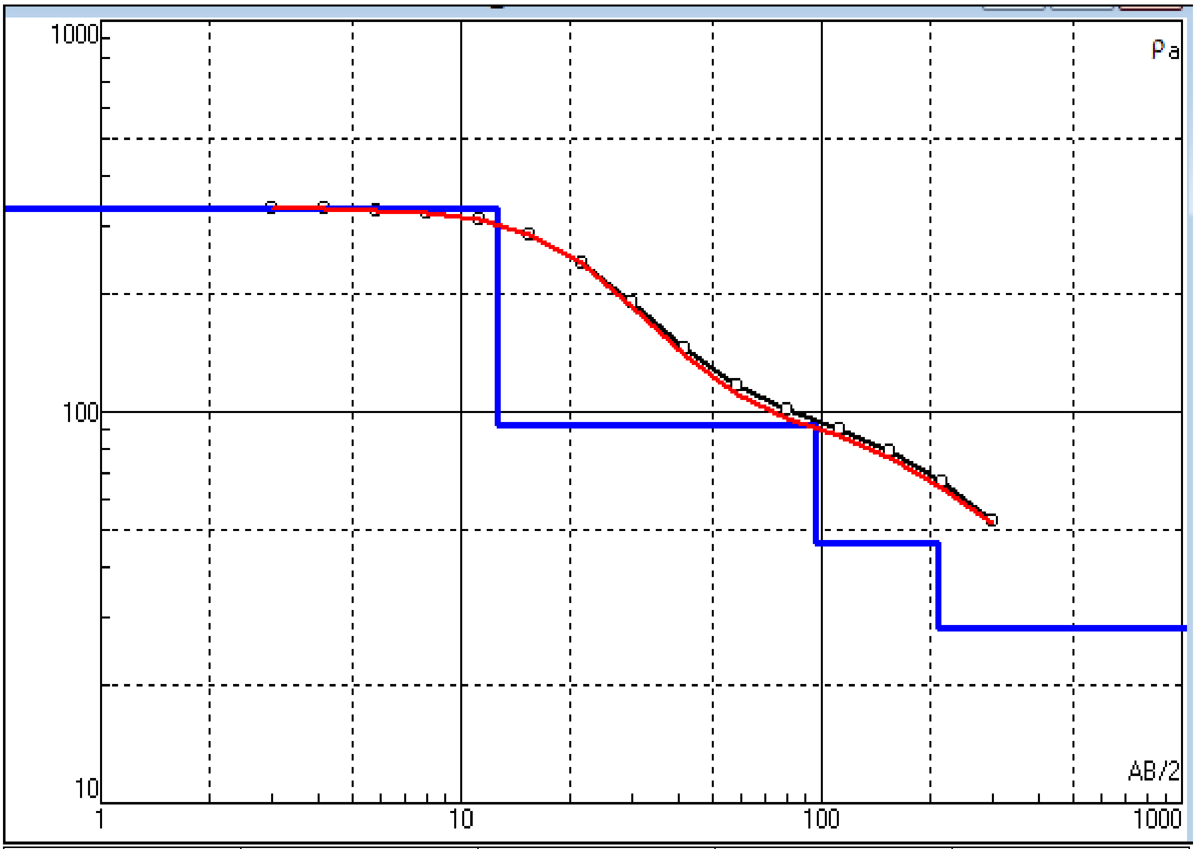
VES-4(Kulubari,BoxaNagarblock,SonamuraSD): Finetomediumsandoccursupto21.6mbelow which,sandyclayispredominantupto164mdepthfollowedbyaverygoodaquiferzonecomprisingcoarsesandlayerupto181mdepth.Totalthicknessofaquiferzoneinthedepthrange60m-200misestimatedas17m as sown in Fig. 4.10d.



no	ρ	h	d	Alt
1	73.9	1.4	1.4	-1.4
2	36.4	20.2	21.6	-21.6
3	11.7	142.7	164.3	-164.3
4	126	16.4	180.7	-180.7
5	614			

Fig. 4.10d. VES-4(Kulubari,BoxNagarblock,SonamuraSD)

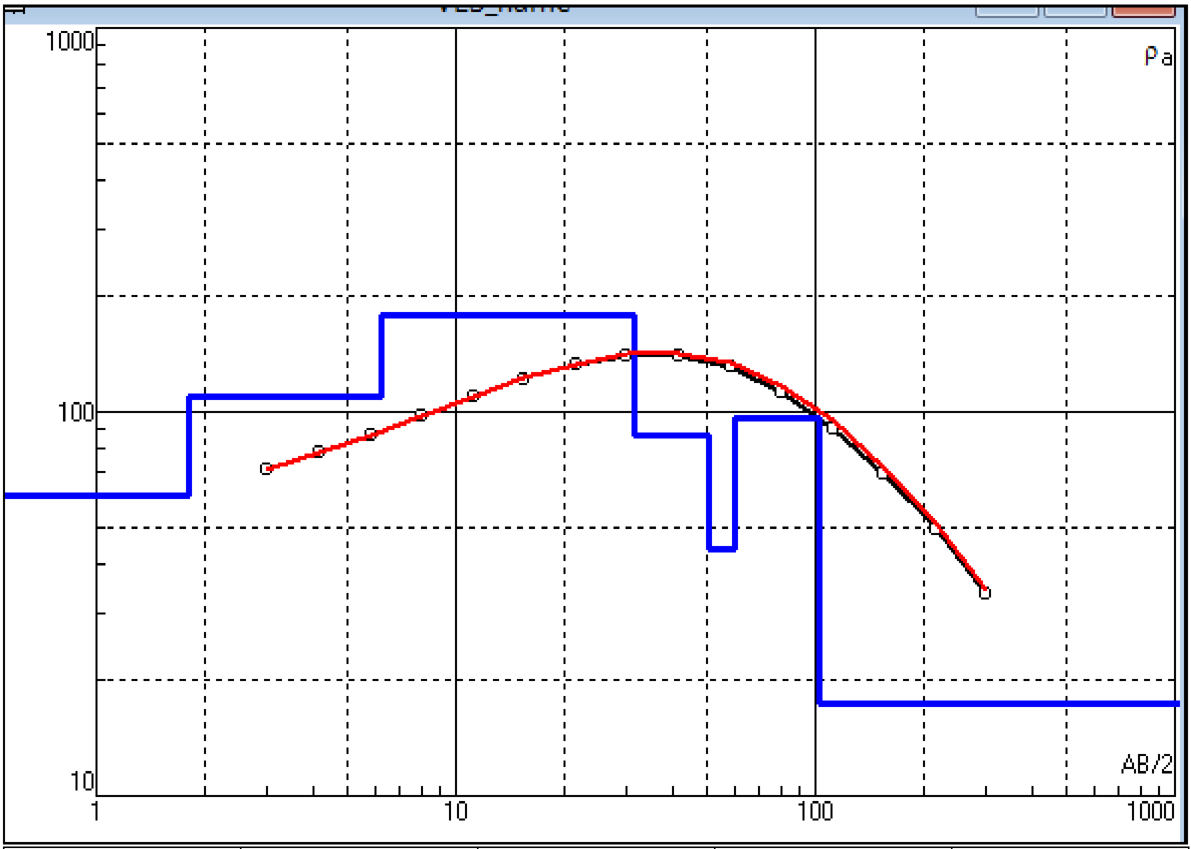
VES-5(GhanabillMath,Teliamurablock,Khoai district): Anexcellentaquifer zonecomprisingcoarsesandisinferredfrom12.6mto212mdepth.Totalthicknessofaquiferzone inthedepth range60 m-200 m is estimatedas140m as given in Fig. 4.10e.



No	ρ	h	d	Alt
1	332	12.6	12.6	-12.6
2	92.6	83.8	96.4	-96.4
3	46	115.6	212	-212
4	28			

Fig. 4.10e. VES-5(GhanabillMath,Teliamurablock,Khowaidistrict)

VES-6(Chikancherra,Jampuijalablock,BishalgarhSD): Anexcellentaquiferzonecomprising coarsesandoccursfrom31.5mto102mdepthbelowwhich,veryfinesandislikely.Totalthicknes sofaquiferzoneinthedepthrange60m-200misestimatedas42m (Fig. 4.10f).

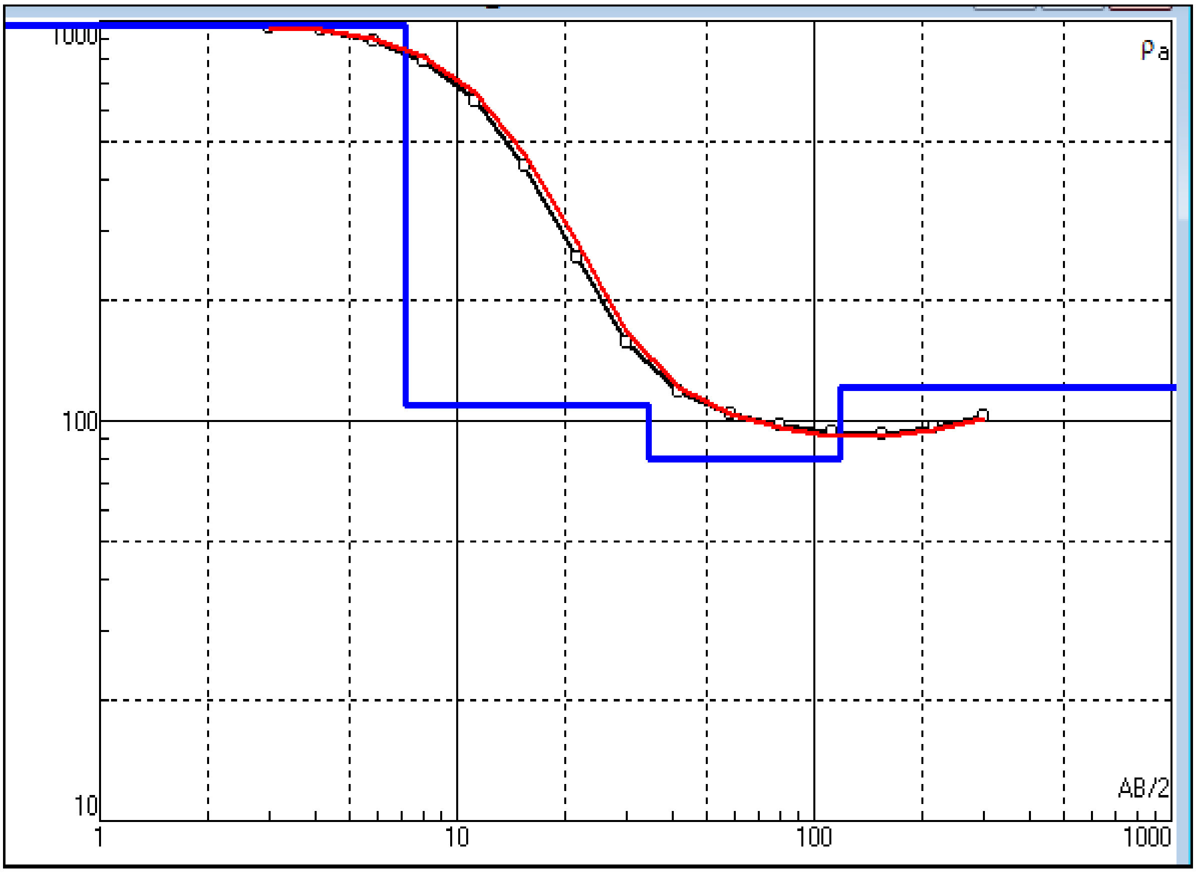


no	ρ	h	d	Alt
1	60.3	1	1.8	-1.8
2	109	4.4	6.2	-6.2
3	178	25.3	31.5	-31.5
4	86.8	18.9	50.4	-50.4
5	44	9.1	59.5	-59.5
6	96.2	42.9	102.4	-102.4
7	17.5			

Fig 4.10f. VES-6(Chikancherra,Jampuijalablock,BishalgarhSD)

UdaipurValley

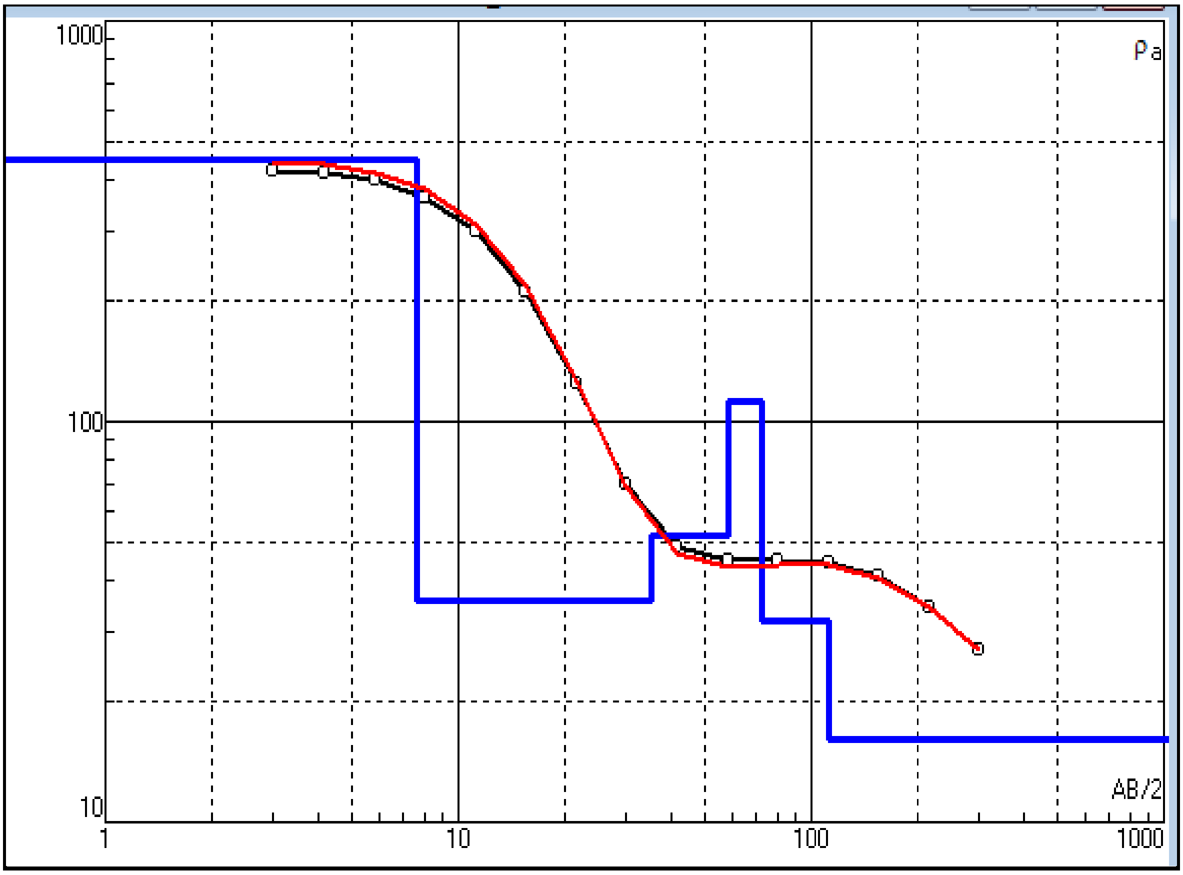
VES-1(SouthSrinagar,Sabroomblock): Averygoodaquiferzonecomprisingmostlycoarsesandis interpretedbelow7.16mcomprisingmostlycoarsesand.Consideringthatgroundwaterintheareaisabstractedfromthedepthrange60m-200m,totalthicknessofaquiferzonehasbeenestimatedinthatdepthintervalandfoundtobe140m (Fig. 4.11a).



no	ρ	h	d	Alt
1	980	7.16	7.16	-7.16
2	109	27.04	34.2	-34.2
3	80.4	83.9	118.1	-118.1
4	121			

Fig. 4.11a. VES-1(SouthSrinagar,Sabroomblock)

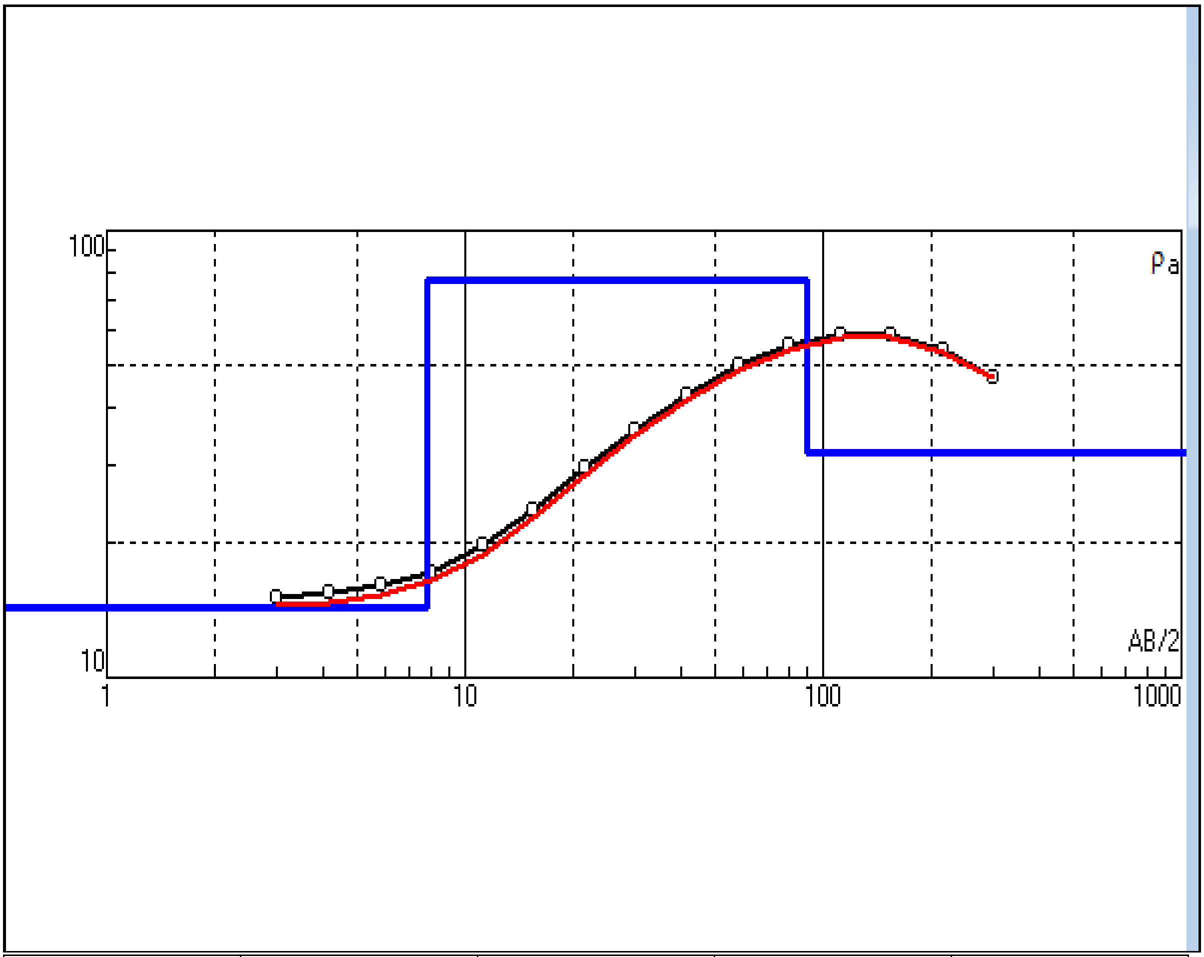
VES-2(BenafaPattar,Rupaichariblock): Mediumsandoccursfrom7.6m to35.2mbelowwhich,coarsesandispredominantupto72.4mfollowedbyanothermediumsand layerupto112mfollowedbyclayeysandatdeeperlevel.Consideringthatgroundwaterin theareaisabstractedfromthedepthrange60m-200m,totalthicknessofaquiferzonehasbeenestimatedinthatdepthintervalandfoundtobe52m as given in Fig. 4.11b.



no	ρ	h	d	Alt
1	450	7.6	7.6	-7.6
2	35.7	27.6	35.2	-35.2
3	51.6	23.1	58.3	-58.3
4	112	14.1	72.4	-72.4
5	32	39.4	111.8	-111.8
6	16			

Fig. 4.11b. VES-2(BenafaPattar,Rupaicharib lock)

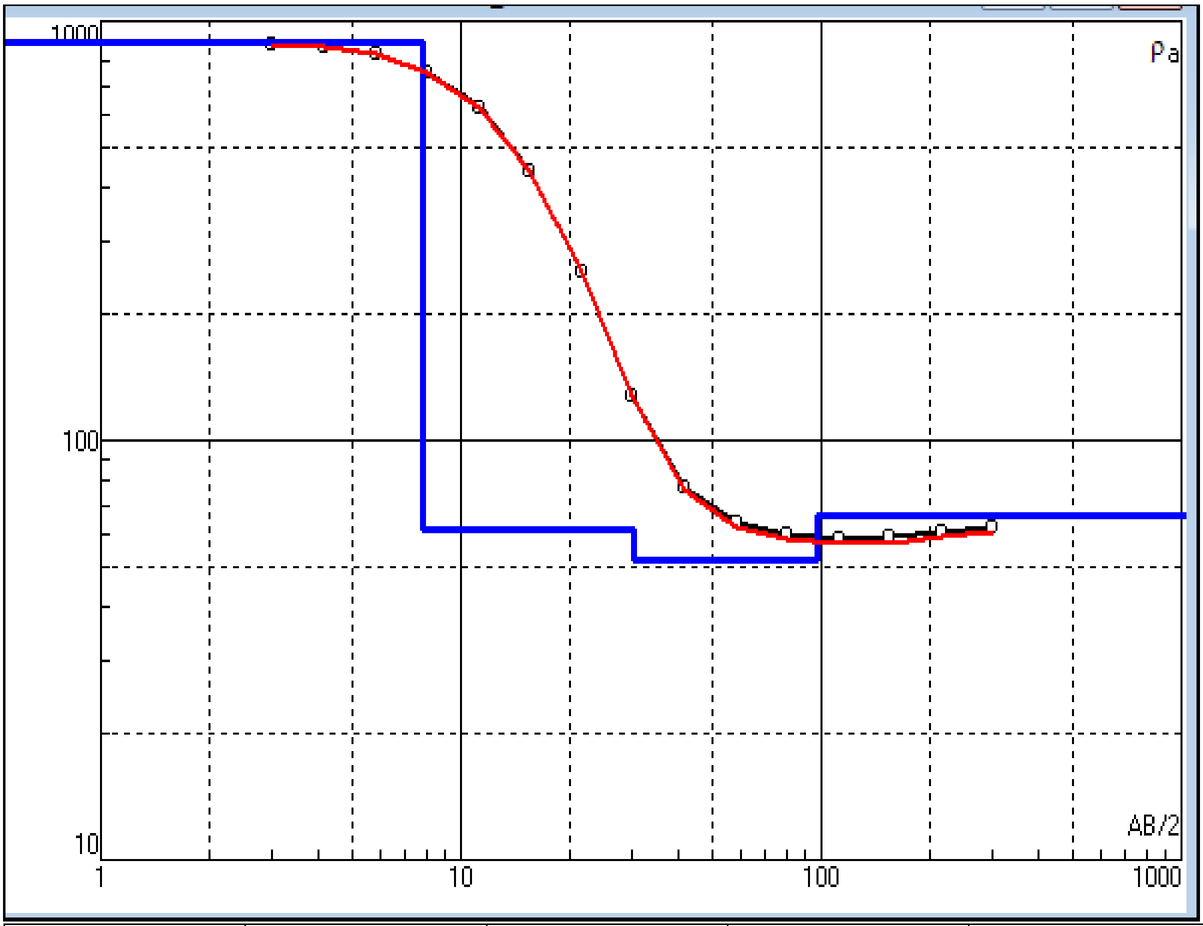
VES-3(UttarBharatchandraNagar,RajnagarRDblock):A very good aquifer zonecomprising coarse sand is interpreted from 7.86 m to 90.6 m below which, an aquifercomprising medium sand occurs. Considering that ground water in the area is abstractedfrom the depth range 60 m-200 m, total thickness of aqifer zone has been estimated in that depth interval and found to be 140 m. as shown in Fig. 4.11c.



no	ρ	h	d	Alt
1	14.3	7.86	7.86	-7.86
2	77.4	82.74	90.6	-90.6
3	32			

Fig. 4.11c. VES-3(UttarBharatchandraNagar,RajnagarRDblock)

VES-4 (Radhanagar no. 4 Tilla, Rajnagar RD 9 block) : A very good aquifer zone comprising mostly coarse sand is likely from 7.8 m downward continuing atleast upto 140 m. Considering that ground water in the area is abstracted from the depth range 60 m. 200m, total thickness of aquifer zone has been estimated in that depth interval and found to be 19.7 m. as depicted in Fig. 4.11d.

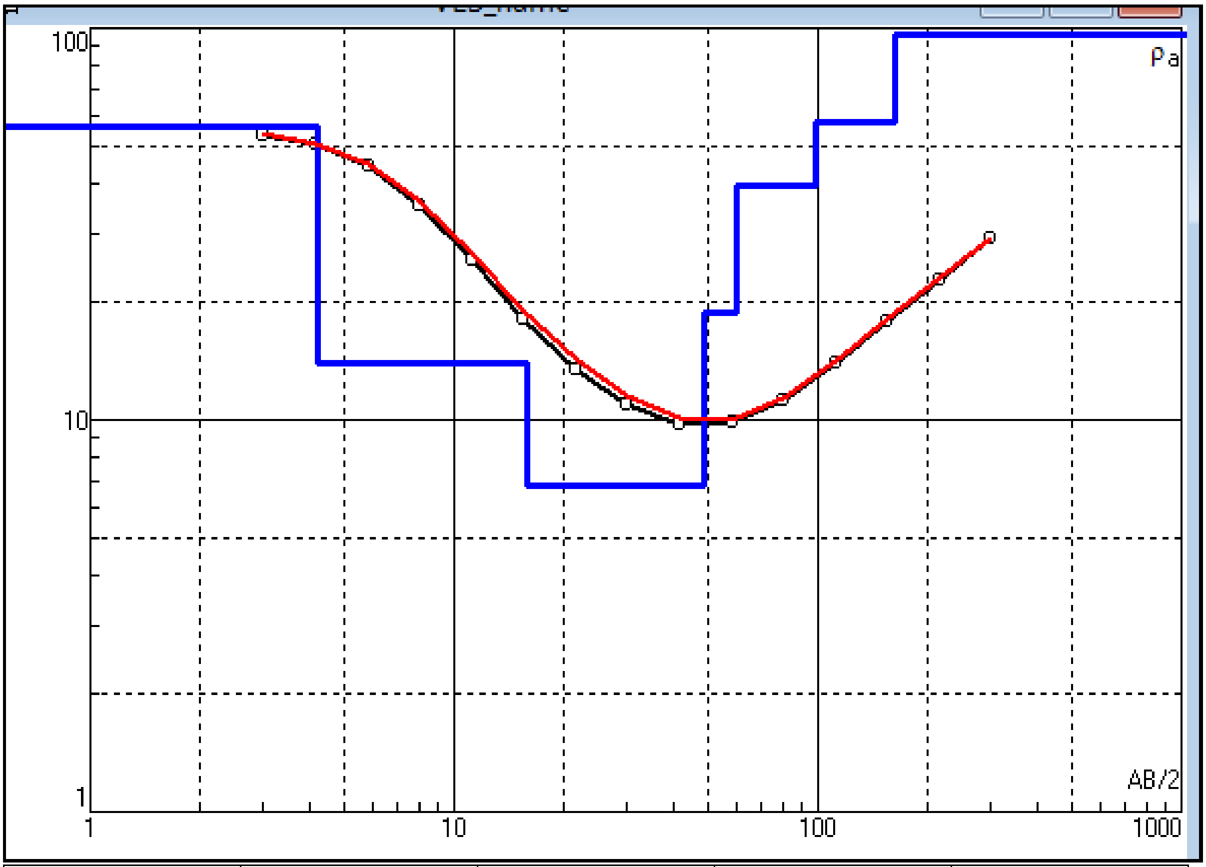


no	ρ	h	d	Alt
1	890	7.8	7.8	-7.8
2	61.7	22.5	30.3	-30.3
3	51.89	66.6	96.9	-96.9
4	66			

Fig. 4.11d. VES-4(Radhanagarno.4Tilla,RajnagarRDblock)

Dharmanagar valley

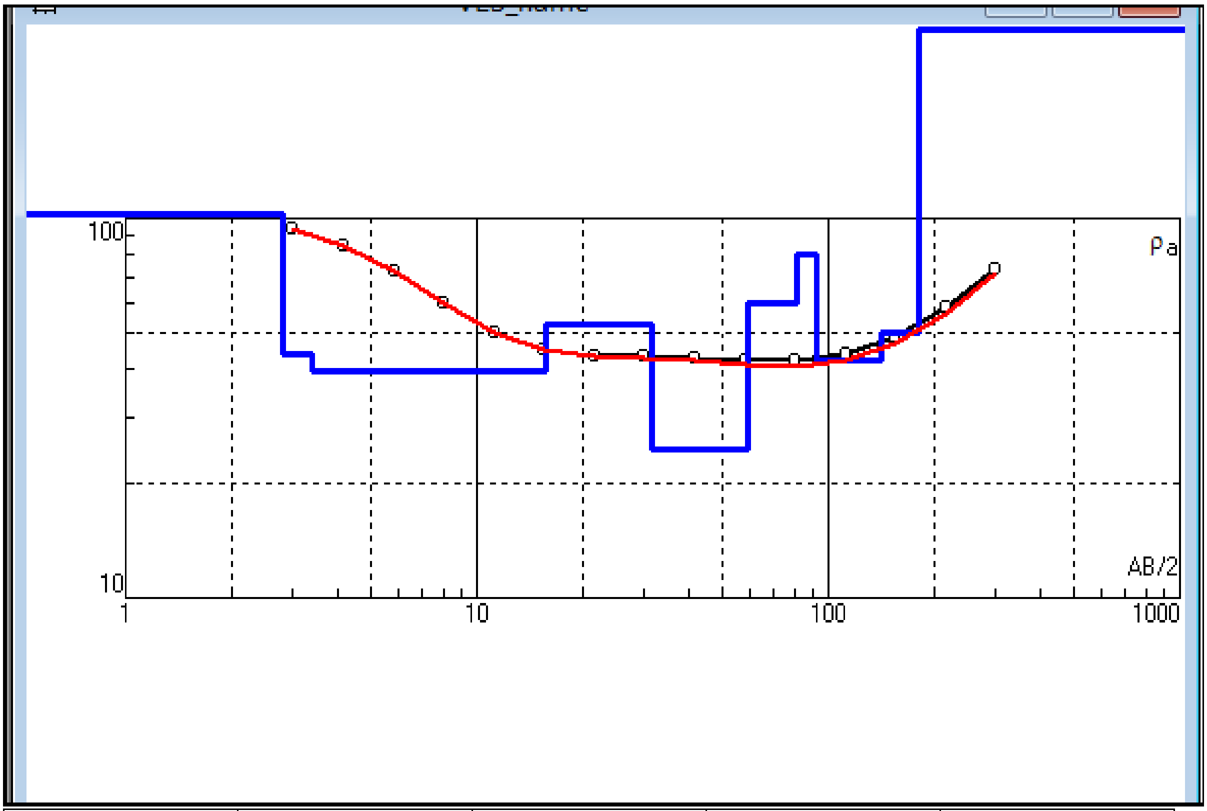
VES-1 (Brajendra Nagar, Kadamtala block) : Clay and very fine sand occur upto 59.4 mdepth followed by a good aquifer zonecomprising medium sand upto 98.5 m andcoarse sand at deeper level upto 180 m or so.Considering that ground water in the area isabstracted from the depth range 60 m -200m, total thickness of aquifer zone has beenestimated in that depth interval and found tobe 140 m.referred in Fig. 4.12a.



no	ρ	h	d	Alt
1	56	4.2	4.2	-4.2
2	14	11.6	15.8	-15.8
3	6.8	32.8	48.6	-48.6
4	18.9	10.8	59.4	-59.4
5	39.6	39.1	98.5	-98.5
6	57.5	64.5	163	-163
7	96.4			

Fig. 4.12a. VES-1(BrajendraNagar,Kadamtalablock)

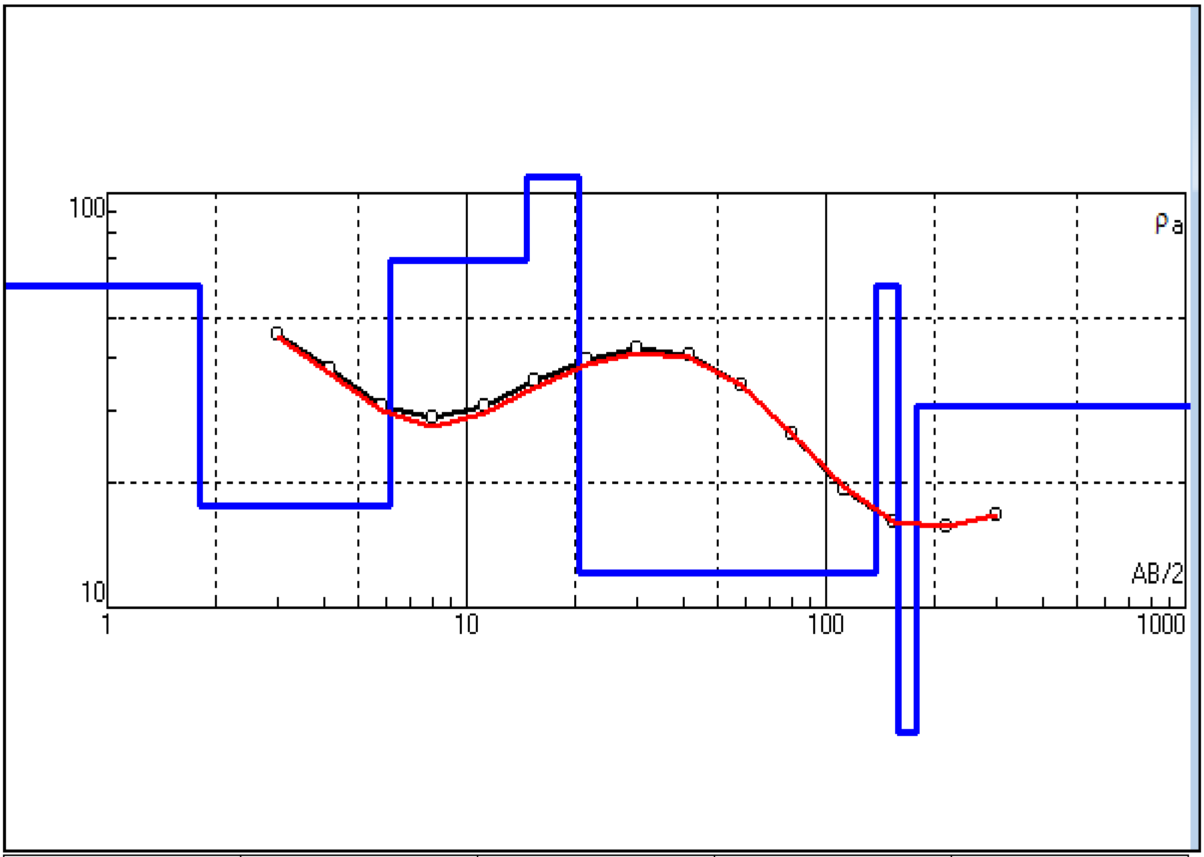
VES-2 (Gatachera, Penchartal RD block) : Alternate layers of medium and coarse sandoccur here. Only one fine sand layer is interpreted between 31.5 m and 58.7 m. Aquifer zone continues throughout with some possible clay intercalations. Considering that ground water in the area is abstracted from the depth range 60 m-200 m, total thickness of aquifer zone has been estimated in that depth interval and found to be 140 m. (Fig. 4.12b).



no	ρ	h	d	Alt
1	102	2.8	2.8	-2.8
2	44.1	0.6	3.4	-3.4
3	39.4	12.2	15.6	-15.6
4	52.5	15.9	31.5	-31.5
5	24.6	27.2	58.7	-58.7
6	59.4	22.6	81.3	-81.3
7	80.3	11.1	92.4	-92.4
8	42.4	48.8	141.2	-141
9	50.2	38.8	180	-180
10	High			

Fig. 4.12b. VES-2(Gatachera,PenchartalRDblock)

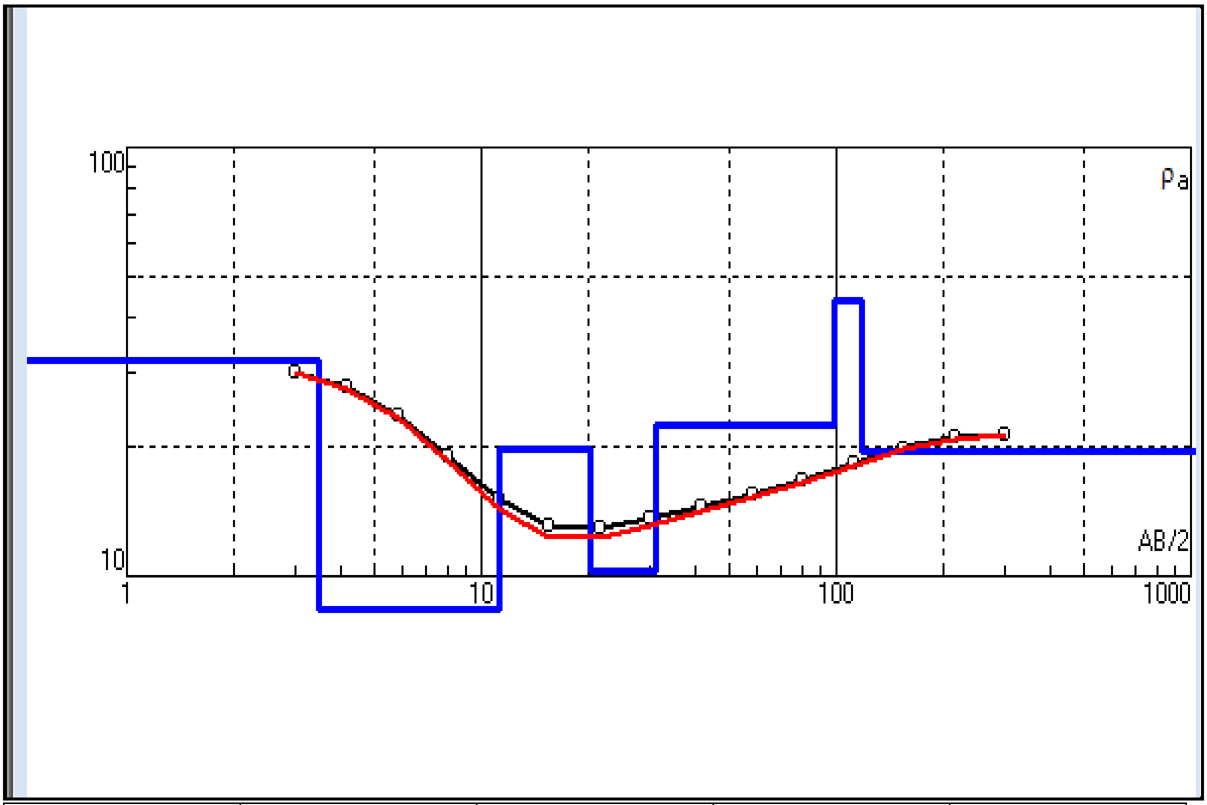
VES-3(NorthGanganagar,Jubarajnagarblock,DharmanagarSD): Coarsesandoccursfrom6.1mto20.5mbelowwhich,sandyclayisinferredupto139mdepthfollowedbyagoodaquiferzonecomprisingcoarseandupto159m.Furtherdownclayandefineto veryfinesandislikely.Consideringthatgroundwaterintheareaisabstracted fromthedepthrange60m-200m,totalthicknessofaquiferzonehasbeenestimatedinthatdepthintervalandfoundtobe41m (Fig. 4.12c).



no	ρ	h	d	Alt
1	59.9	1.8	1.8	-1.8
2	17.6	4.3	6.1	-6.1
3	68.9	8.7	14.8	-14.8
4	109	5.7	20.5	-20.5
5	12.1	118.5	139	-139
6	59.4	20.2	159.2	-159.2
7	5.02	19.6	178.8	-178.8
8	30.6			

Fig. 4.12c. VES-3(NorthGanganagar,Jubarajnagarblock,DharmanagarSD)

VES-4(Jayantipur,DosdaRDblock,KanchanpurSD): Clay,sandyclayandveryfinesandremostlypresentupto99.3m.Belowthisanaquiferzonecomprisingmediumtocoarsesandisinferredupto119m.Furtherdown,veryfinesandoccurs.Considerinthat groundwaterintheareaisabstractedfromthedepthrange60m-200m,totalthicknesstoaquiferzonehasbeenestimatedinthatdepthintervalandfoundtobe19.7m as depicted in Fig. 4.12d.

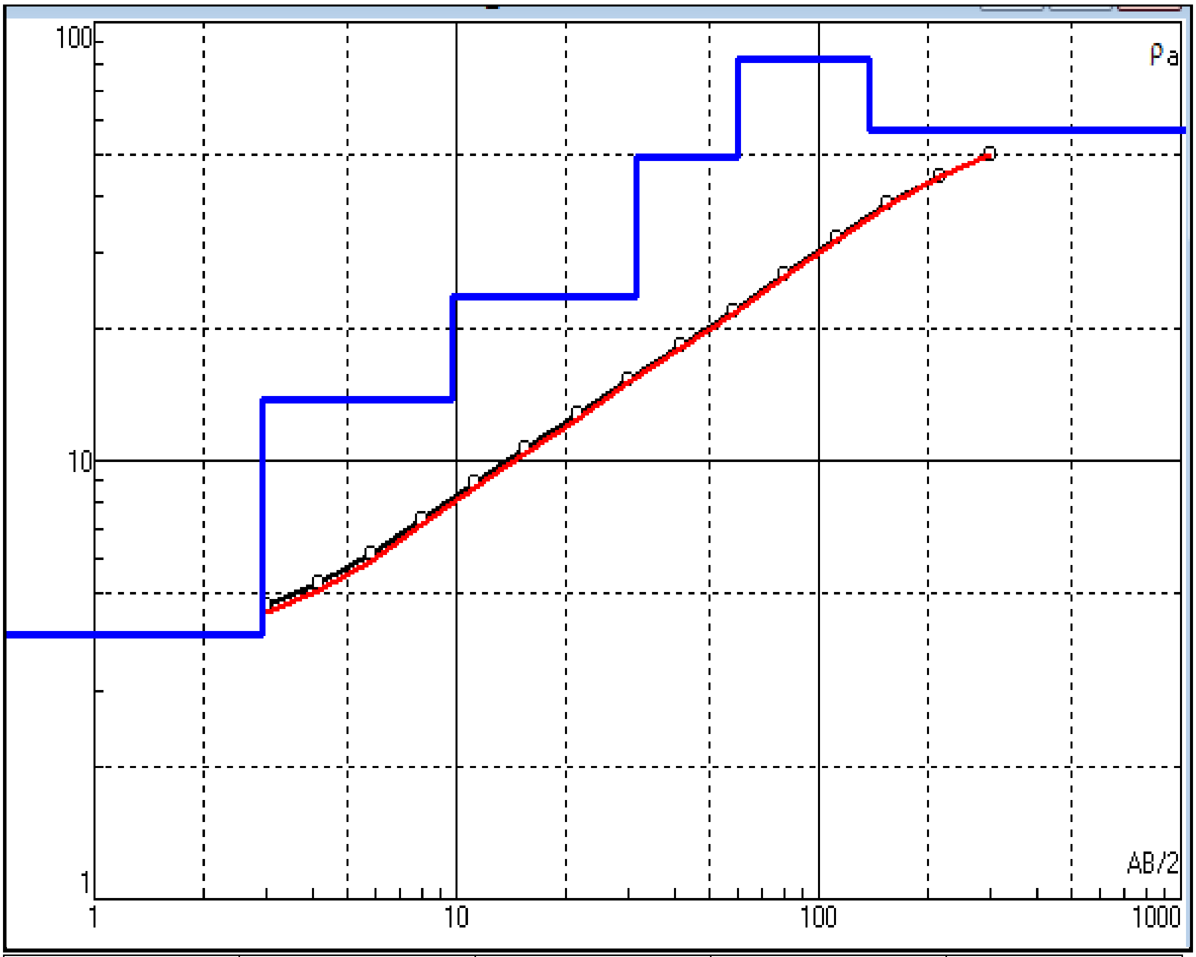


no	ρ	h	d	Alt
1	31.7	3.5	3.5	-3.5
2	8.35	7.7	11.2	-11.2
3	19.9	9.2	20.4	-20.4
4	10.2	10.8	31.2	-31.2
5	22.5	68.1	99.3	-99.3
6	44	19.7	119	-119
7	19.6			

Fig. 4.12d. VES-4(Jayantipur,DosdaRDblock,KanchanpurSD)

Kailasahar Valley

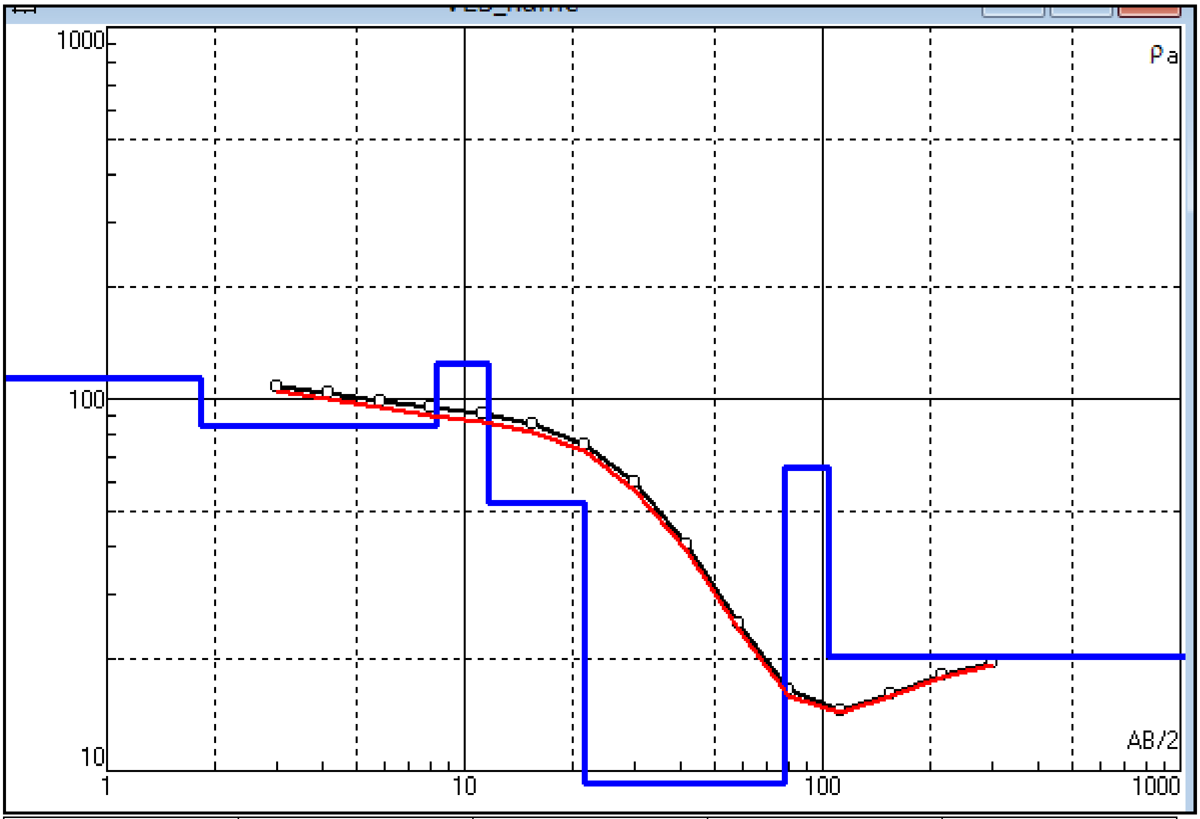
VES-1 (Sreerampur, Chandipur RD block) : Clay occur upto 2.9 m, then very fine sandupto 9.8 m and fine sand upto 31.5 m. Below this, an excellent aquifer comprising mostlycoarse sand is inferred atleast upto 150 m depth. Considering that ground water in thearea is abstracted from the depth range 60 m-200 m, total thickness of aquifer zone hasbeen estimated in that depth interval and found to be 140 m. (Fig. 4.13a).



no	ρ	h	d	Alt
1	4.01	2.9	2.9	-2.9
2	13.8	6.9	9.8	-9.8
3	23.6	21.7	31.5	-31.5
4	49.4	27.9	59.4	-59.4
5	82	79.2	138.6	-138.6
6	56.9			

Fig. 4.13a. VES-1(Sreerampur,ChandipurRDblock)

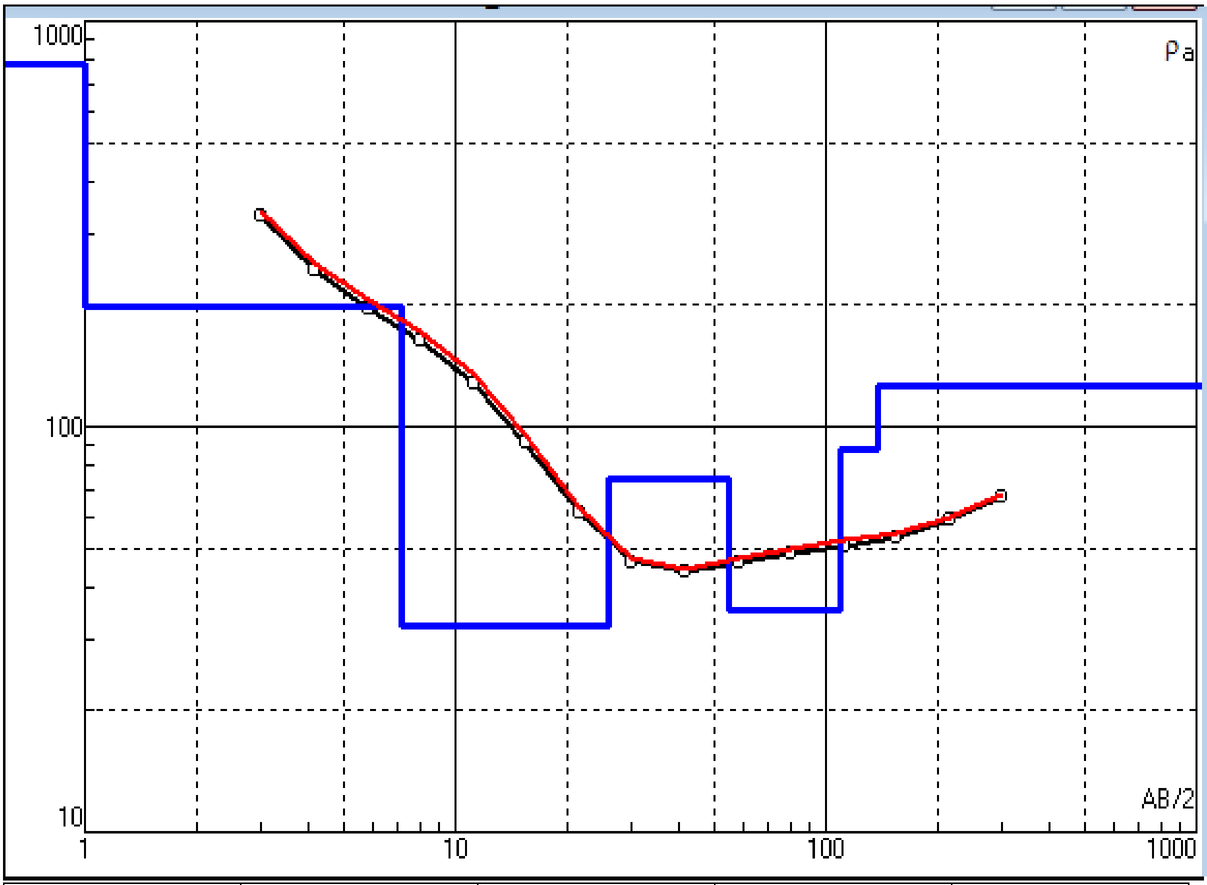
VES-2 (Kuleshnagar, Kumarghat RD block) : Coarse sand occurs from 8.3 m to 21.6 mfollowed by clay upto 78.5 and a good aquifer zone of coarse sand from 78.5 m to 103 mdepth. Further down, very fine sand is inferred Considering that ground water in the area isabstracted from the depth range 60 m-200 m, total thickness of aquifer zone has beenestimated in that depth interval and found to be 24.5. as reflected in Fig. 4.13b.



no	ρ	h	d	Alt
1	114	1.83	1.83	-1.83
2	84.6	6.47	8.3	-8.3
3	124	3.4	11.7	-11.7
4	52.9	9.9	21.6	-21.6
5	9.2	56.9	78.5	-78.5
6	65	24.5	103	-103
7	20.3			

Fig. 4.13b. VES-2(Kuleshnagar,KumarghatRDblock)

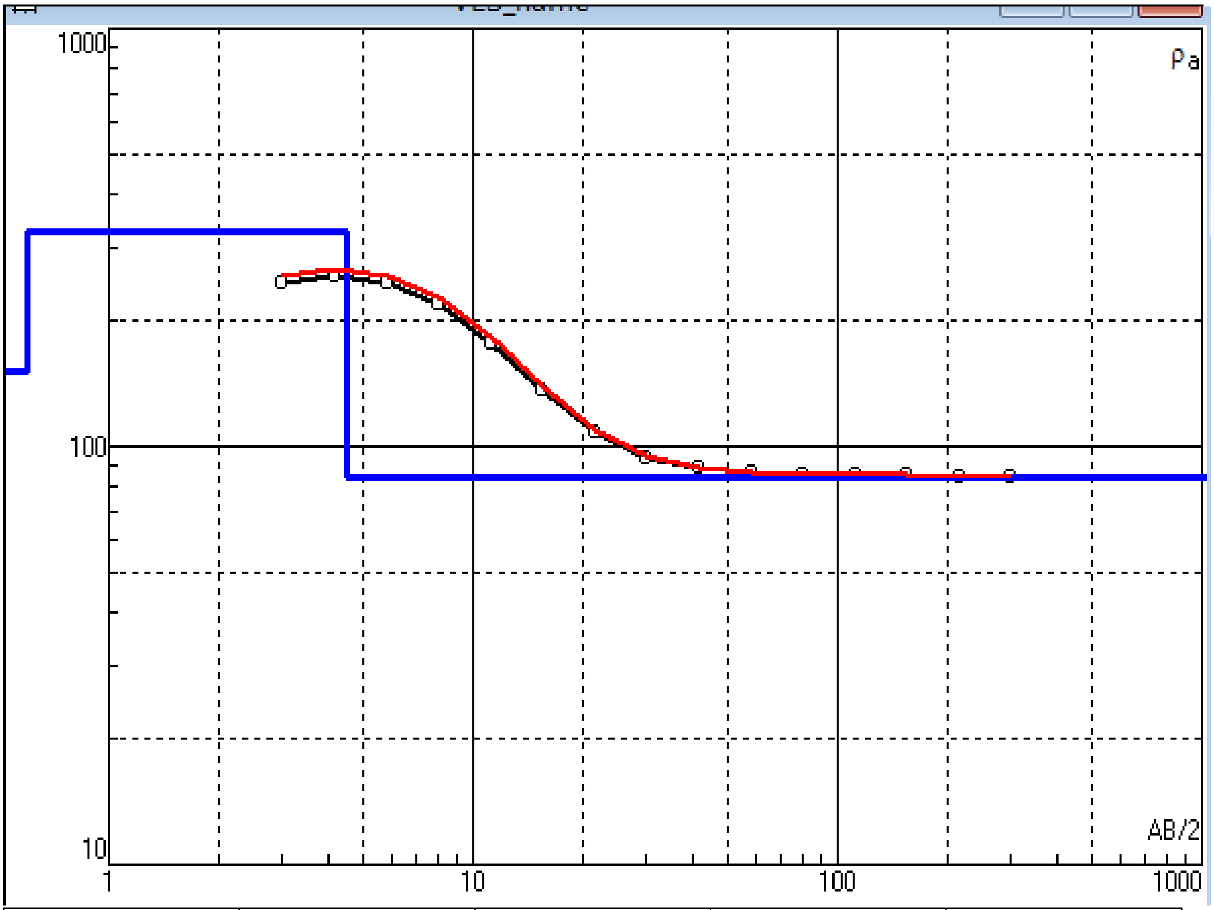
VES-3 (Ram Durlavpara, Salema block) : Medium sand occurs from 7.2 m to 25.8 m and from 54.3 m to 110 m. Coarse sand is interpreted from 25.8 m to 54.3 m and from 110 m to 138 m and beyond. All these formations contain good amount of ground water. Considering that ground water in the area is abstracted from the depth range 60 m-200 m, total thickness of aquifer zone has been estimated in that depth interval and found to be 140 m. as highlighted in Fig. 4.13c.



no	ρ	h	d	Alt
1	786	1	1	-1
2	198	6.2	7.2	-7.2
3	32.2	18.6	25.8	-25.8
4	74.4	28.5	54.3	-54.3
5	35.5	55.4	109.7	-109.7
6	87.6	28.4	138.1	-138.1
7	126			

Fig. 4.13c. VES-3(RamDurlavpara,Salemablock)

VES-4(Karamcherra,NutanBazar,Manublock): Agood aquifercomprisingmostlycoarsesandoccursfrom4.5m downwardcontinuingatleastupto150mdepth.Consideringthat groundwater intheareaisabstractedfromthedepthrange60m-200m,totalthicknessofaquiferzonehasbeenestimatedinthatdepthintervalandfoundtobe140 m as observed in Fig. 4.13d.



no	ρ	h	d	Alt
1	150	0.6	0.6	-0.6
2	327	3.9	4.5	-4.5
3	85			

Fig. 4.13d. VES-4(Karamcherra,NutanBazar,Manublock)

4.4.Critical Study of Sub-surface Aquifer: A Part of Dhalai Tripura

Total 19 nos. of location has been considered for the proposed study. Two nos. of point has been surveyed for each location with a total number of 38 points for the resistivity survey. A map is prepared referred in Fig. 4.14 from google map mentioned all VES locations and accordingly resist survey is carried out with the help of VES instrument. The lithological strata for all locations are prepared for all sampling points with effective sand media even 250 m bgl from ground level. Finally after studying the geological and geophysical properties of the area and all field datas are interpolated through various hydrogeological softwares and also it is been inferred here.

4.4.1. Characteristics of sub-surface aquifer

After studying and interpreting the satellite imagery the area seems to fall under mountainous and elevated portion of Dhalai district. The soil of the region is somewhat alluvial in nature, with occasional Hills of alluviums. The soil has a thick cover of clay at top and lateritic formation with slate in abundance.The rivers are here in their mature stage and forms meanders. The main river is Gomati and distributaries of its crisscrossed the region.Theregion is well fertile and practiced with agricultural land by the local farmers. Natural vegetation is also seemed to be in good proportion.

4.4.1.1.Geological and Physiographical settings

The proposed site falls on the east side of Dhalai district. The geological formation is of tertiary sediment sand of pliestocene–lower age. The lithostratigraphic units of alluvial formation consisting of Residual soil and is composed of sand, silt, clay (soft sediments) with rock fragments and laterite out crops and slate stone (hard formation).

Geomorphologically the area is a mountainous and hillock area.During rainy season the shallow river beds frequently over flow. The soil of the region is somewhat alluvial in nature. The area has been subjected to earthquakes in the past and land has formed hills of alluviums. Their folded structure is a synclinorium consisting of broad synclines and tight-faulted anticlines.

Hydro geologically the area is a moderate to good zone for groundwater development.The water table lies between 15 m and 20 m below ground level in the unconsolidated sandy sediments of recent alluvium. Here the groundwater yield is good and can be developed with the use of deep tube wells.

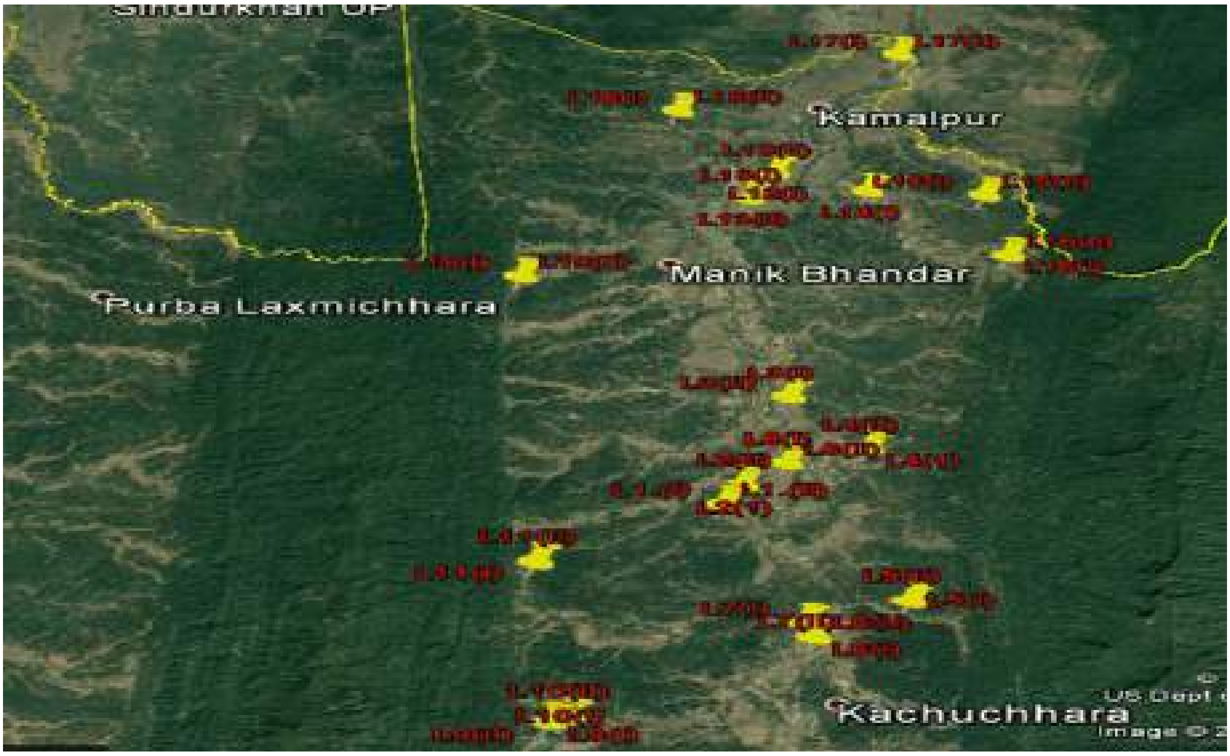


Fig. 4.14. VES location map of Dhalai, Tripura

4.4.1.2. Hydrogeologyand Hydrology

The area and blocks water supply is augmented with dug wells, shallow hand pumps and mini deeptubewells. Drinking water supply division, resource water division has taken initiatives and has installed number oftubewellsin the area, which are in operation mode.

The tube wells are installed with water jet method and rotary rig method (direct/reverse).Static water level is in the range of 10-15m below ground level (bgl).Numbers of waterponds are also there which augments village water supply. Rainfall is high in the range of 1800-2000 mm annually. The study area is mostly dominated by dense vegetation. Paddy cultivation is practicedbased on the rainfall.

4.4.2. Data Interpretation and Discussion: Dhali District

The area under study is a part of the eastern margin of Dhalai district.The water prospects hereareby the saturated water present in the sand aquifers below.The tract is alluvial and composition of layers of the different sites (locations) investigated are almost identical, as such the tube wells may be installed at any of the points surveyed as per suitability. VES survey is carried out for two sampling location for each site with a total number of 38 VES points mentioned even block also. The location wise of the VES survey at different sites were carried out with two multiple sounding numbers and a sample copy is represented in Table 4.4. The resistivity results depicted that the aquifer depth are varied between 90 m and 180 m whereas the expected yields are calculated ranged between 27.27 and 45.46 m^3/h as highlighted in Table 4.5. The interpreted results depicted that the expected yield is found to be higher where resistivity values are varied between lower and higher reflected in Tables 4.6 (a), (b), (c), (d) and (e). Due to paucity of space and reducing the chapter length, the positional map of VES at different site was surveyed and a sample copy is represented in Fig. 4.15a whereas Fig. 4.15b and 4.15c and Fig.4.15d and 4.15e represent the typical resistivity and thickness of different sub-surface layer considered as sample figures for one location against two stations. Similarly a pseudo section is made for individual location of VES to overview an idea of different resistivity against depth referred in Fig. 4.15f. It is observed that the resistance values are found at different distance shown in Fig.4.15b and 4.15c whereas the aquifer formation at the same points is highlighted in Fig.4.15d and 4.15e.

Table 4.4. Location L1(1) and L 1(2) of the VES Survey Data's at Site

Sounding Survey no 1 **Sounding Survey no 2**

AB/2	Rho	Strip	AB/2	Rho	Strip
5	348.47	0	5	211.20	0
10	54.839	0	10	46.638	0
10	117.76	0	10	78.466	0
20	22.133	0	20	21.544	0
30	21.853	0	30	21.052	0
40	20.602	0	40	23.007	0
50	21.21	0	50	24.116	0
50	25.524	0	50	26.211	0
60	25.607	0	60	19.388	0
70	27.121	0	70	21.122	0
80	27.207	0	80	19.769	0
90	30.388	0	90	20.397	0
100	32.166	0	100	25.032	0
100	21.84	0	100	38.163	0
110	26.878	0	110	36.828	0
120	33.638	0	120	34.554	0
130	30.726	0	130	35.54	0
140	37.684	0	140	37.465	0
150	38.519	0	150	38.31	0
160	38.013	0	160	41.959	0
170	40.507	0	170	41.387	0
180	40.25	0	180	43.1	0
190	38.171	0	190	42.52	0
200	39.791	0	190	37.63	0
210	24.147	0	200	37.995	0
220	36.72	0	210	38.025	0
			230	37.188	0
			240	38.659	0
			250	37.468	0

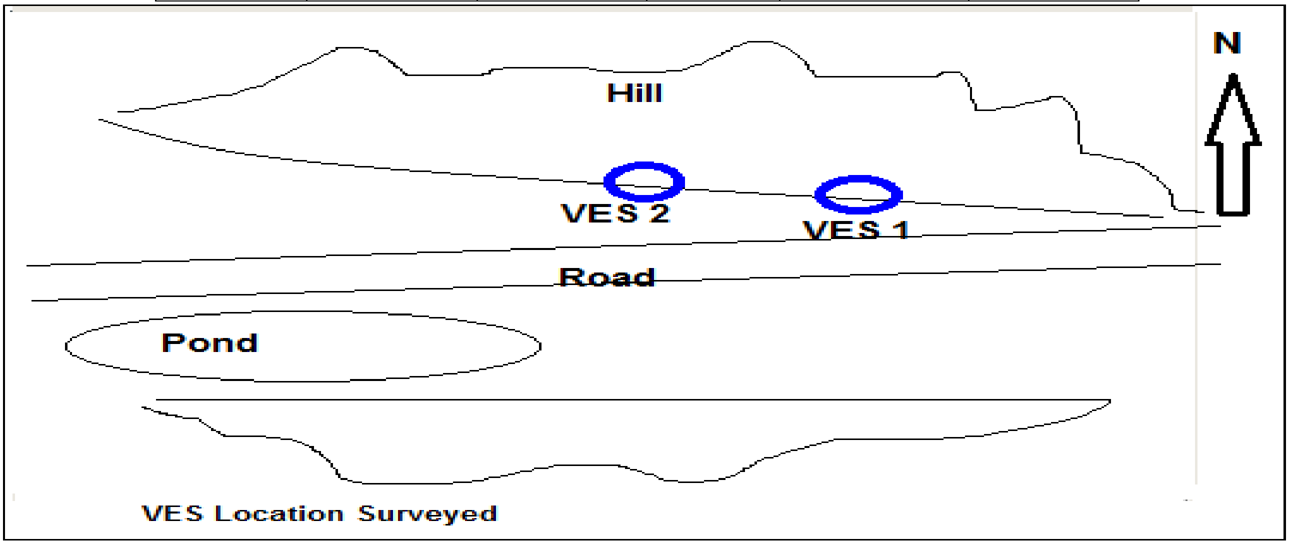


Fig 4.15a: Positional Location L1(1) and L1 (2) of the VES Survey Done at Site

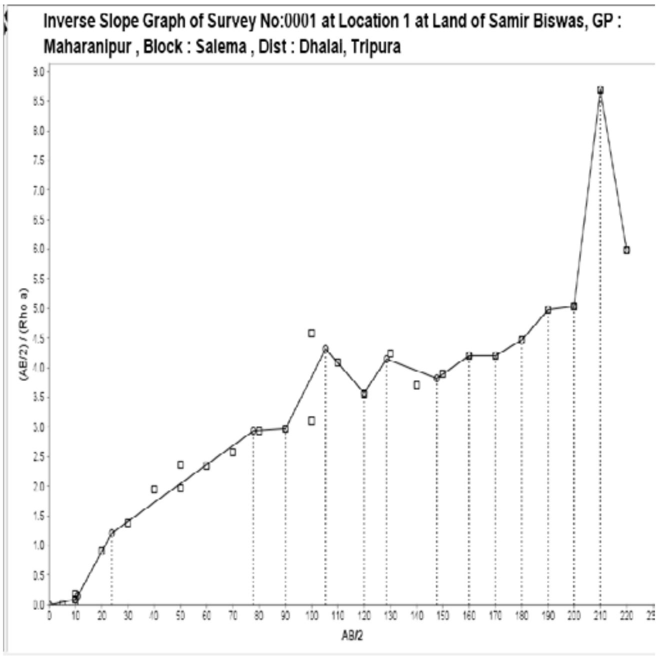


Fig 4.15b.Distance vs. Resistivity of VES L1(1)

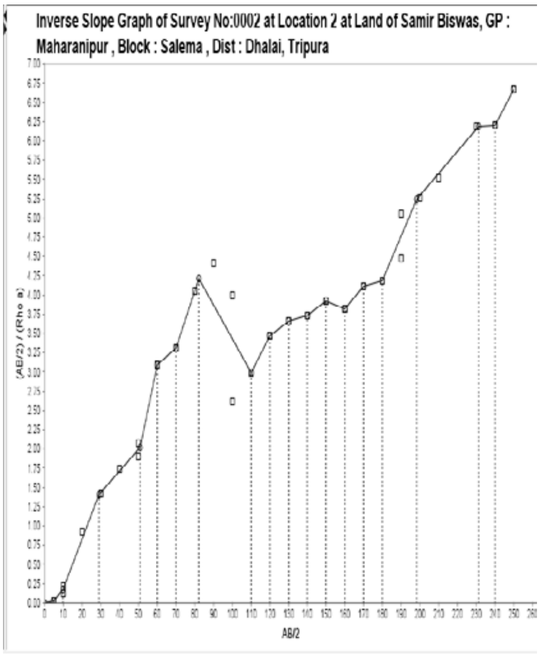


Fig 4.15c.Distance vs. Resistivity of VES L1(2)

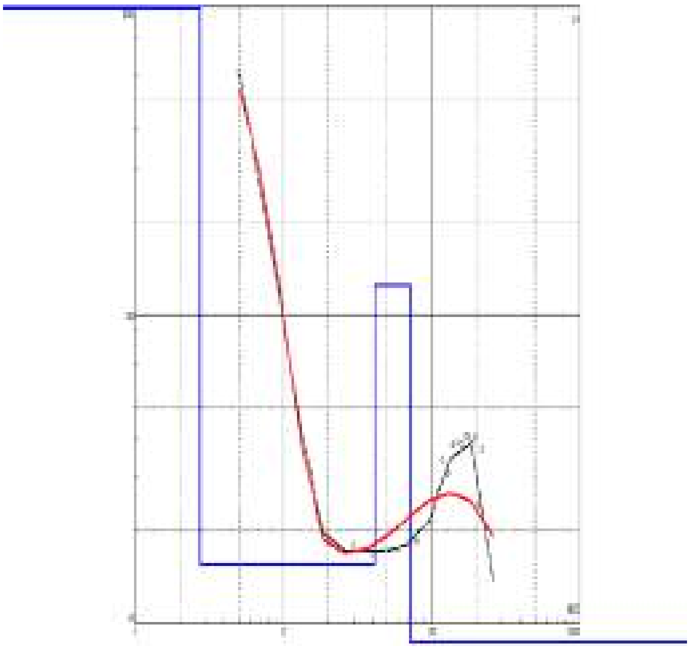


Fig 4.15d.Depth vs. Resistivity of VESL1(1)

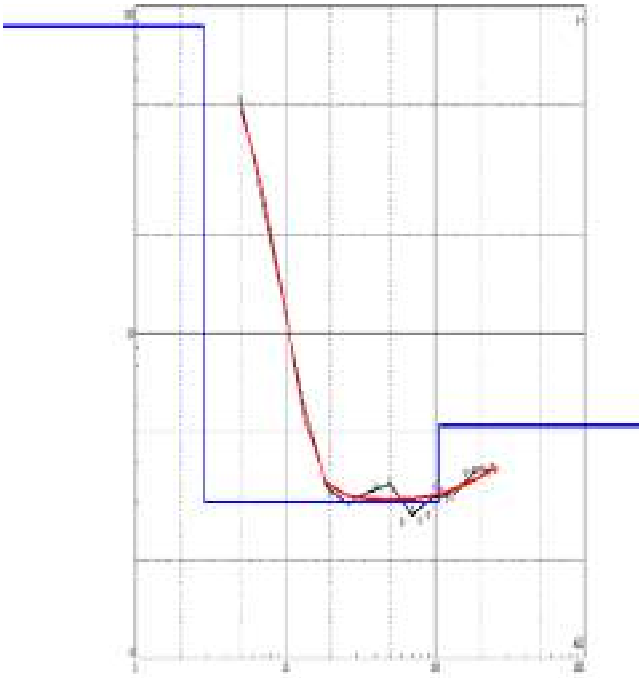


Fig 4.15e.Depth vs. Resistvity of VESL1(2)

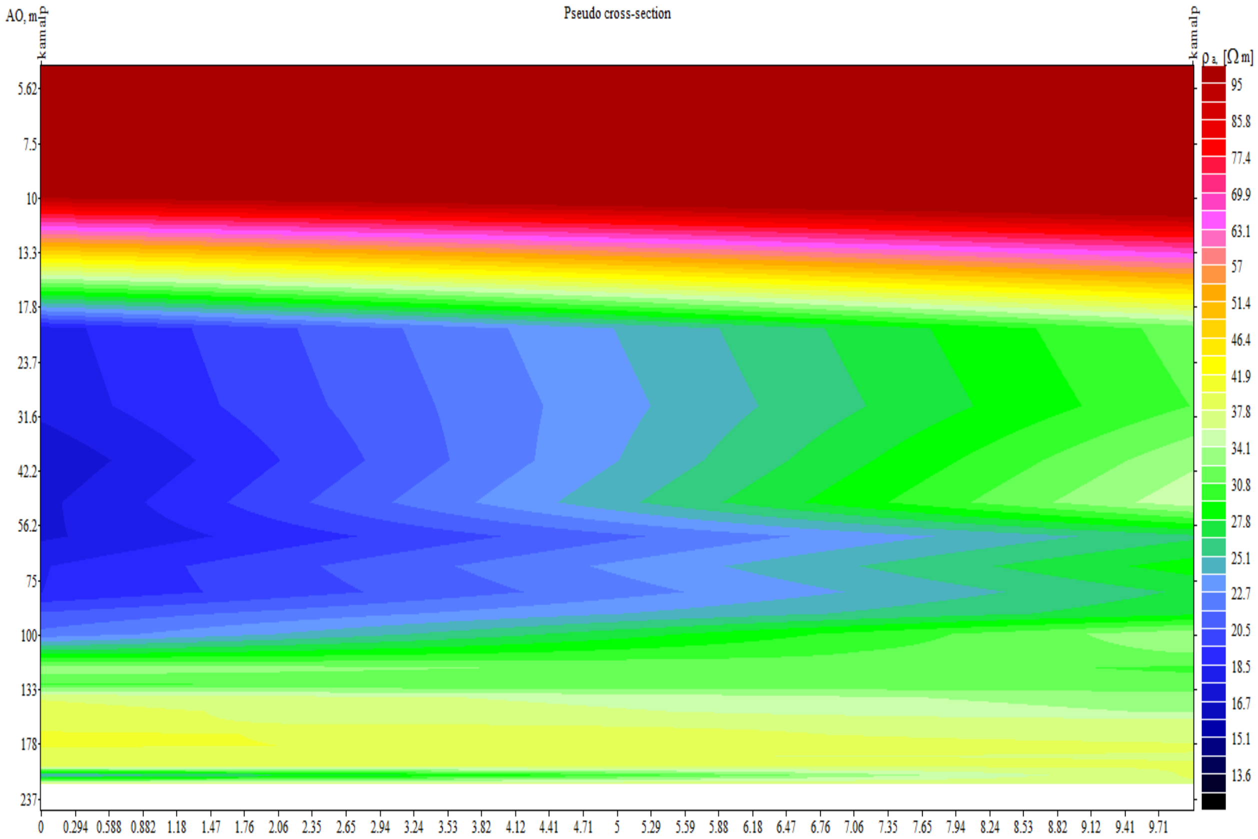


Fig 4.15f. Pseudo Section of VES L1 (1) and (2)

Photo 4.1. VES instrument at field level

Table 4.5.Aquifer information with expected yield in different blocks of Dhalai district

Sl No	District	Block	G.P./VC*	Location-1			Location-2			Aquifer Zones depth (m)	Expected Yield (m^3/h)
				Latitude	Longitude	Map Location	Latitude	Longitude	Map Location		
1	Dhalai	Salema	Maharanipur VC	24.05374°N	91.82157°E	L-1(1)	24.05374°N	91.82138°E	L-1(2)	110-140	36.38–45.46
2	Dhalai	Salema	MaharanipurVC	24.05987°N	91.82454°E	L-2(1)	24.05982°N	91.82448°E	L-2(2)	120-150	36.38–45.46
3	Dhalai	Durgachowmu hani	Debichara	24.08876°N	91.83137°E	L-3(1)	24.08882°N	91.83136°E	L-3(2)	90-130	36.38–45.46
4	Dhalai	Durgachowmu hani	Chankap	24.07136°N	91.84688°E	L-4(1)	24.07129°N	91.84681°E	L-4(2)	110 -140	36.38–45.46
5	Dhalai	Salema	South Kachuchara	24.02309°N	91.85622°E	L-5(1)	24.02308°N	91.85642°E	L-5(2)	90 -130	31.82–36.38
6	Dhalai	Salema	Singinala	24.01234°N	91.84012°E	L-6(1)	24.01223°N	91.84005°E	L-6(2)	100-130	31.82–36.38
7	Dhalai	Salema	Avanga	24.01652°N	91.83810°E	L-7(1)	24.01662°N	91.83815°E	L-7(2)	150 -180	36.38–45.46
8	Dhalai	Salema	Dabbari	24.06684°N	91.83202°E	L-8(1)	24.06682°N	91.83223°E	L-8(2)	110-140	36.38–45.46
9	Dhalai	Salema	PaschimDaluchara	23.98741°N	91.79570°E	L-9(1)	23.98742°N	91.79552°E	L-9(2)	110-130	31.82–36.38
10	Dhalai	Salema	AshapurnaRoaza Para	23.98878°N	91.79886°E	L-10(1)	23.98877°N	91.79860°E	L-10(2)	105-125	36.38–45.46
11	Dhalai	Salema	Mendhi	24.03603°N	91.78931°E	L-11(1)	24.03558°N	91.78925°E	L-11(2)	105-125	27.27–36.38
12	Dhalai	Durgachowmu hani	WestKuchainala	24.16816°N	91.82442°E	L-12(1)	24.16794°N	91.82425°E	L-12(2)	100-130	36.38–45.46
13	Dhalai	Durgachowmu hani	West Kuchainala	24.15864°N	91.81969°E	L-13(1)	24.15884°N	91.82020°E	L-13(2)	100-130	36.38–45.46
14	Dhalai	Durgachowmu hani	Kuchainala	24.16117°N	91.84283°E	L-14(1)	24.16143°N	91.84279°E	L-14(2)	90-110	27.27–36.38
15	Dhalai	Durgachowmu hani	Marachara	24.15960°N	91.86553°E	L-15(1)	24.15944°N	91.86561°E	L-15(2)	120-140	31.82–36.38
16	Dhalai	Durgachowmu hani	Shibbari	24.13744°N	91.87054°E	L-16(1)	24.13735°N	91.87082°E	L-16(2)	120-150	36.38–45.46
17	Dhalai	Durgachowmu hani	Mohanpur	24.21344°N	91.84650°E	L-17(1)	24.21352°N	91.84650°E	L-17(2)	110-140	36.38–45.46
18	Dhalai	Durgachowmu hani	Noagaon	24.19168°N	91.80380°E	L-18(1)	24.19205°N	91.80382°E	L-18(2)	110-140	27.27–31.82
19	Dhalai	Durgachowmu hani	Srirampur	24.13080°N	91.77812°E	L-19(1)	24.13104°N	91.77832°E	L-19(2)	120-150	27.27–36.38

*VC-Village Council

Table 4.6 (a).Resistivity survey with interpreted results for four locations (LS-1 to LS-4)

Sl. No	**Location-1**	**Location-2**	**Probable Strata section as interpreted from Inverse slope & VES curve**			**Resistivity nature**
	Map Location	**Map Location**				
1	L-1(1)	L-1(2)	1stlayer	0–30 m	Shallow Depth Soil and Sand-Dry	Very High to High Resistance
			2ndlayer	30–40 m	Fine Sand	High Resistance
			3rdlayer	40- 110 m	Clay Beds	Moderate High to Low Resistance
			4thlayer	110– 140m	Finesand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	140- 250 m	Clay Beds	Low Resistance
2	L-2(1)	L-2(2)	1stlayer	0–30 m	ShallowDepthSoilandSand-Dry	Very High to High Resistance (Topsoil& Dry Sand)
			2ndlayer	30–45 m	Fine Sand	High Resistance (Ist Aquifer Fine Sand)
			3rdlayer	45- 120 m	Clay Beds	Moderate High to Low Resistance
			4thlayer	120–150 m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	140- 220 m	Clay Beds	Low Resistance
3	L-3(1)	L-3(2)	1stlayer	0–20m	Shallow Depth Soil and Sand-Dry	Very High to High Resistance (Top soil & Dry Sand)
			2nd layer	20–40 m	FineSand	High Resistance
			3rdlayer	40- 90 m	Sandy Clay	Moderate Highto Low Resistance
			4thlayer	90– 120m	Fine sand(Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	120- 240 m	Clay Beds	Low Resistance
4	L-4(1)	L-4(2)	1stlayer	0–20m	Shallow Depth Soil and Sand-Dry	Very High to High Resistance (Topsoil & Dry Sand)
			2ndlayer	20–30 m	Fine Sand	High Resistance (Ist Aquifer Fine Sand)
			3rdlayer	30- 110 m	Clay Beds	Moderate Highto Low Resistance
			4thlayer	110– 150 m	Fine to Medium sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	150- 230 m	Clay Beds	Low Resistance

Table 4.6(b).Resistivity survey with interpreted results for four locations (LS-5 to LS-8)

Sl No	Location-1	Location-2	Probable Strata section as interpreted from Inverse slope & VES curve			Resistivity nature
	Map Location	Map Location				
5	L-5(1)	L-5(2)	1stlayer	0–70 m	Clay	Low Resistance (Topsoil & Clay
			2ndlaye r	70–90 m	Sandy Clay	Low to High Resistance (Ist Aquifer Fine Sand)
			3rdlayer	90- 130 m	Fine Sand	High Resistance
			4thlayer	130– 150 m	Fine to Very Fine sand	High to Low Resistance
			5thlayer	150- 210 m	Clay Beds	Low Resistance
6	L-6(1)	L-6(2)	1stlayer	0–40 m	Clay	Low Resistance
			2ndlaye r	40–70 m	Sandy Clay	Low to Moderate High Resistance
			3rdlayer	70- 100 m	Sandy Clay & Fine sand	Moderate High to High Resistance
			4thlayer	100 – 130 m	Fine to Medium sand (Aquifer Zone for Strainer)	High Resistance
			5thlayer	130- 220 m	Clay Beds	High to Low Resistance
7	L-7(1)	L-7(2)	1stlayer	0–30 m	Clay	Low Resistance
			2ndlaye r	30–40 m	Fine Sand	Low to Moderate High Resistance
			3rdlayer	40- 110 m	sandy Clay	Moderate High to High Resistance
			4thlayer	150–170 m	Fine sand (Aquifer Zone for Strainer)	High Resistance
			5thlayer	170- 220 m	Clay Beds	Constant Resistance
8	L-8(1)	L-8(2)	1stlayer	0–70	Shallow Depth Soil and Sand-Dry	Very High to High Resistance
			2ndlayer	70–90 m	Fine Sand	High Resistance
			3rdlayer	90- 110 m	Sandy Clay	Moderate High to Low Resistance
			4thlayer	110–140 m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	140- 250 m	Clay Beds	Low Resistance

Table 4.6(c).Resistivity survey with interpreted results for four locations (LS-9 to LS-12)

Sl. No.	**Location-1**	**Location-2**	**Probable Strata section as interpreted from Inverse slope & VES curve**			**Resistivity nature**
	Map Location	**Map Location**				
9	L-9(1)	L-9(2)	1stlayer	0–30 m	Clay	Low Resistance
			2ndlayer	30–40 m	Fine Sand	High Resistance
			3rdlayer	40- 110 m	Clay Beds	Moderate High to Low Resistance
			4thlayer	110– 130m	Fine to Medium sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	130- 240 m	Clay Beds	Low Resistance
10	L-10(1)	L-10(2)	1stlayer	0–60 m	Clay	Low Resistance
			2ndlayer	60–70 m	Fine Sand	Low to High Resistance
			3rdlayer	70- 105 m	Sandy Clay	Moderate High to High Resistance
			4thlayer	105–125m	Fine sand (Aquifer Zone for Strainer)	High Resistance
			5thlayer	125- 220 m	Clay Beds	Very High Resistance
11	L-11(1)	L-11(2)	1stlayer	0–20 m	Shallow Depth Soil and Sand-Dry	Very High to High Resistance
			2ndlayer	20–50 m	Fine Sand	High & Low Resistance
			3rdlayer	50- 105 m	Clay Beds with slate formations	Moderate High to Low Resistance
			4thlayer	105– 125m	Fine sand (Aquifer Zone for Strainer)	Fluctuating Low to High Resistance
			5thlayer	125- 220 m	Clay Beds	Low Resistance
12	L-12(1)	L-12(2)	1stlayer	0–30 m	Sandy Clay	High Resistance
			2ndlayer	30–40 m	Fine Sand	High & Low Resistance
			3rdlayer	40- 100 m	Fins Sand & Clay Beds	Moderate High to Low Resistance
			4thlayer	100– 130m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	130- 240 m	Clay Beds	Low Resistance

Table 4.6 (d).Resistivity survey with interpreted results for four locations (LS-13 to LS-16)

Sl. No.	Location-1	Location-2	Probable Strata section as interpreted from Inverse slope & VES curve			Resistivity nature
	Map Location	**Map Location**				
13	L-13(1)	L-13(2)	1stlayer	0–30m	Shallow Depth Soil and Sand-Dry	Very High to High Resistance
			2ndlayer	30–40 m	Fine Sand	High Resistance
			3rdlayer	40- 100 m	Clay Beds	Moderate High to Low Resistance
			4thlayer	100– 130 m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	130- 220 m	Clay Beds	Low Resistance
14	L-14(1)	L-14(2)	1stlayer	0–30 m	Sandy Clay	Very High to High Resistance
			2ndlayer	30–40 m	Fine Sand & Sandy Clay	High Resistance
			3rdlayer	40- 90 m	Fine Sand	Moderate High to Low Resistance
			4thlayer	90– 110m	Fine to Very Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	110- 200m	Clay Beds	Low Resistance
15	L-15(1)	L-15(2)	1stlayer	0–30m	Clay zones	Low Resistance
			2ndlayer	30–40m	Fine Sand	Low to High Resistance
			3rdlayer	40- 120 m	Sandy Clay	Moderate High to Low Resistance
			4thlayer	120–140m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	140- 200m	Sandy Clay	High Resistance
16	L-16(1)	L-16(2)	1stlayer	0–30m	Sandy Clay	Very High to High Resistance
			2ndlayer	30–60 m	Fine Sand	High Resistance
			3rdlayer	40- 120 m	Clay Beds	Moderate High to Low Resistance
			4thlayer	120–150m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	150- 200 m	Clay Beds	Low Resistance

Table 4.6 (e).Resistivity survey with interpreted results for three locations (LS-17 to LS-19)

Sl No	Location-1	Location-2	Probable Strata section as interpreted from Inverse slope & VES curve			Resistivity nature
	Map Location	Map Location				
17	L-17(1)	L-17(2)	1stlayer	0–30 m	Clay	Low Resistance
			2ndlayer	30–40 m	Sandy Clay	Low Resistance
			3rdlayer	40- 110 m	Very Fine sand & Clay	Moderate High to Low Resistance
			4thlayer	110– 140 m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	140- 210 m	Fine Sand & Sandy Clay	High Resistance
18	L-18(1)	L-18(2)	1stlayer	0–30m	Sandy Clay	Very High to High Resistance
			2ndlayer	30–40 m	Fine Sand	High Resistance
			3rdlayer	40- 110 m	Sandy Clay	Moderate High to Low Resistance
			4thlayer	110–140m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	140- 250 m	Clay Beds	High to Low Resistance
19	L-19(1)	L-19(2)	1stlayer	0–30m	Surface sand & Sandy Clay	Very High to High Resistance
			2ndlayer	30–50 m	Sandy Clay	High Resistance
			3rdlayer	50- 120 m	Clay Beds	Moderate High to Low Resistance
			4thlayer	120–150m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	150- 220 m	Clay Beds	Low Resistance

4.5. Critical Study of Groundwater Overflow Zone of Tripura

Rainfall and evaporation, and evapo-transpiration data has been collected for the last twenty years (1996-2015) from different Govt. organizations and the historical discharge of major rivers collected from Central Water Commission (CWC), Govt. of India. Groundwater level, lithologs of different locations, specific yield, storativity etc. are collected from Central Groundwater Board (CGWB), Govt. of India.Original slopes are calculated based on topo-sheets collected from GSI, Govt. of India, water level of CGWB and Google Earth. Maps are prepared with the help of AutoCAD.

All lithologs are collected from PWD (Water Resource) and Drinking Water & Sanitation, Govt. of Tripura and verified accordingly with the help of actual field data.Deep tubewellborings at different locations and depths have been carried out by using rig (reverse/direct) machine.Tests are conducted for the continuous operation of 48 hours and accordingly drawdowns are observed with respect to time to estimate the aquifer parameters using different formulae given by Roy et al. (2015).Vertical Resistivity Survey (VES) has been carried out at different locations and analysis was done using Schlumberger technique. All hydrological components are estimated with the help of historical as well as primary data.

In Tripura, there are many rivers and most of the rivers are almost dry due to high amount of silt carries from higher altitude and deposits as well at river bed. Six districts with sixtytwo Gram Panchayats (GPs) have been considered to assess the overflow zone of Tripura given in Table 4.7.

4.5.1. Results on Groundwater Overflow Zone

Maps of Tripura Valley: All spots identified by latitude and longitude are marked using Google map with the help of Auto-Cad referred in Fig.4.16. Valleys are delineated using secondary data collected from Google map. Primary data are collected through CGWB given in Fig.4.17. Lands are classified based on deep tube well, marshy land, and groundwater level to identify the overflow the zone of Tripura highlighted in Fig. 4.18 and 4.19.

Table 4.7. General Information of overflow zones of Tripura

Sl. No.	Block	GP/VC	Sl. No.	Block	GP/VC
Dhalai district			**Khowai district**		
1	Ambassa	Kamalacherra II	33	Khowai	Sonatala
2	DurgaChowmuhani	Latiabill	34	Khowai	South Singicherra
3	DurgaChowmuhani	Bilashcherra	35	Khowai	West Chebri
4	DurgaChowmuhani	Halahali	36	Khowai	West Ganki
5	DurgaChowmuhani	Srirampur	37	Khowai	West Singicherra
6	Chowmanu	West Karamcherra	38	Khowai	West Sonatala
7	Chowmanu	Khetuicherra	39	KMC	KMC
8	Manu	West Kathalcherra	40	Padmabill	Rasarajnagar
9	Salema	Avanga	**Sepahijala district**		
10	Salema	Baralutma	41	Charilam	Sutarmura
11	Salema	Maharanipur	42	Jampuijala	Jampuijala
12	Salema	Santirbazar	**South Tripura district**		
Gomati district			43	B C Nagar	Chittamara
13	Kakrabon	Mirza, South rani ADC Village	44	B C Nagar	North Bharat Chandra Nagar
14	Matabari	East Chandrapur R.F	45	Bagafa	Lowgang
15	Matabari	East Mogpuskarini,Maidabari (Purba mock puskarini)	46	Bagafa	Bagafa
16	Matabari	East Mogpuskarini, Nuatia para (Purba mock puskarini)	47	Jolaibari	North Jolaibari
17	Matabari	Matabari	48	Jolaibari	West Charakbai
18	Tepania	Chataria	49	Jolaibari	West Pillak
Khowai district			50	Rajnagar	Sonaicherra
19	Khowai	Bagan	51	Rajnagar	Indiranagar
20	Khowai	Barabil	52	Rupaichari	BankulMahamani
21	Khowai	Dhalabil	53	Rupaichari	Kathalchari
22	Khowai	East Chebri	54	Satchand	Bijoynagar
23	Khowai	East Ganki	55	Satchand	Indiranagar
24	Khowai	East RamchandraGhat	56	Satchand	Kalapania
25	Khowai	East Sonatala	57	Satchand	Magurcherra
26	Khowai	Gournagar	58	Satchand	Sakbari
27	Khowai	Jambura	59	Satchand	Satchand
28	Khowai	LaxmiNarayanpur	60	Satchand	SindukPathar
29	Khowai	Madhya Ganki	61	Satchand	West Harina
30	Khowai	Madhya Singicherra	**Unakoti district**		
31	Khowai	North Chebri	62	Chandipur	Chandipur
32	Khowai	Paharmura			

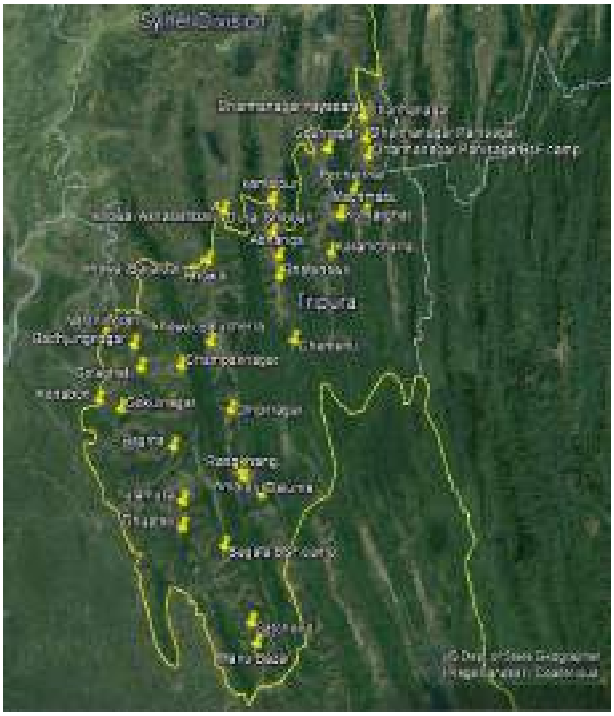


Fig.4.16. Groundwater layer location of seven valleys

Fig.4.17. Hilly and valleys zone of Tripura

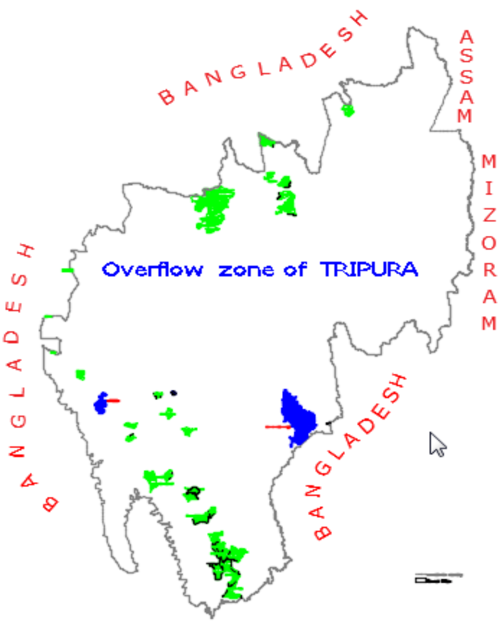


Fig.4.18. Overflow zone of Tripura

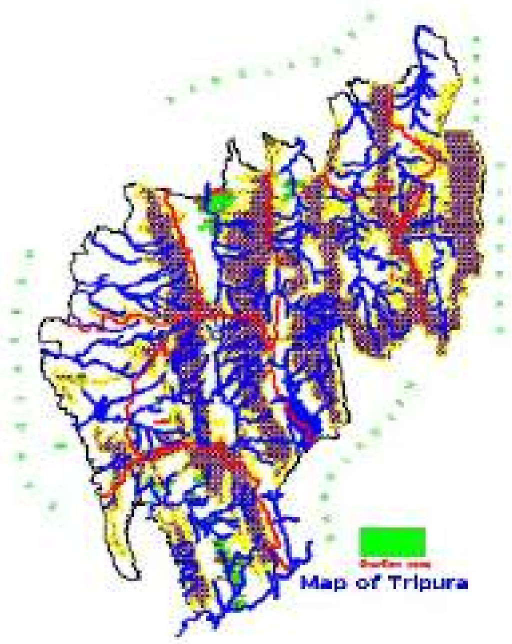


Fig. 4.19. Overflow zone of Tripura along with flat portion of the valley

4.5.2. Valley wise Water Layer Zone

Fig.4.20 to Fig.4.28 indicated that water layers are differentiated along the distance and it runs parallelly through ground surface for almost all valleys. Figures also depicted that every thin layers have got connected with thick layers that represents all water layers are interconnected and groundwater flow moves towards upward to downward along with river slope direction which is parallel to surface water depth in Tripura state whereas all river are rainfed river and no ice melt water are available in the state and two or three majors waterfalls are available at Tripura in the whole year and mini periodical waterfalls are available in rainy season at top of the hills. Figures also highlighted that piezomteric head increased in rainy season and decreased during non-rainy periods.

At dry season in hilly areas no water is available. All mini waterfalls are situated at the top of the hills that could be stopped for flowing of water. At plain land of the valley referred in Fig. 4.19, overflow water are available throughout the year which comes usually from static groundwater level (< 50 m). The dynamic ground water level has got decreased about 2 to 3 m in plain land during rainy season whereas about 20 to 100 m has got reduced in case of hilly areas and thus resulting there is a relationship developed between static water layer and dynamic water layer due to downward movement (hilly zone to flat zone).given in Table 4.8

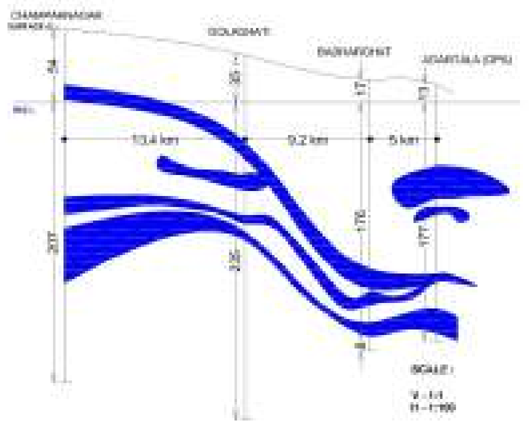


Fig. 4.20. Water Zone of Agartala Valley 1 Champaknagar-Agartala

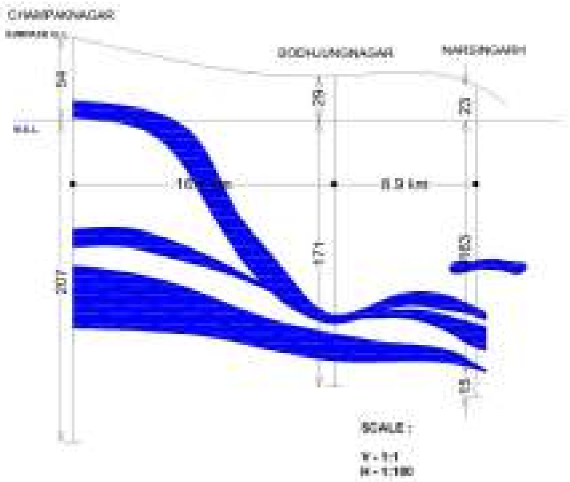


Fig. 4.21. Water Zone of Agartala Valley 2 Champaknagar -Narsingarh

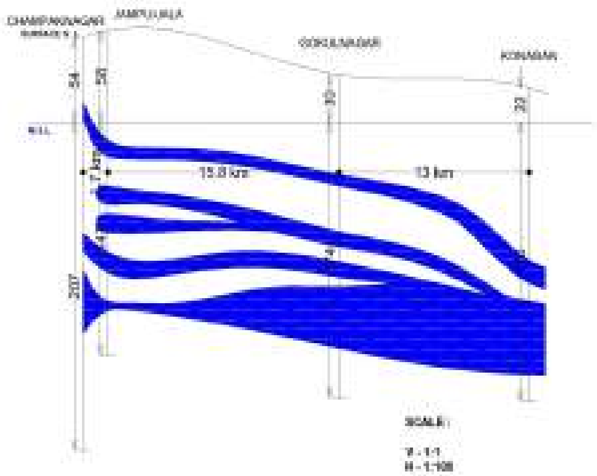


Fig. 4.22. Water Zone of Agartala Valley 3 Champaknagar -Gokulnagar

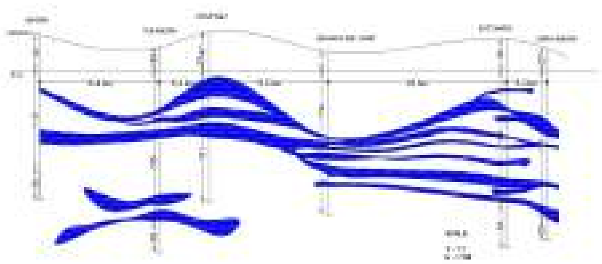


Fig. 4.23. Water Zone of Udaipur Valley

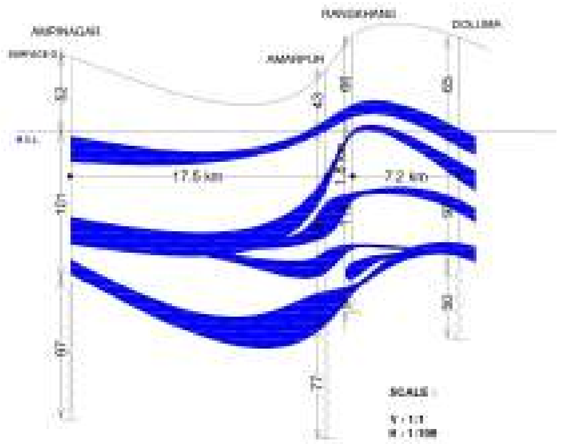


Fig. 4.24. Water Zone of Amarpur Valley

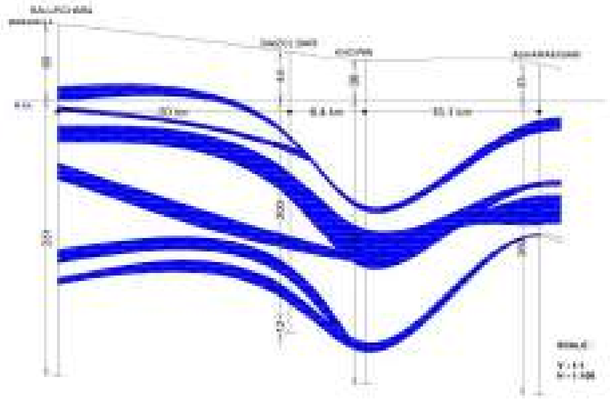


Fig. 4.25. Water Zone of Khowai Valley

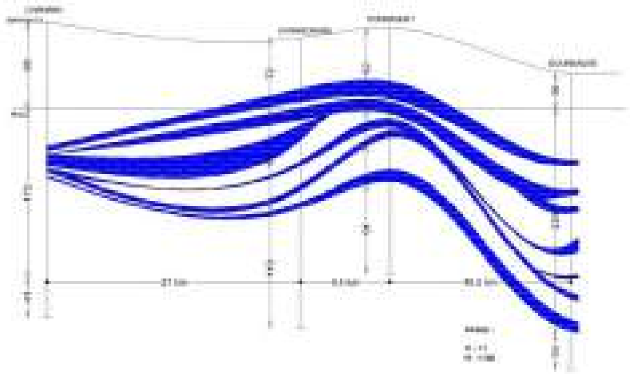


Fig. 4.26. Water Zone of Kailasashar Valley

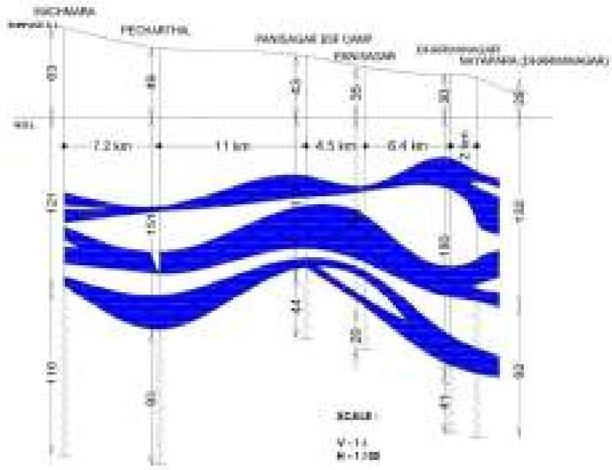


Fig. 4.27. Water Zone of Dharmanagar Valley

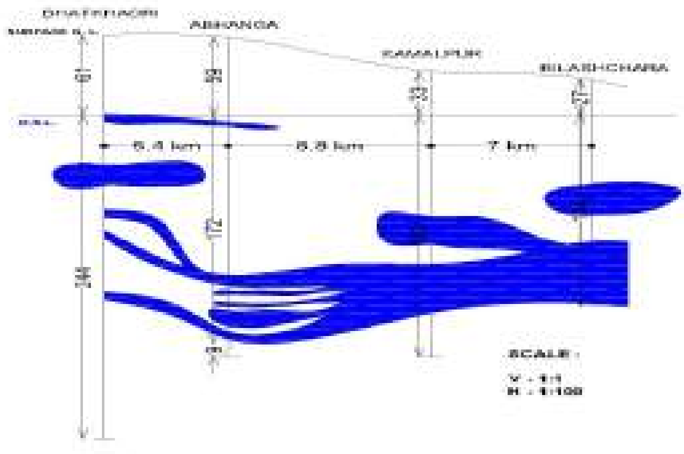


Fig. 4.28. Water Zone of Kamalpur Valley

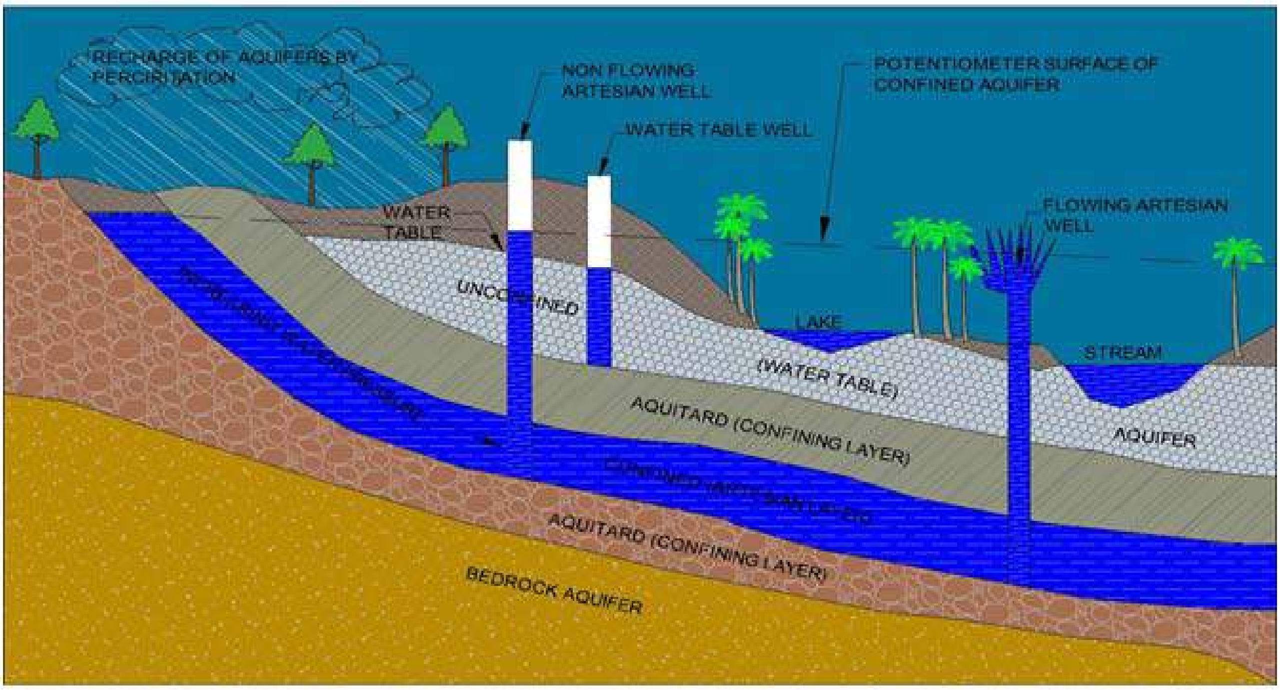


Fig.4.29. Typical Overflow zone of Tripura State

Table 4.8.Water layer zone of Tripura (Water movement hilly zone to flat zone).
DETAILS OF EXPLORATORY WELLS

DHARMANAGAR VALLEY

Sl No	Well Location	Depth Drilled/ Assembly lowered (m)	Position of slot (m)	Thickness of aquifer tapped (m)	Mean see level (m)
1	**2**	**3**	**4**	**5**	**6**
1	Nayapara	251.8/160	66-73 77-103 128-145 148-157	59	28
2	Dharmanagar	251/210	59-80 135-156 183-204	63	30
3	Panisagar	198/178	83-89 100-137 143-149 162-168	55	35
4	Pecharthal	292.9/199.8	112-115 144-159 174-198	42	49
5	Machmara	300/184	116-125 128-137 140-149 154-166 175-181	45	63
6	Panisagar BSF camp	197.45 / 154	84 – 99	51	43

			105 – 135 142 – 148		

KAILASAHAR VALLEY

Sl No	Well Location	Depth Drilled/ Assembly lowered (m)	Position of slot (m)	Thickness of aquifer tapped (m)	Mean see level (m)
1	Gaurnagar	300/265	88-94 118-124 136-142 172-184 205-208 223-229 250-262	51	36
2	Kumarghat	250/159	54-72 75-87 92-101 104-111 144-150 150-156	55	82
3	Karamcherra	294/175	52-65 71-83 89-104 125-130 149-155 167-173	57	72
4	Chawmanu	300/259.5	126-131 134-146 148-152 156-158	60	88

KAMALPUR VALLEY

Sl No	Well Location	Depth Drilled/ Assembly lowered (m)	Position of slot (m)	Thickness of aquifer tapped (m)	Mean see level (m)
1	Abhanga	240/231	64-67 179-188 191-194 200-203 206-218 222-228	36	59
2	Bhatkhowri	305/203	60-66 98-114 120-123 132-138 147-154 194-200	44	61
3	Kamalpur	215/250	110-128 148-176	46	33
4	Bilascharra//	171/213	86-103 119-153	51	27

KHOWAI VALLEY

Sl No	Well Location	Depth Drilled/ Assembly lowered	Position of slot (m)	Thickness of aquifer tapped	Mean see level (m)

		(m)		(m)	
1	Asharambari	301.6	51-62 107-112 120-146 155-157	54	33
2	Khowai	295	132-137 153-188 256-255	59	36
3	Baijalbari	256.7/231	76-80 86-92 110-134 168-180 195-208 217-229	71	44
4	Balucherra	320	56-70 75-79 92-107 126-141 205-217 231-237	66	69

AGARTALA VALLEY

Sl No	Well Location	Depth Drilled/ Assembly lowered (m)	Position of slot (m)	Thickness of aquifer tapped (m)	Mean see level (m)
1	**2**	**3**	**4**	**5**	**6**
1	Champaknagar	261.3	41-52 124-136 147-188	64	54
2	GPA, Agartala	190	60-84 90-96 140-146 166-184	54	13
3	Jampaijala	205	69-80 98-110 116-128 140-153 171-177	53	58
4	Golaghati	270	65-77 88-100 119-125 131-137	50	35
5	Gokulnagar BSF Campus	200	57 – 61 69 – 73 82 – 91 109 – 111 115 – 119 125 – 127 145 - 160	40	30
6	Konaban	280	105-117	-	22-

			132-189		
7	Badharghat	200.60 / 193	140 – 155 157 – 167 180 – 190	35	17
8	Narsinggargh	200.55 / 186	113 – 119 143 – 149 154 – 169 180 0 183	30	23
9	Bodhjungnagar	200.45 / 187	154 – 160 166 – 184	24	29

UDAIPUR-SABRUM VALLEY

Sl No	Well Location	Depth Drilled/ Assembly lowered (m)	Position of slot (m)	Thickness of aquifer tapped (m)	Mean see level (m)
1	**2**	**3**	**4**	**5**	**6**
1	Bagma	201/162	64-70 115-133	36	44
2	Tulamura	247/212.6	75-81 85-91 99-111 179-191 197-210	48	28
3	Dhupthali	208/132	56-80 92-104 110-128	54	47
4	Bagafa BSF Campus	197.50	103 – 106 109 – 114 116 – 119 123 – 131 138 – 150 158 - 164	37	23
5	Satchand	253/200	60-63 83-88 93-99 117-120 130-133 147-153 168-180 183-189 192-198	50	38
6	Manubazar	233/208	87-106 117-120 162-168 193-205	40	27

AMARPUR VALLEY

Sl No	Well Location	Depth Drilled/ Assembly lowered (m)	Position of slot (m)	Thickness of aquifer tapped (m)	Mean see level (m)
1	Amarpur	255/178	35-42	79	43

			72-83 92-115 125-140 153-176		
2	Ompinagar	250/153	55-73 111-130 140-150	47	52
3	Rangkhang	190/181	47-56 65-68 108-114 144-147 156-168 172-178	39	66
4	Duluma	208/158	63-75 86-98 112-121 142-151	42	65

4.5.3. Overflow zone of Tripura

The artesian head ranged between 0.3 m and 1.5 m given in Table 4.9 which falls under green zone referred by Fyfe et al. (2005). Thereforethe pipe would need to be extended more than the present artesian head above the ground level. In general, a 30 percent bentonite grout may be used for flowing well construction or repair. A general overview of flowing artesian wells as shown in Fig. 4.29 is prepared to assess discharging groundwater above the top of the well casing with the variation of geological and topographical features. The discharge is found to be 29.5 m^3/h considered as lower with a thickness of aquifer 28.5 m whereas the maximum discharge is observed as 136.3 m^3/h with almost the same thickness reflected in Table 4.9. Therefore the potential zone is varying with valley wise even the same amount of aquifer thickness with more amount of pipe lowering is found. It is also noticed that the suitable lithological strata is observed maximum in duptil and tipan sandstone delineated in Fig. 4.30. Therefore the more the hydraulic conductivity more would be the recharged in the same region.

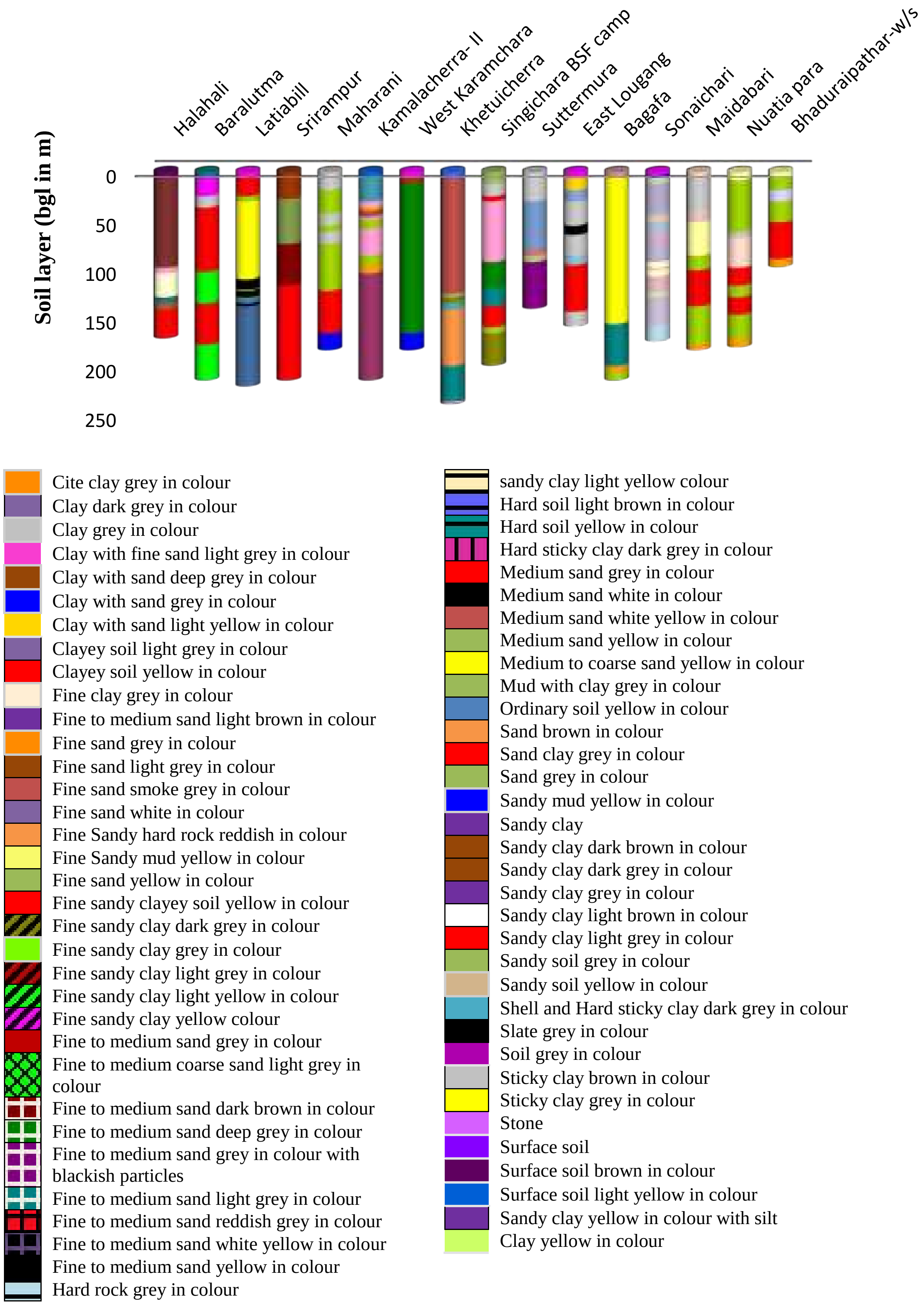


Fig.4.30. Lithological Strata of Overflow borehole at different locations in Tripura

Table 4.9. Groundwater information of overflow borehole of Tripura

Sl. No	GP/VC	Name of Valley	Depth of bore hole (m- BGL)	Depth of pipe lowering (m-[1]BGL)	Filter layer depth (m- BGL)	Discharge (m^3/h) (thickness of aquifer in m)	**Artesian head(m-[2]AGL)
1	Halahali	Kamalpur	170.7	201.2	102.1-139	68.2 (36.9)	0.5
2	Baralutma	Kamalpur	213.4	136.5	104.8-139.4	29.5 (28.5)	0.6
3	*Latiabill	Kamalpur	219.5	140.8	110.4-137.7	68.2 (20.2)	0.8
4	Srirampur	Kamalpur	213.4	205.2	167.1-202.1	68.2 (35.0)	0.7
5	Maharani	Kamalpur	182.9	164.8	125.2-161.7	81.8 (36.5)	1.0
6	*Kamalacherra II	Kamalpur	213.4	106.7	54.9-103.9	59.1 (32.6)	0.4
7	West Karamcherra	Kailasahar	183	165.5	125.9-162.4	90.9 (36.6)	0.5
8	Khetuicherra	Kailasahar	237.8	231.4	198.6-228.3	22.8 (29.7)	1.3
9	Singicherra BSF Camp	Khowai	198.1	158.0	121-157.4	136.3(36.4)	1.5
10	Sutarmura	Agartala	152.4	138.8	99.2-135.7	68.2 (36.5)	0.7
11	East Lowgang	Udaipur Sabrum	158.5	146.4	106.7-143.2	68.2 (36.5)	0.6
12	Bagafa	Udaipur Sabrum	213.4	202.6	163-199.5	68.2 (36.5)	0.7
13	*Sonaicherra	Udaipur Sabrum	173.8	159.2	110.4-156.5	52.2 (36.8)	0.3
14	Maidabari	Udaipur Sabrum	182.9	140.2	100.7-137.5	54.0 (36.5)	0.6
15	Noatia para	Udaipur Sabrum	182.9	152.5	100.6-118.9	59.5 (36.7)	0.4
16	Bhaduraipathar-w/s	Amarpur	97.5	92.0	52.1-89.0	56.8 (36.9)	0.4

**filter layer depth is not continuous*; ***indicates hydraulic water pressure developed through pipe*; 1: *Below Ground Level*; 2: *Above Ground Level*

4.6. Surface and Groundwater Interaction of Tripura State: Case Studies

The data such as litholog data, pumping test data etc. have been collected from field survey from Water Resource Department, Govt. of Tripura. The time-drawdown data has been analyzed by employing 'Cooper-Jacob method' in order to estimate the aquifer parameters for 50 m-distance observation well when pumped at a rate of 80 m^3/hr. for duration of 1440 min. From analysis of time-drawdown data collected at different observation wells for different discharges, the average value of storativity (s) were estimated ranged between 0.00027 and 0.00059 whereas transmissivity (T) values were found to be varied between 1100 and 1689 m^2/day based on unconfined nature of the aquifer. The hydraulic conductivity (K) of the site is within the range of 15 – 28 m/day.

From the available data two study areas namely Agartala and Khowai are selected from this study area. The study areas are located in Google Earth Software. The area of study area, river details and the terrain elevation data with latitude and longitude are collected from the Google Earth Software. After collecting the raw data during field survey fromWater Resource

Department, Govt. of Tripura, it is prepared for the software input. Layers are created for both the study areas. The layer data are created from the litholog and pumping test data. Two layers are defined for each model. The input data should be in text document format for input in GMS. Two photographs are made for two study area and located two or three points with their corresponding world coordinate (latitude and longitude) data.

To develop the model at first the photographs are inserted into the model with their world coordinate. Then 2D scatter point data were opened from the text document created for 2D scatter point data. After that new conceptual model is developed in which boundary coverage, recharge coverage, sources/sink coverage, layer-1, layer-2 coverage and grid frame were created. Next 3D grid data was made and new MODFLOW converge was constructed into 3D grid data. The terrain and elevation in 2D scatter point were interpolated to the MODFLOW converge. Before running the model run check option is selected to check the model. After run check and correction the model, it is run and then the model result is analyzed. The flow chart GMS conceptual model with individual parameters collected and estimated from field data collected from Water Resource Department, Govt. of Tripura with different empirical equations is given in Fig. 4.31. Ten GMS models out of which six for Agartala and four for Khowai, have been developed to estimate the groundwater volumetric mass balance with hydraulic head variation. In case of Agartala, the layer 1 is considered for both confined as well as convertible (neither confined nor unconfined). Five different wells with two rivers namely Haora and Keta Khal have been considered given as source or sink in these models. Whereas for Khowai both layer 1 and layer 2 are considered as convertible with varying numbers of well and two rivers (Khowai and other canal) defined as source or sink in this conceptual model.

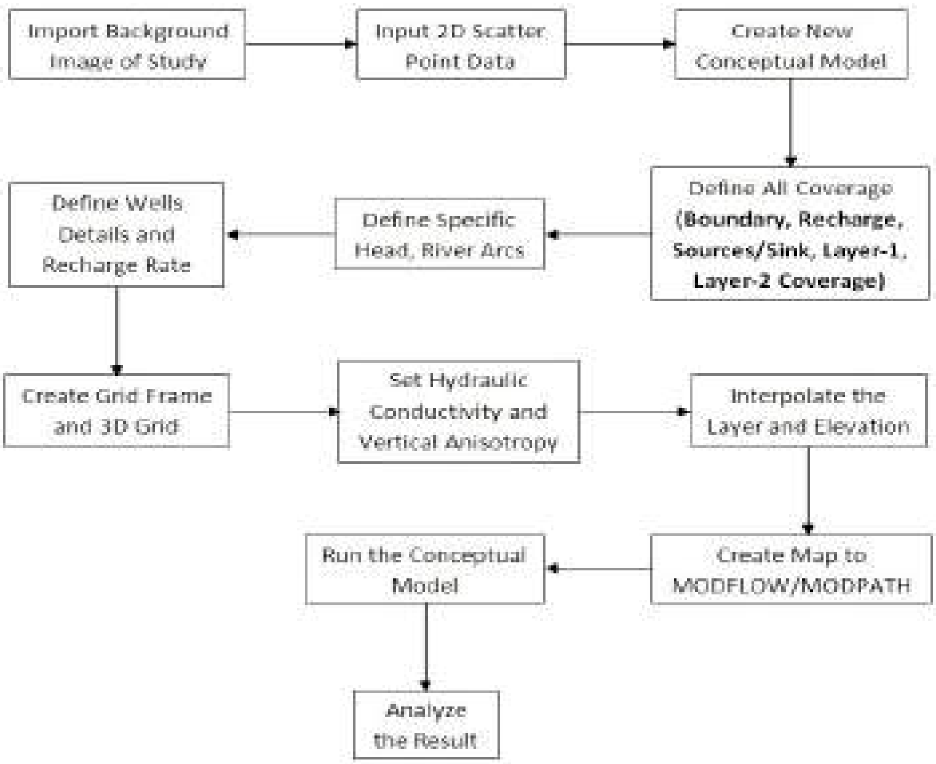


Fig. 4.31. Flow Chart for development of GMS conceptual model [Halder, 2014]

The conceptual model of the study areas have been developed using software GMS (Ground Water Modeling System). This model allows a much better understanding of site conditions to define the groundwater problem. The conceptual model includes the potentiometric surface, hydraulic properties, and recharge and discharge components. Developing the conceptual model is the most important part of the modeling process. It simplifies the field situation and organizes associated field data for easy analysis of the system. It is critical that the conceptual model be a valid representation of the vital hydro-geological conditions and involves definition of the hydro-stratigraphic units, water balances and flow system. This involves identifying sources of recharge, discharge and variation of aquifer properties and variation of hydraulic heads. In the present study model was run with the help of MODFLOW modeling.

The study area has been demarcated with available GPS data collected during survey from Water Resource Department, Govt. of Tripura. Accordingly all hydrologic and hydraulic features have been defined in the MODFLOW conceptual model. From litholog all soil types including depth and place were traced as input parameter in the model. Aquifer characteristics including yield of well have been given in the specified locations. The river head-stage along with bottom elevation on river arc has been assumed to vary linearly along the length of the arc. The ground elevation of the different points in the site has been derived using GPS information available to us based on scatter point techniques. There are two layers in the model. The influx to the system is primarily made through recharge due to rainfall. Since then groundwater level data of the catchment area was not available at regular basis. So the actual groundwater recharge could not be estimated exactly and it was taken as 2% of total precipitation.

MODFLOW conceptual model has been simulated on the basis of hydraulic parameters.

The following assumptions were made to develop the conceptual model:

I. The river is not separated from the aquifer by any confining material.

II. The influx to the system is primarily through recharge due to rainfall.

III. The flow in the aquifer system is steady-state.

IV. There are no evaporation losses into the aquifer(other losses are considered excepting evaporation loss in case of groundwater flow).

V. The rainfall is uniform for the total time span taken for run the model(average rainfall is considered here).

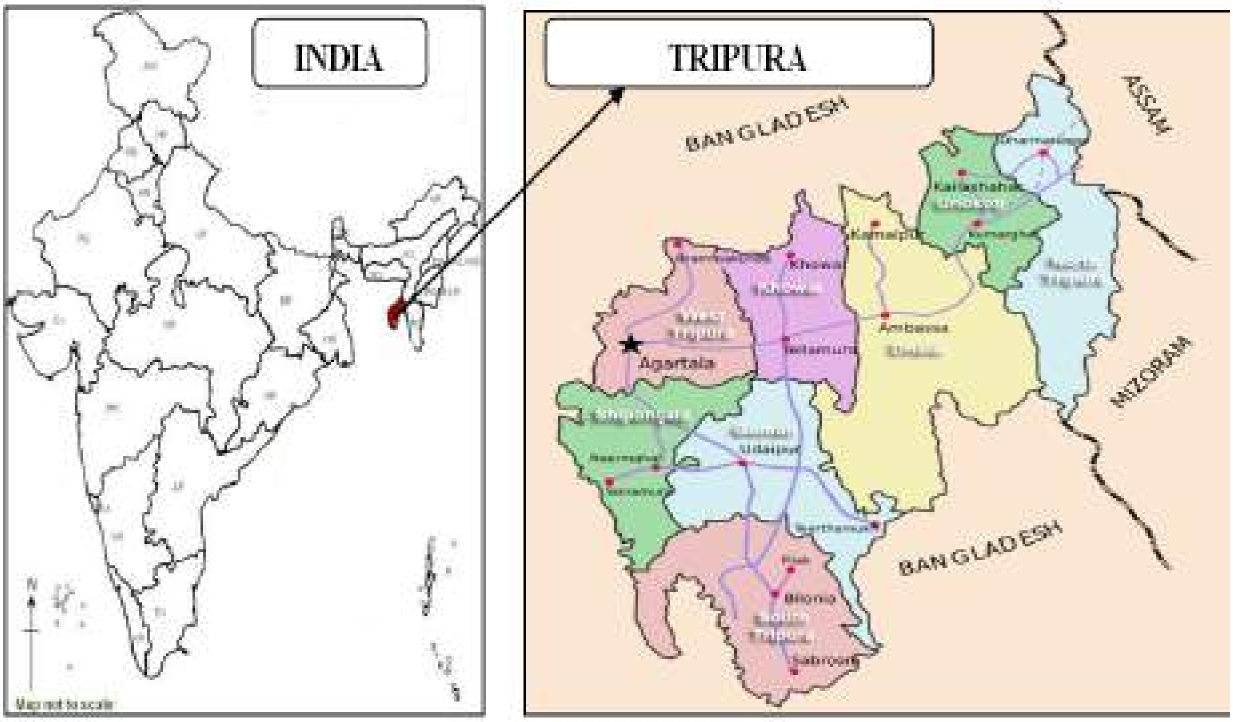


Fig.4.32. Location map of study area for Agartala and Khowai

4.6.1. Development of Conceptual Model applied in the area

West Tripura district lies in the western part of Tripura state. The district is bounded on the north by the country Bangladesh, on the south by Sepahijala district, on the west by the country Bangladesh and on the east by Khowai district. The district has total area of 983.63 km^2 and it lies between the Latitude 23°16' N to 24°14' N and Longitude 91°47' E to 92°20' E (Fig. 4.32). The district is divided into 3 sub-divisions and 9 administrative blocks. The district comprises of 1 number of Municipal Corporation, 1 number of Nagar Panchayat. The total population of the West Tripura district as per the 2011 census is 918200 persons. The density of population is 576 persons per sq. km. The district headquarter is located at Agartala, which is also the capital of the state Tripura. Globally it is situated between 23° 45’ and 23° 55’ N latitude and 91°14’ to 91°20’ E longitude, in the flood plains of the ‘Haora River’. There is also a canal named ‘Keta Khal Canal’ gone through Agartala parallel to ‘Haora River’. Historically, the city has been an important border-trading town having trading linkages with Bangladesh. The area of Agartala model is 137.42 km^2. Agartala receives an annual average rainfall of 2146 mm. The semi-consolidated formations consisting of friable sandstone, sandy shale etc. of Tertiary age forms the main rock types of the area [Economic Review of Tripura, (2013-14)].

Khowai district lies in the northern part of Tripura state. The district is bounded on the north by the country Bangladesh, on the south by Gomati district, on the west by Dhalai district and on the east by West Tripura district. The district has total area of 1377.28 km^2 and it lies between the latitude 23°42' N to 24°14' N and longitude 91°39' E to 91°46' E (Figure 1). The district is divided into 2 sub-divisions and 6 administrative blocks. The district comprises of 3 numbers of revenue circles, 2 numbers of Nagar Panchayats, 79 numbers of maujas and 107 numbers of villages. The total population of the Khowai district as per the 2011 census is 327564 persons. The district headquarter is located at Khowai. Khowai is a town and recently the Khowai Nagar Panchayat has been converted to Khowai Municipal Council in the newly formed Khowai district in the Indian state of Tripura. It is named after the Khowai River passing by the town. It is near the Bangladesh border. Globally the model is situated between 24°03’17”, and 24°05’07”, N latitude and 91°35’16”to 91°37’03”E longitude, in the flood plains of the ‘Khowai River’ with a catchment area of 7.38 km^2 [Economic Review of Tripura, (2013-14)]. The maximum elevation of Agartala study area is 50 m and minimum is 8 m from sea level. The average elevation is 20 m from sea level. Tripura is predominantly a hilly state. Agartala is also no exception. About 30% of the total Agartala area is hilly, 20% area is undulating in nature and remaining 50% area is composed of plain land. The plain land is not also a dead level land; rather it is broken by many low hills and till as having altitudes ranging between 30-60 m [15]. The ground rises from west to east. There are six important hill ranges in Tripura, all of which are situated almost parallel in a NW-SE direction. Among them the Baramura hill range is situated in the extreme western part of the state from which the Haora has originated. Contour map of the study area indicates that the actual slope of the whole basin has gradually decreased from east (Baramura Hills) to west (Bangladesh boarder). Whereas the maximum elevation of Khowai study area is 43 m and minimum is 26 m from sea level. The average elevation is 32 m from sea level.

First GPS reading are taken in sampling point with attribute data and plotted in Q-GIS software. By using contour plug in contour lines are generated and DEM model was developed. Then the geo referenced DEM model imported in GMS software as base map and other model input data inserted for smooth simulation of flow model (Fig. 4.33 and 4.34).

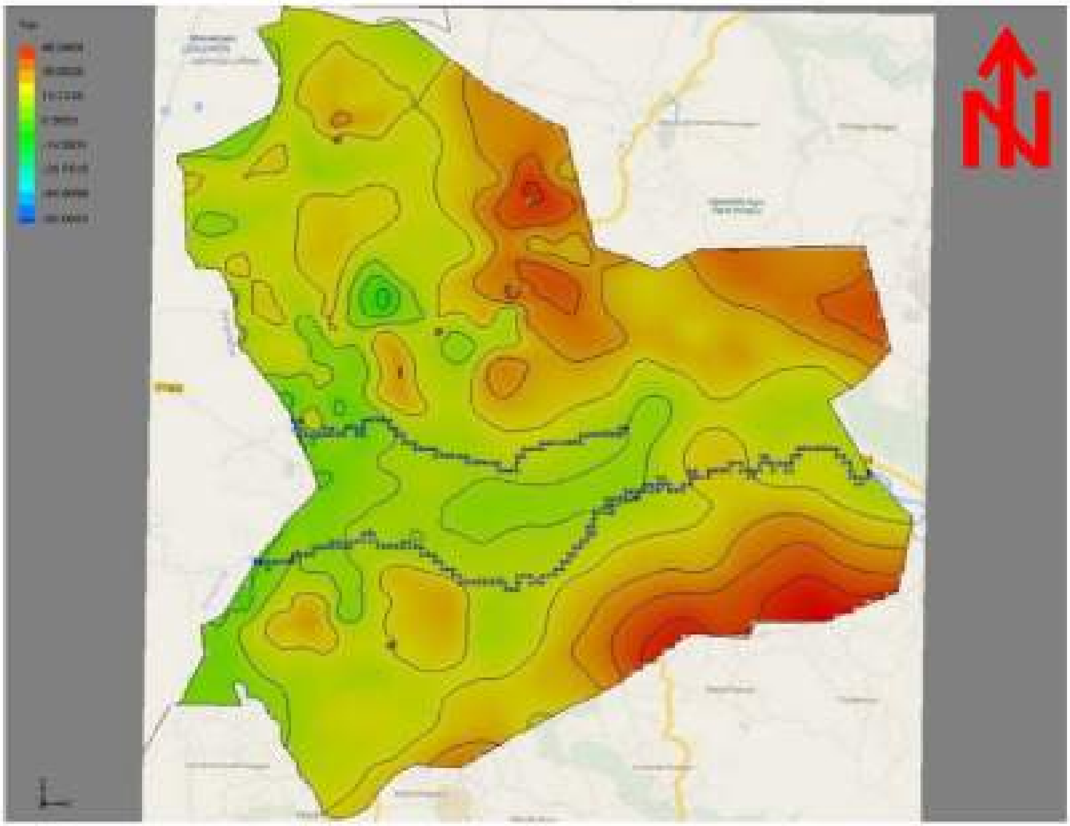


Fig.4.33.ContourelevationmapofAgartalastudyarea

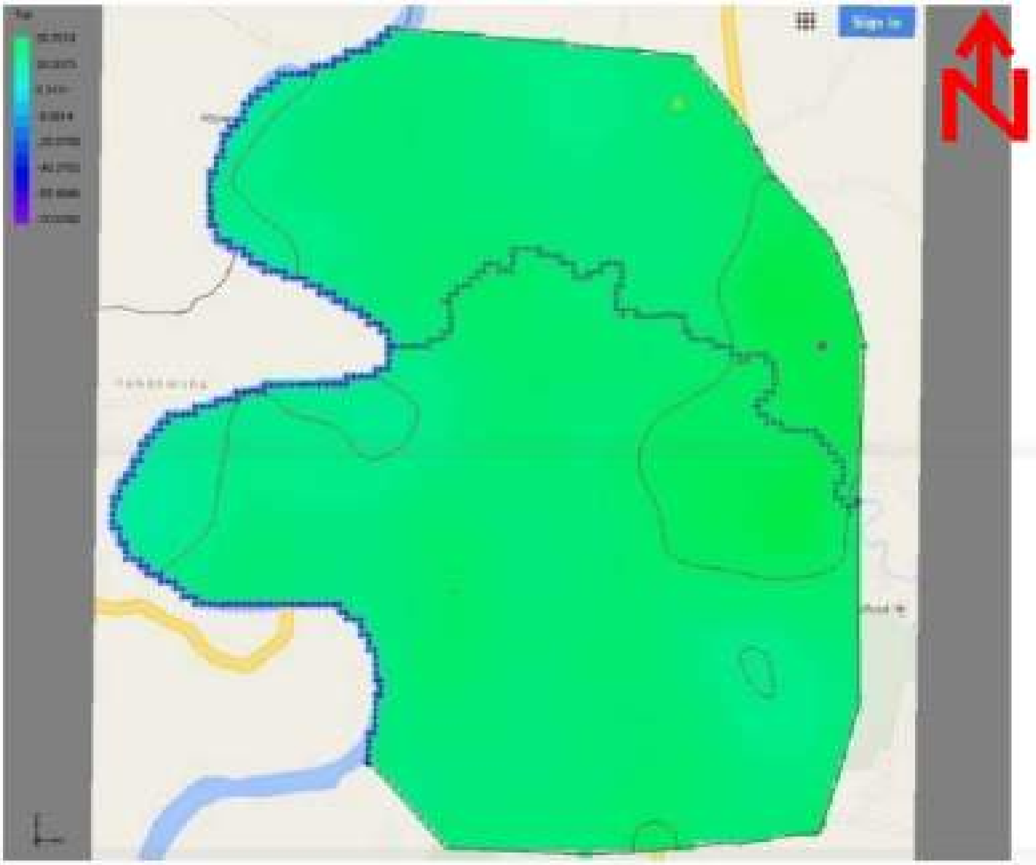


Fig.4.34.ContourelevationmapofKhowaistudyarea

4.6.2. Input Parameters for Selected Model

There are two tables given (Table4.10 and 4.11) where all input parameters are highlighted to develop the conceptual model for this study.

Table 4.10. The input head-stage for the conceptual model of Agartala Study Area

Name of River	Conductance ($(m^2/d)/m$)	Head-stage (m)		Bottom-elevation (m)	
		Extreme Upstream	Extreme Downstream	Extreme Upstream	Extreme Downstream
Haora	700	21	11	17.15	6.91
Keta Khal	650	15	12	12.32	8.76
Additional Parameter	Yearly Rainfall (mm)	Hydraulic Conductivity (m/day)	Vertical Anisotropy	Recharge rate (m/day)	Discharge (m^3/day)
Layer-1	2146	20.94	3	0.00011759	1000-4000
Layer-2		25.94	3		

Table 4.11. The input head-stage for the conceptual model of Khowai Study Area

Name of River	Conductance ($(m^2/d)/m$)	Head-stage (m)		Bottom-elevation (m)	
		Extreme Upstream	Extreme Downstream	Extreme Upstream	Extreme Downstream
Khowai River	550	30.27	24.78	27.8	22.2
Canal	500	28.95	26.95	26.59	24.72
Additional Parameter	Yearly Rainfall (mm)	Hydraulic Conductivity (m/day)	Vertical Anisotropy	Recharge rate (m/day)	Discharge (m^3/day)
Layer-1	2718	23.4	4	0.0001468932	4000-5000
Layer-2		28.4	4		

4.6.3. Remarks on Surface and Groundwater Interaction using Software

Ten MODFLOW conceptual model out of which six models are from the Agartala study area and remaining four models from Khowai area. There are mainly three MODFLOW conceptual models in Agartala study area each divided into two parts, one has confined layer in top and another has convertible layer in top of the conceptual model.

For Agartala Area

Three models have been considered with different input parameters**.**

MODFLOW Model-A1, A2 and A3

In the Model-A1, A2 and A3, the precipitations are considered as average precipitation in the tune of 2146 mm/year and the values are 2146, 2683 and 2253 mm/year respectively for both confined as well as convertible conditions. So, the recharge rates are to be considered 0.00011759 m/day, 0.017883333 m/day and 0.0003577 m/day for all three models. The maximum hydraulic heads of three models are found to be ranged 20.35 m, 21.84 m and 19.33 m respectively in the extreme upstream side whereas the minimum hydraulic heads are obtained as 11.64 m, 13.17 m and 10.64 m at extreme downstream side.

In GMS MODFLOW convertible layer indicate that the layer may be behave like both confined and unconfined layer. There are no flooded cells in the model which top layer is taken as confined, indicate that the recharge water coming from precipitation is completely percolated downward to the aquifer. In the other hand there are flooded cells are which top layer is taken as convertible, indicate that the recharge water coming from precipitation is not completely percolated downward to the aquifer. In the Agartala study area the water withdrawal from the aquifer is taken as a fixed amount for every well and varied starting specific head and precipitation are taken for three conceptual models. For rainy season both precipitation and starting specific head are taken high. For winter season both precipitation and starting specific head are taken low. The volumetric flow budget in two different conditions for three models are obtained represented as Table 4.12, 4.13 and 4.14 respectively. The output summary results are found well excepting the model A2 which may be due to insufficient data.

Table4.12. Volumetric Flow budget for model-A1

layer-1 considered as confined (A1)

Volumetric Budget for Entire Model	
Budget Terms	Flow (m^3/d)
In:	
Constant heads	0
Rivers	54930.48225
Wells	0
Recharge	15737.73125
Total In	70668.2135
Out:	
Constant heads	0
Rivers	54633.28349
Wells	16034.3999
Recharge	0
Total Out	70667.68339
Summary:	
In - Out	0.530107856
Percent Discrepancy	0.000750136

layer-1 considered as convertible (A1)

Volumetric Budget for Entire Model	
Budget Terms	Flow (m^3/d)
In:	
Constant heads	0
Rivers	53941.47459
Wells	0
Recharge	15737.73125
Total In	69679.20585
Out:	
Constant heads	0
Rivers	53644.29894
Wells	16034.3999
Recharge	0
Total Out	69678.69884
Summary:	
In - Out	0.507005215
Percent Discrepancy	0.000727628

Table4.13. Volumetric Flow budget for model-A2

layer-1 is considered as confined (A2)

Volumetric Budget for Entire Model	
Budget Terms	Flow (m^3/d)
In:	
Constant heads	0
Rivers	38493.69911
Wells	0
Recharge	48001.19112
Total In	86494.89022
Out:	
Constant heads	0
Rivers	70457.19062
Wells	16034.3999
Recharge	0
Total Out	86491.59053
Summary:	
In - Out	3.299696863
Percent Discrepancy	0.003814904

layer-1 considered as convertible (A2)

Volumetric Budget for Entire Model	
Budget Terms	Flow (m^3/d)
In:	
Constant heads	0
Rivers	37668.44071
Wells	0
Recharge	48001.19112
Total In	85669.63183
Out:	
Constant heads	0
Rivers	69632.01784
Wells	16034.3999
Recharge	0
Total Out	85666.41774
Summary:	
In - Out	3.214081421
Percent Discrepancy	0.003751716

Table 4.14. Volumetric flow budget for Model-A3

layer-1 considered as confined (A3)

Volumetric Budget for Entire Model	
Budget Terms	Flow (m^3/d)
In:	
Constant heads	0
Rivers	59001.90855
Wells	0
Recharge	958.4554281
Total In	59960.36398
Out:	
Constant heads	0
Rivers	43925.3738
Wells	16034.3999
Recharge	0
Total Out	59959.77371
Summary:	
In - Out	0.590270594
Percent Discrepancy	0.000984435

layer-1 considered as convertible (A3)

Volumetric Budget for Entire Model	
Budget Terms	Flow (m^3/d)
In:	
Constant heads	0
Rivers	57898.80218
Wells	0
Recharge	958.4554281
Total In	58857.25761
Out:	
Constant heads	0
Rivers	42822.31414
Wells	16034.3999
Recharge	0
Total Out	58856.71404
Summary:	
In - Out	0.543568075
Percent Discrepancy	0.000923536

For KhowaiArea

Four models have been considered with different input parameters**.** In Khowai study area both the layer (top and bottom) are convertible for every conceptual model. So every model shows the flooded cell in top layer.

MODFLOW Model-B1, B2, B3 and B4

The maximum and minimum hydraulic head are depicted in the tune of 31.42 m and 25.26 m respectively which are almost same for other three models. The recharge rate, starting specific head and river stage are fixed for every model. The only variation is the withdrawal rate from the aquifer. The number of well and the discharge rate of wells are different for every conceptual model and it is observed that how the static head differ from each conceptual model. The changes of static head are clearly seen for each conceptual model. The volumetric flow budget for each model is found with given condition delineated as Table 4.15 and Table 4.16 and the difference between input and output of these for models are quite satisfactorily.

Table.4.15. Volumetric Flow Budget forModel-B1 & B2

layer-1 & 2 considered as convertible (B1)

Volumetric Budget for Entire Model	
Budget Terms	Flow (m^3/d)
In:	
Constant heads	0
Rivers	40243.4954
Wells	0
Recharge	1093.149571
Total In	41336.64497
Out:	
Constant heads	0
Rivers	32216.18958
Wells	9120
Recharge	0
Total Out	41336.18958
Summary:	
In - Out	0.455390712
Percent Discrepancy	0.001101663

layer-1 & 2 considered as convertible (B2)

Volumetric Budget for Entire Model	
Budget Terms	Flow (m^3/d)
In:	
Constant heads	0
Rivers	46364.67969
Wells	0
Recharge	1093.149571
Total In	47457.82927
Out:	
Constant heads	0
Rivers	28337.36534
Wells	19120
Recharge	0
Total Out	47457.36534
Summary:	
In - Out	0.463928018
Percent Discrepancy	0.000977558

Table.4.16. Volumetric Flow Budget forModel-B3 & B4

layer-1 & 2 considered as convertible (B3)

Volumetric Budget for Entire Model	
Budget Terms	Flow (m^3/d)
In:	
Constant heads	0
Rivers	49091.5402
Wells	0
Recharge	1093.14957
Total In	50184.68976
Out:	
Constant heads	0
Rivers	26064.22637
Wells	24120.0
Recharge	0
Total Out	50184.22637
Summary:	
In - Out	0.463393234
Percent Discrepancy	0.000923376

layer-1 & 2 considered as convertible (B4)

Volumetric Budget for Entire Model	
Budget Terms	Flow (m^3/d)
In:	
Constant heads	0
Rivers	44533.21616
Wells	11000
Recharge	1093.149571
Total In	56626.36573
Out:	
Constant heads	0
Rivers	32505.90216
Wells	24120
Recharge	0
Total Out	56625.90216
Summary:	
In - Out	0.463571846
Percent Discrepancy	0.00081865

CHAPTER 5

RESULTS AND DISCUSSION

5.1. Demarcation of Area of Newly Added District and Block of Tripura

As we know, Tripura was divided into four districts in the year of 2013 but at present another four districts were added within the same geographical area. In the past, there were thirty eight (38) blocks whereas another twenty blocks have been included in that same area.

Actually districts are distributed based on primary as well as secondary data collected from four different Govt. organizations and the same thing has been validated based on our physical data collected from field using Remote Sensing Software.

The following important names of different organization used for collection of data are given below.

Sl. No.	Name of Organization	Description
1	Tripura space research organization(T.S.A.C)	Govt. of Tripura
2	Director of Panchayat	Govt. of Tripura
3	Land record and Settlement	Govt. of Tripura
4	Director of Statics	Govt. of Tripura
5	Public Works Department (W.R)	Govt. of Tripura
	Remote Sensing analysis	Actual Field survey (hotspots area)

The total geographical area is found to be in the tune of 1049169 ha for both hilly and plain area as demarcated in Table 5.1 (a), (b) and (c). About 46.7% are found as hilly area whereas the rest 53.3% are categorized as plain area.

Table 5.1 (a). Newly added district of existing area in Tripura

Geographical Area		**Area (ha)**		**Hilly area (ha)**	**Plain area (ha)**
Name of District	**Name of Block**	**GP/VC***	**MC/NP****		
Dhalai District	Chamanu	45829		42224	3605
	Manu	46331		21001	25330
	Ambasa	29079		18663	10416
	Ganganagar	25624		22296	3328
	Salema	22431		10314	12117
	Durga Chawmuhani	14587		8656	5931
	Dumburnagar	28157		14342	13815
	Raishabari	16958		7840	9118
	Ambassa MC		1477	114	1363
	Kamalpur NP		1016	0	1016
	Total District	**228996 (i)**	**2493 (ii)**	**145450**	**86039**
	In Total (i) + (ii)	*231489*			
North Tripura District	Kadamtala	8509		110	8399
	Kalacherra	7768		102	7666
	Yuvarajnagar	14386		6018	8368
	Panisagar	8866		4072	4794
	Damcherra	18510		18337	173
	Jampuihill	18889		15088	3801
	Dasda	37545		23586	13959
	Laljuri	19950		9806	10144
	Dharmanagar MC		1069	0	1069
	Panisagar NP		300	13	287
	Total District	**134423 (i)**	**1369 (ii)**	**77132**	**58660**
	In Total (i) + (ii)	135792			
Unakoti District	Gournagar	11576		4081	7495
	Chandipur	12845		5394	7451
	Kumarghat	24347		12019	12328
	Pecherthal	15966		11609	4357
	Kailashahar MC		619	0	619
	Kumarghat NP		350	17	333
	Total District	**64734 (i)**	**969 (ii)**	**33120**	**32583**
	In Total (i) + (ii)	65703			

** GP/VC*- Gram Panchayat/Village Committee*
*MC/NP**- Municipality/Nagar Panchayat*

Table 5.1 (b). Newly added district of existing area in Tripura

Geographical Area		Area (ha)		Hilly area (ha)	Plain area (ha)
Name of District	**Name of Block**	**GP/VC**	**MC/NP**		
South Tripura District	Rajnagar	20248		5040	15208
	Bharat Chandra Nagar	12209		4075	8134
	Hrishyamukh	18260		6195	12065
	poyangbari	7415		4150	3265
	Rupaichari	18485		13283	5202
	Satchand	19684		11854	7830
	Bagafa	27525		11238	16287
	Jolaibari	23601		10991	12610
	Belonia MC		574	0	574
	Sabroom NP		506	0	506
	Santirbazar NP		2694	0	2694
	Total District	**147427 (i)**	**3774 (ii)**	**66826**	**84375**
	In Total (i) + (ii)	151201			
Gomati District	Matabari	22270		5122	17148
	Tepania	8656		2705	5951
	Killa	19372		8192	11180
	Kakraban	10378		4665	5713
	Amarpur	40191		20255	19936
	Ompi	30511		19432	11079
	Karbook	21468		8383	13085
	Silachari	7394		5230	2164
	Udaipur MC		610	0	610
	Amarpur NP		855	0	855
	Total District	**160240 (i)**	**1465 (ii)**	**73984**	**87721**
	In Total (i) + (ii)	161705			
West Tripura District	Dukli	10445		477	9968
	Hezamara	18366		6955	11411
	Mohanpur	9081		543	8538
	Bamutia	5471		0	5471
	Lefunga	4942		0	4942
	Jirania	5035		953	4082
	Old Agartala	6524		0	6524
	Belbari	9655		2144	7511
	Mandai	18073		6198	11875
	Agartala M.C		7650	0	7650
	Mohanpur MC		1805	0	1805
	Jirania NP		400	0	400
	Ranirbazar NP		195	0	195
	Total District	**87592 (i)**	**10050 (ii)**	**17270**	**80372**
	In Total (i) + (ii)	97642			

Table 5.1 (c). Newly added district of existing area in Tripura

Geographical Area		**Area (ha)**		**Hilly area (ha)**	**Plain area (ha)**
Name of District	**Name of Block**	**GP/VC**	**MC/NP**		
Sepahijala District	Nalchar	8172		2320	5852
	Mohanbhog	8716		2576	6140
	Kathalia	15167		3810	11357
	Boxanagar	11806		794	11012
	Bishalgarh	14083		1266	12817
	Charilam	12675		1149	11526
	Jampuijala	30652		5011	25641
	Melaghar M.C.		1793	245	1548
	Bishalgarh MC		915	0	915
	Sonamura NP		413	0	413
	Total District	**101271 (i)**	**3121 (ii)**	**17171**	**87221**
	In Total (i) + (ii)	104392			
Khowai District	Khowai	9591		187	9404
	Padmabill	11904		5179	6725
	Tulashikhar	26461		19102	7359
	Teliamura	12887		10805	2082
	Mungiakami	29292		18109	11183
	Kalyanpur	10153		5825	4328
	Khowai MC		582	0	582
	Teliamura MC		375	12	363
	Total District	**100288 (i)**	**957 (ii)**	**59219**	**42026**
	In Total (i) + (ii)	101245			
Total eight district		**1024971(a)**	**24198 (b)**	**490172**	**558997**
State Total	**Total (a) +(b)**	**1049169**			

5.2. (I) Analysis of Climatological Parameters: Rainfall

All historical rainfall data are collected from Indian Meteorological Department (IMD), Kolkata and State Agriculture Department, Tripura for the period of 1970 to 2009. The average rainfall is observed to be in the tune of 2116 mm referred in Fig. 5.1. About 59.25% of total annual rainfall is occurred during monsoon whereas the rest 40.75% is considered as non-monsoon period depicted in Fig. 5.2.

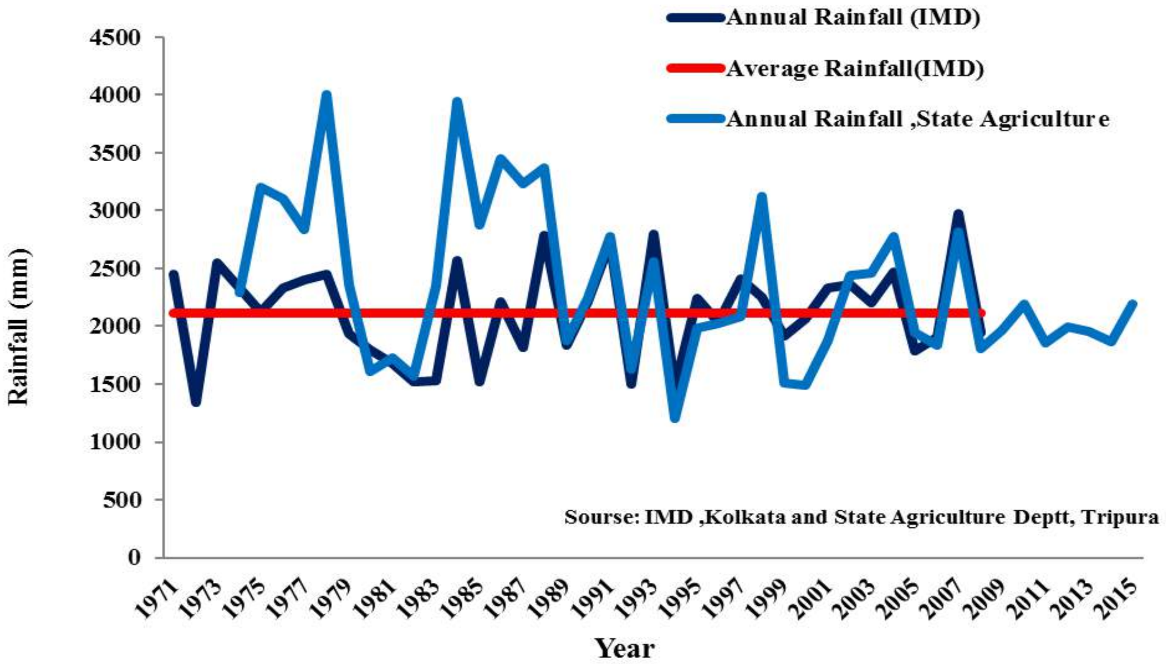


Fig. 5.1. Annual rainfall variation of Tripura

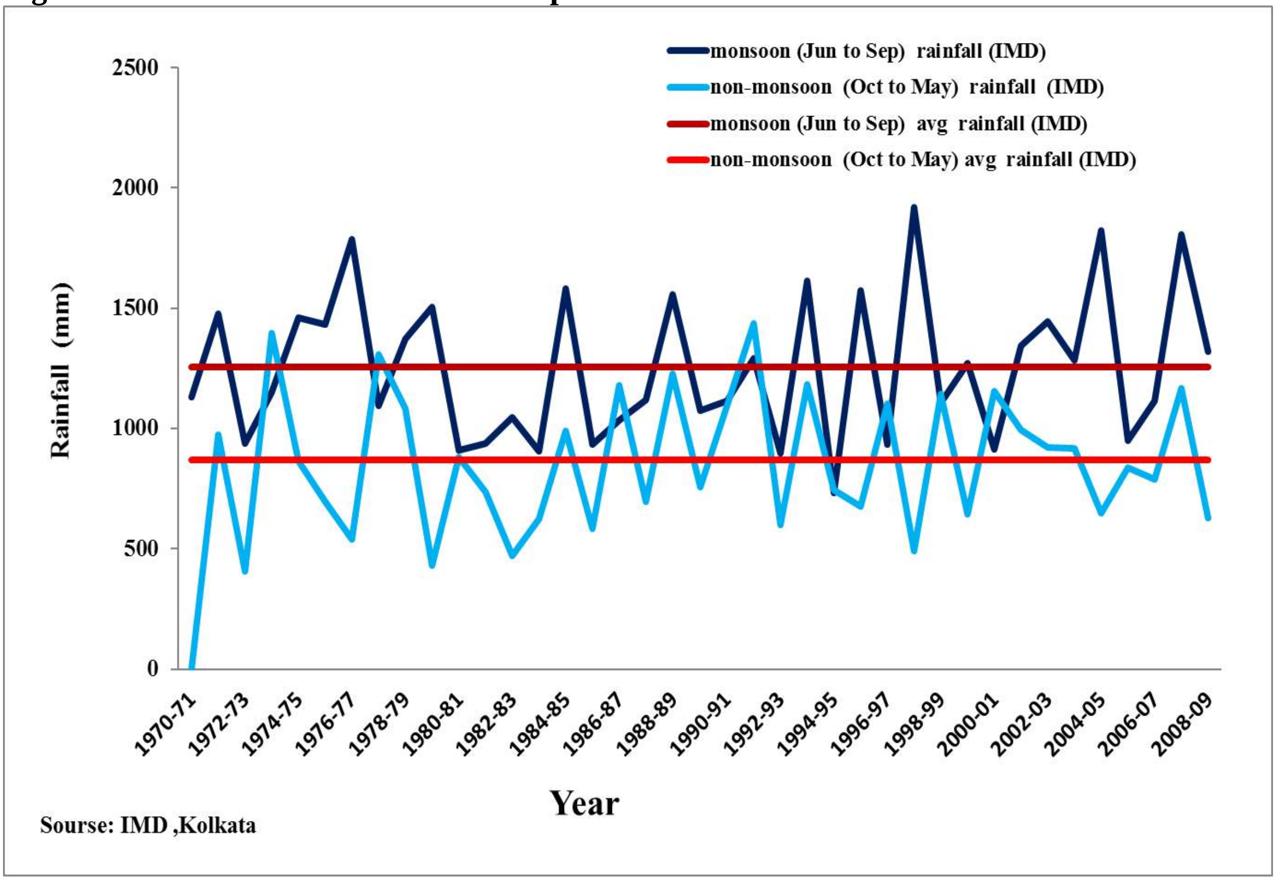


Fig. 5.2. Year wise monsoon and non-monsoon rainfall of Tripura

The month wise rainfall of eight districts of Tripura is given in Fig. 5.3. Fig. 5.3 highlighted that there are two other districts such as Unokoti and Goumoti fall under the district of North and South Tripura respectively. But in West Tripura, there are added two other district namely Sipahijala and Khowai. The figure also indicated that the distribution patterns of all eight districts are in similar trend and it is totally matching with the average line of rainfall of Tripura state.

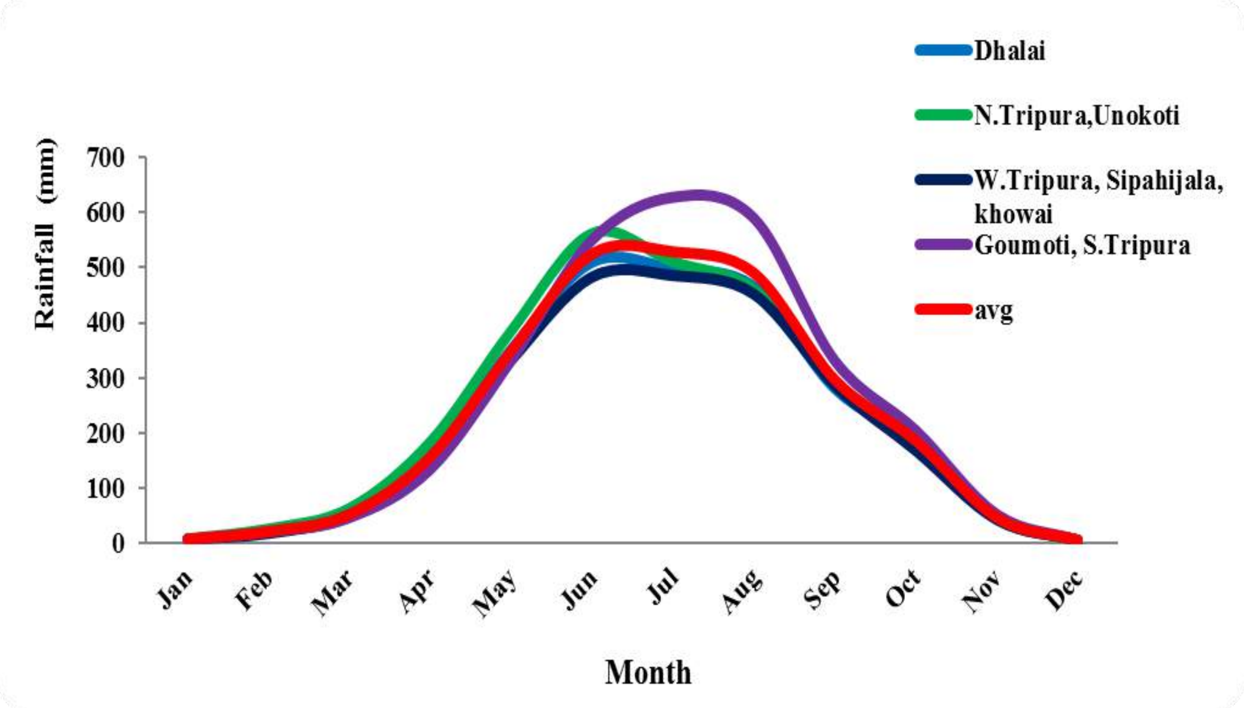


Fig. 5.3. Month wise average (District) precipitation of Tripura

5.2. (II). Analysis of Climatological Parameters: Temperature

The average temperature of Tripura state is found to be ranged between 12.13 and 32.34 ^{0}C for the last forty years as given in Fig. 5.4. The average maximum temperature is observed in the month of April whereas the minimum temperature is observed in the month of January.

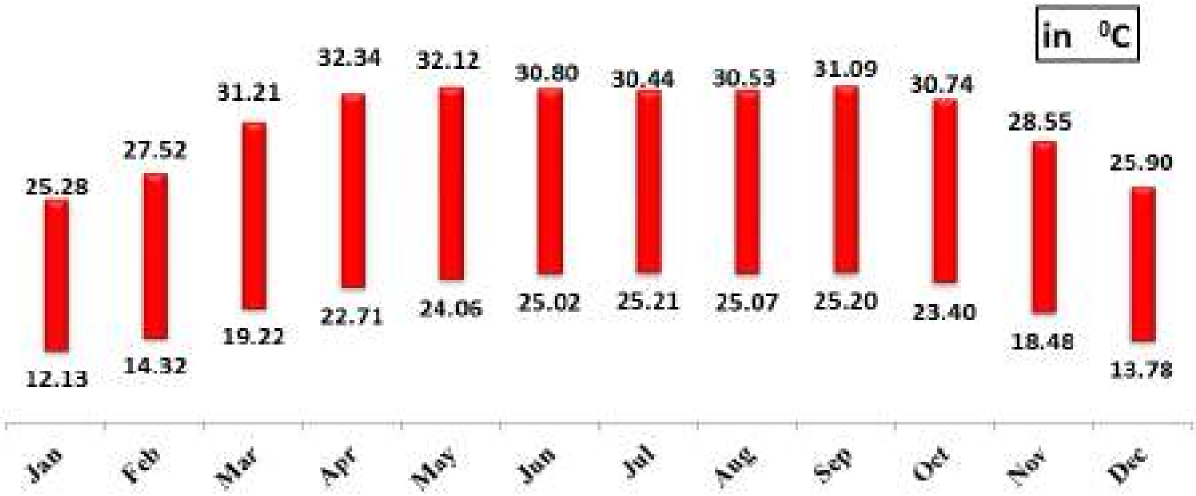


Fig 5.4. Average Maximum & Minimum Temperature of Tripura

Figures 5.5 and 5.6 depicted that in x-axis all individual years showing in graphs are considered as thirty years average (i.e. the first bar diagram considered as 1901-1930 and so on). Figures also highlighted that as the time increased the temperature is also increased considerably with the magnitude of 0.3 ^{0}C and 0.4 ^{0}C as maximum and minimum value respectively. Thus it is true that there is an effect on hydrological cycle throughout the year.

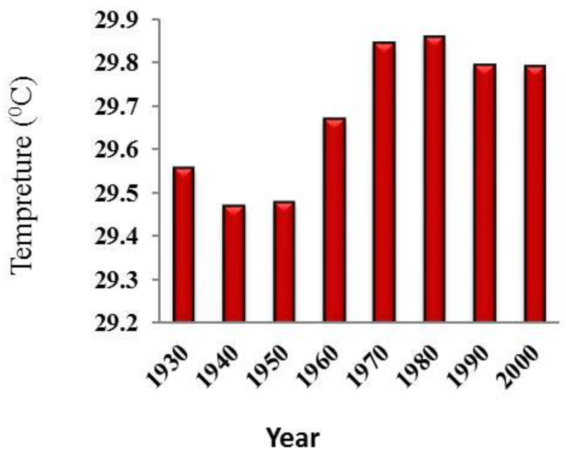


Fig. 5.5. Thirty years Avg Maximum Temperature

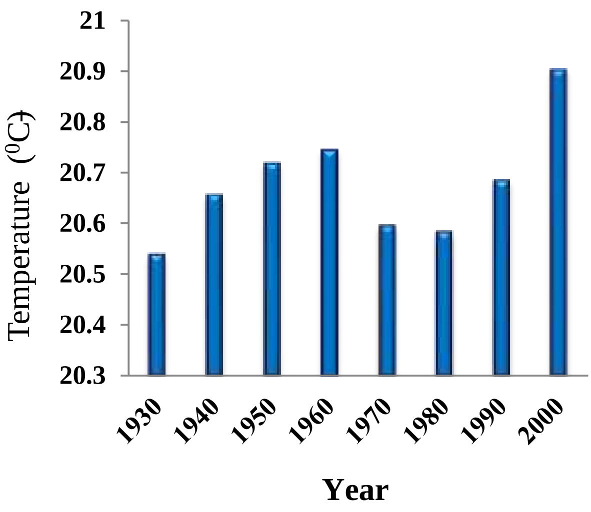


Fig. 5.6. Thirty years Average Minimum Temperature

5.2. (III). Analysis of Climatological Parameters: Evapo-transpiration

The potential evapotranspiration (PET) is calculated based on empirical equation referred by researchers. The maximum value is obtained in the month of April-May where the PET is found to be ranged between 160 mm and 180 mm reflected in Fig. 5.7.

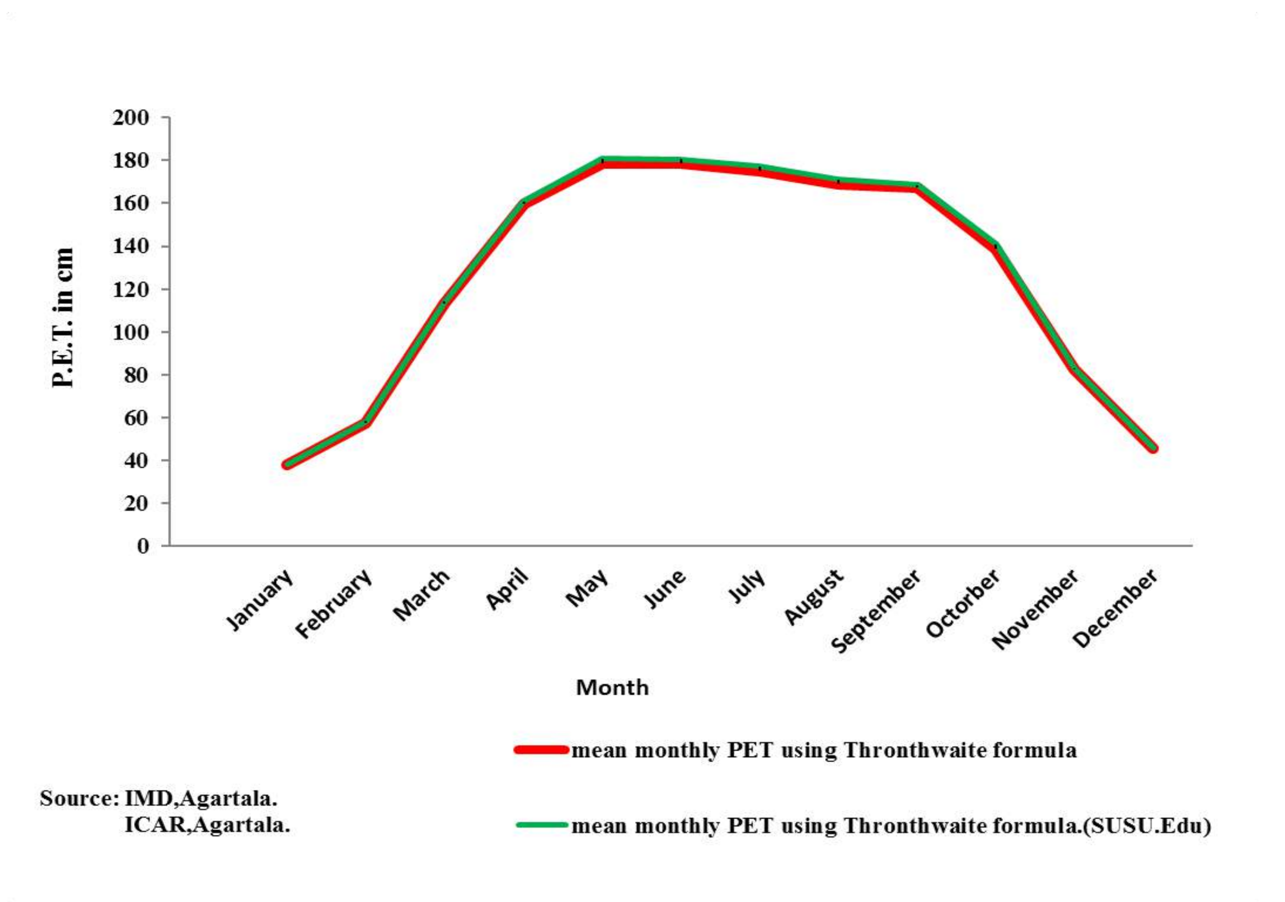


Fig. 5.7. Mean monthly Potential Evapotranspiration

5.3. (I) Analysis of Hydrological Parameters: Annual River Flow

There are eight major rivers in Tripura state covered by geographical area 868800 ha. The maximum annual discharge is found to be 2.71 billion cubic metre (bcm) in case of Manu river whereas the base flow is observed to be 1.43 bcm for Goumati river shown in Fig. 5.8. The daily highest and lowest flows are observed for each river as depicted in Fig. 5.9. It may be concluded that all rivers are originated from Tripura state and its flow towards Bangladesh and also it is under the basin of Megha-Barak sub-basin.

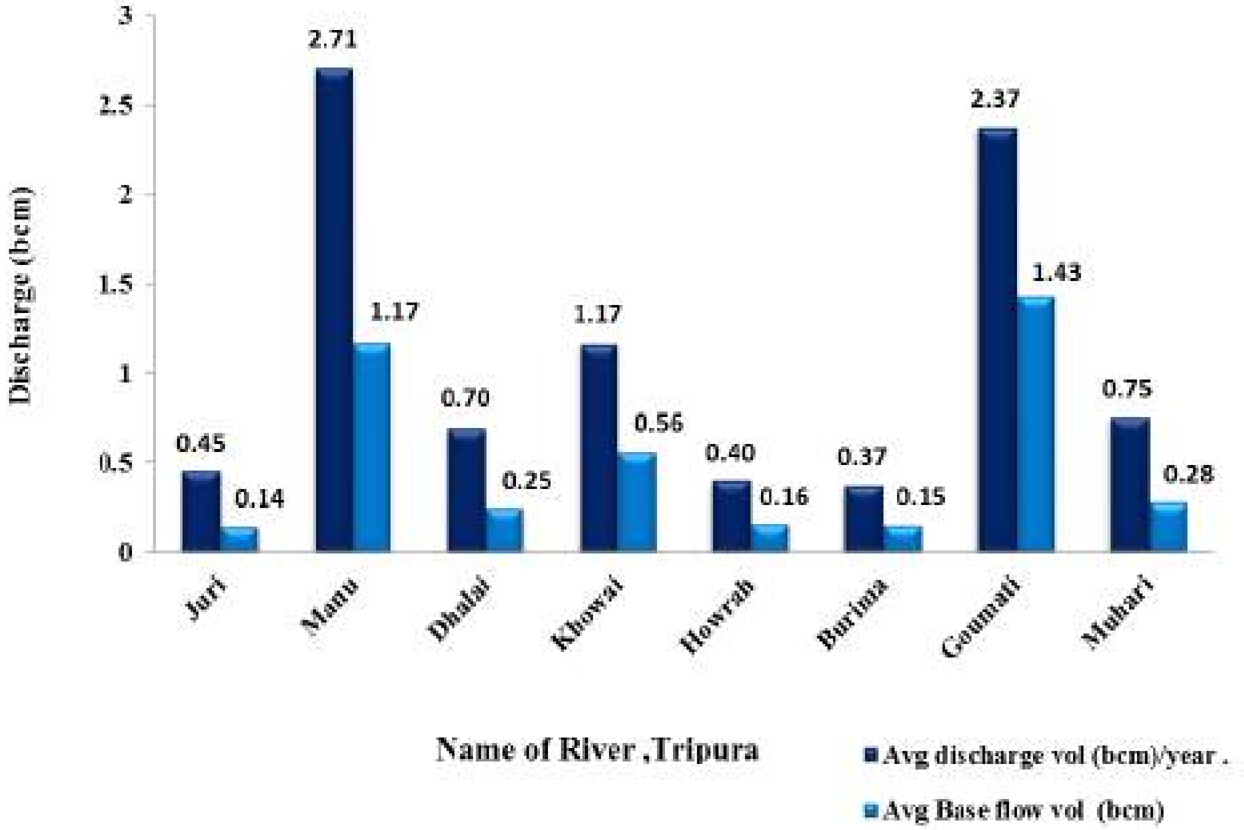


Fig. 5.8. Average Discharge and Base Flow of Major Rivers of Tripura

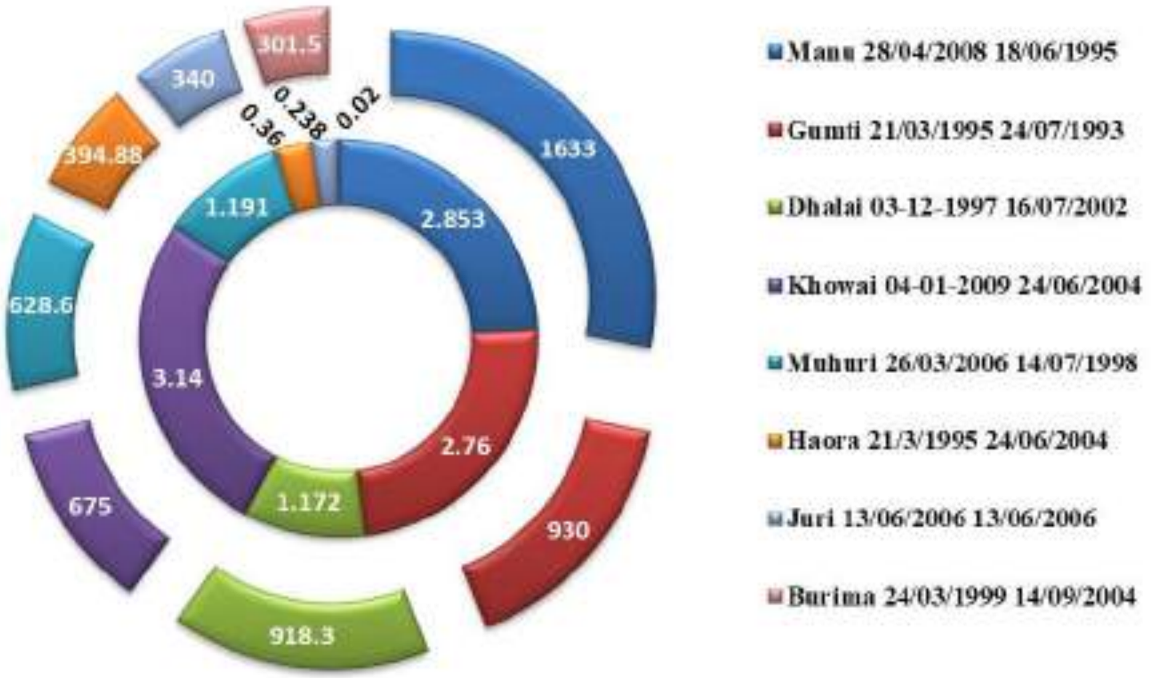


Fig. 5.9. Minimum and Maximum Discharge (m^3/s) of Major Rivers

5.3. (II) Analysis of Hydrological Parameters: Month wise River Flow

Annual monthly hydrographs of eight important river located in Tripura state have been prepared based on past hydrological data collected from Central Water Commission as shown in Figs. 5.10-5.17. In Mahuri river, the 20-years month-wise average annual discharge is found to be 722 cumec and the month-wise peak discharge is observed as 5088 cumec in the year of 1998 which is closed to seven more than the average line of peak discharge (Fig. 5.10 (b)).

The 20-years month-wise average annual discharge is found to be 1127 cumec and the month-wise peak discharge is observed as 5334 cumec in the year of 2002 which is closed to five times more than the average line of peak discharge (Fig. 5.11 (c)) in Khowai river.

The 20-years month-wise average annual discharge of Haora river is observed as 388 cumec and the month-wise peak discharge is found to be 1724 cumec in the year of 2002 which is closed to four and half times more than the average line of peak discharge (Fig. 5.12 (c)).

The 20-years month-wise average annual discharge of Manu River is observed as 2613cumec and the month-wise peak discharge is found to be 11444 cumec in the year of 2004 closed to four and half times more than the average line of peak discharge (Fig. 5.13 (c)).

The 20-years month-wise average annual discharge of Burima river is observed as 358 cumec and the month-wise peak discharge is found to be 1951 cumec in the year of 2002 closed to five and half times more than the average line of peak discharge (Fig. 5.14 (c)).

The 20-years month-wise average annual discharge of Juri River is observed as 435 cumec and the month-wise peak discharge is found to be 2092 cumec in the year of 2006 closed to five times more than the average line of peak discharge (Fig. 5.15 (d)).

The 20-years month-wise average annual discharge of Gumati River is observed as 2290 cumec and the month-wise peak discharge is found to be 9016 cumec in the year of 1998 closed to four times more than the average line of peak discharge (Fig. 5.16 (b)).

The 20-years month-wise average annual discharge of Dhalai River is observed as 671 cumec and the month-wise peak discharge is found to be 5656 cumec in the year of 2002 closed to eight and half times more than the average line of peak discharge (Fig. 5.17 (c)).

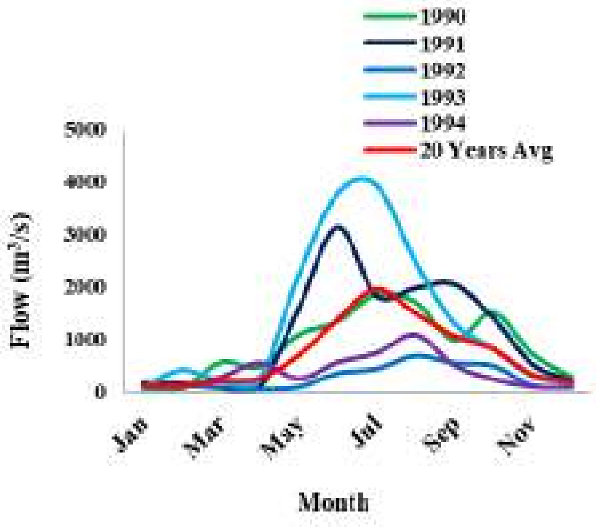


Fig. 5.10 (a). Discharge of River Muhuri

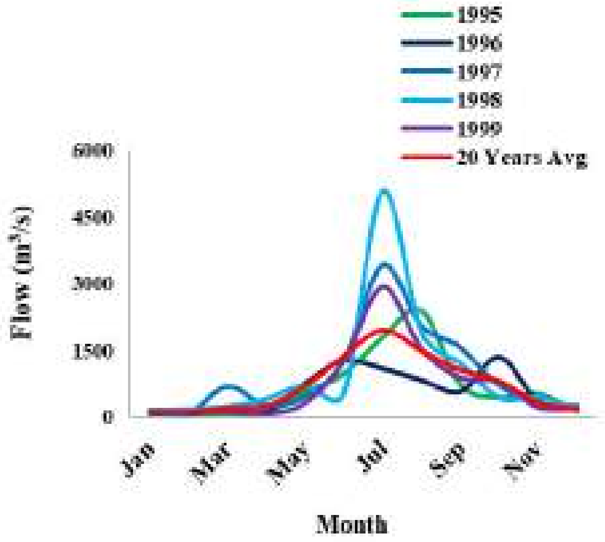


Fig.5.10 (b). Discharge of River Muhuri

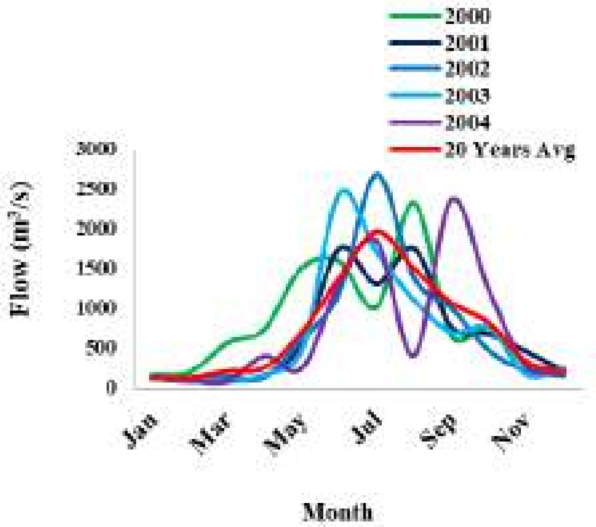


Fig.5.10 (c). Discharge of River Muhuri

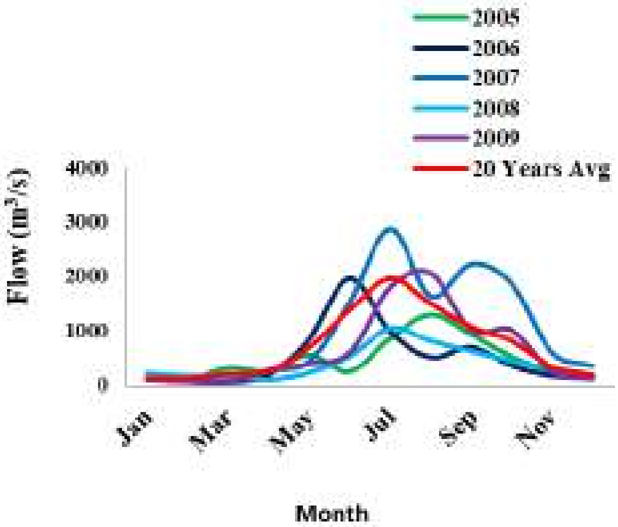


Fig.5.10 (d). Discharge of River Muhuri

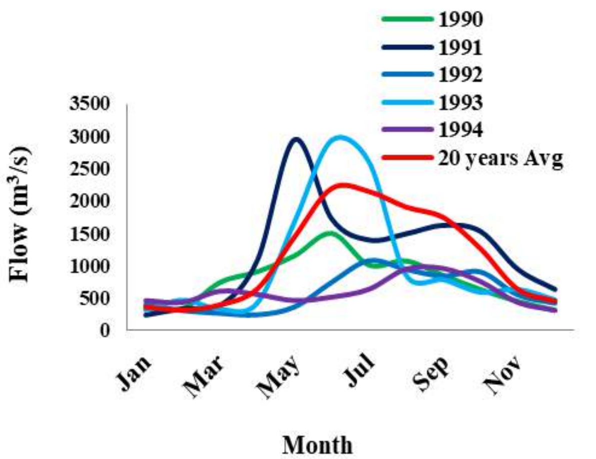


Fig.5.11 (a). Discharge of River Khowai

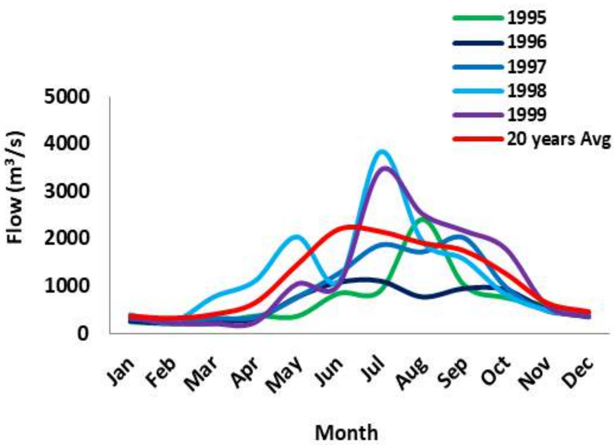


Fig.5.11 (b).Discharge of River Khowai

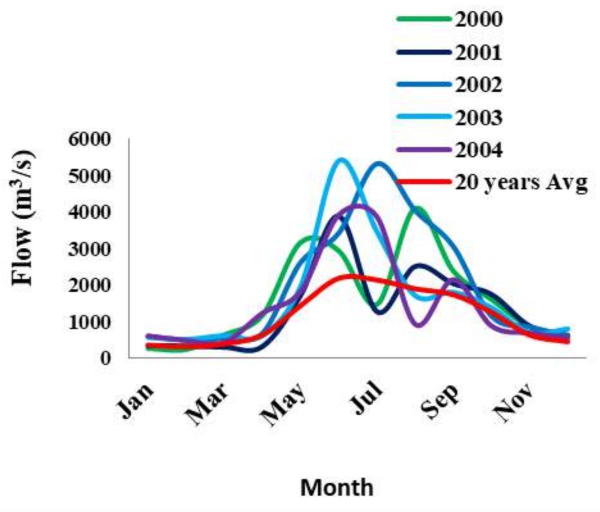


Fig.5.11 (c). Discharge of River Khowai

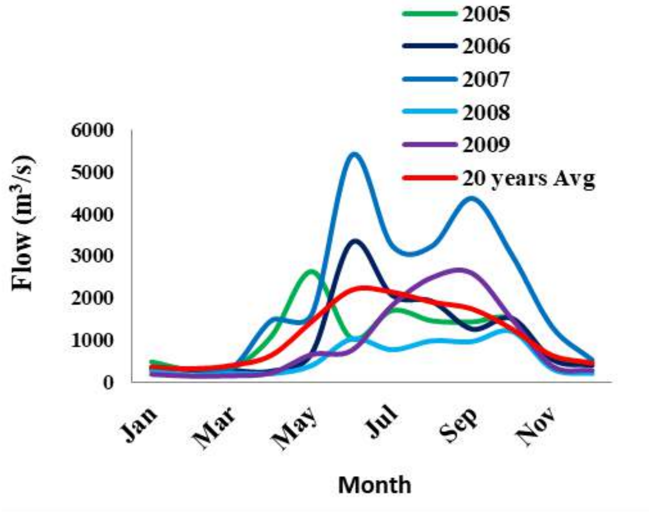


Fig.5.11 (d). Discharge of River Khowai

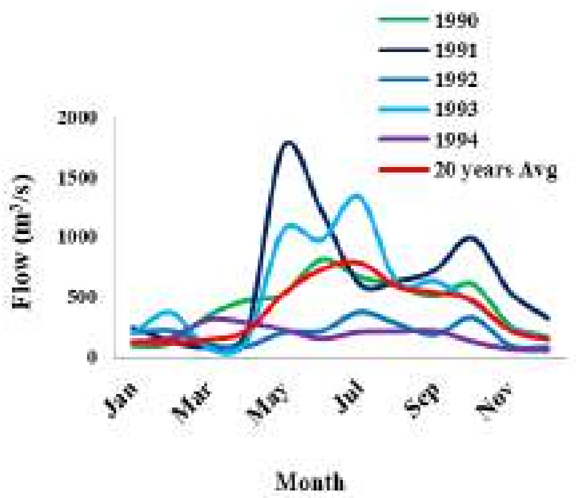


Fig. 5.12 (a). Discharge of River Haora

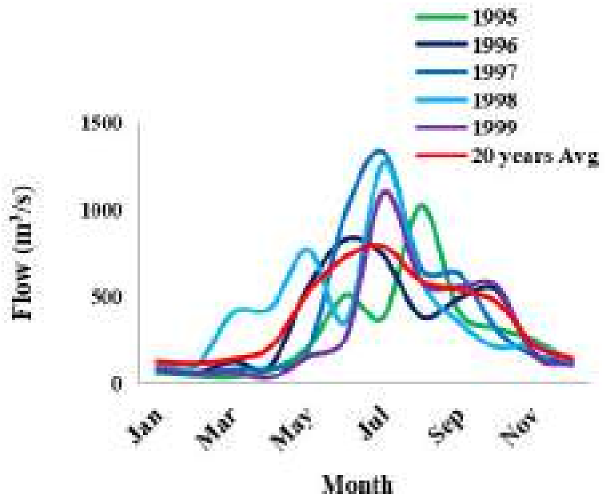


Fig. 5.12 (b). Discharge of River Haora

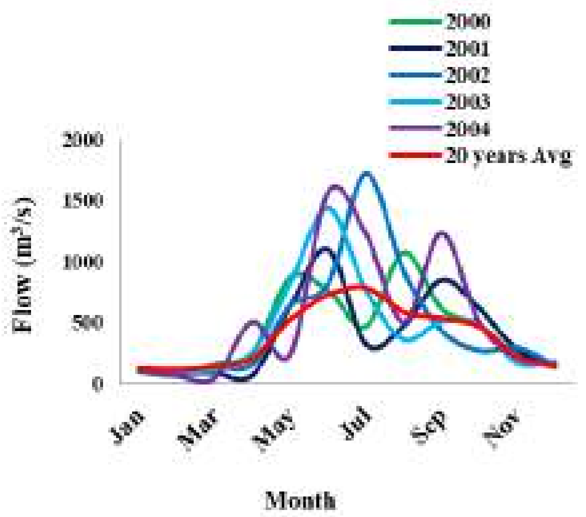


Fig. 5.12 (c). Discharge of River Haora

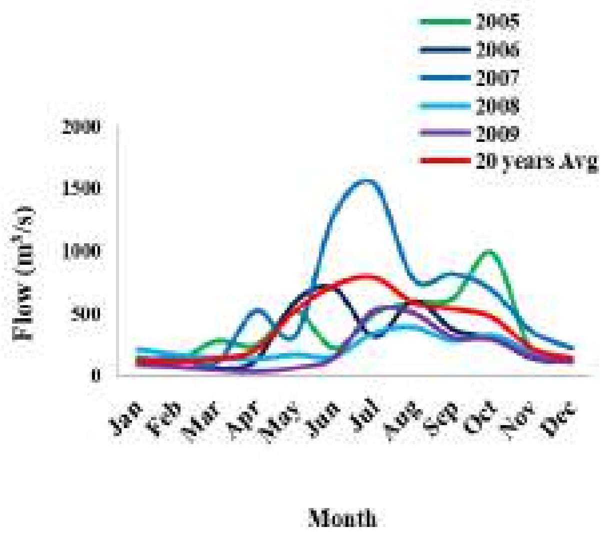


Fig. 5.12 (d) Discharge of River Haora

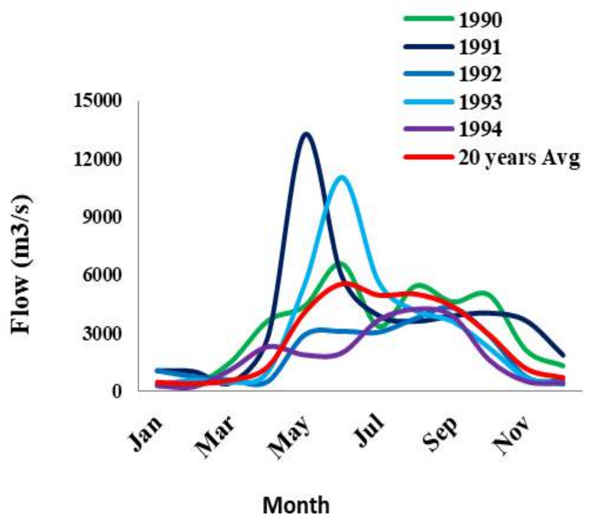


Fig. 5.13(a). Discharge of River Manu

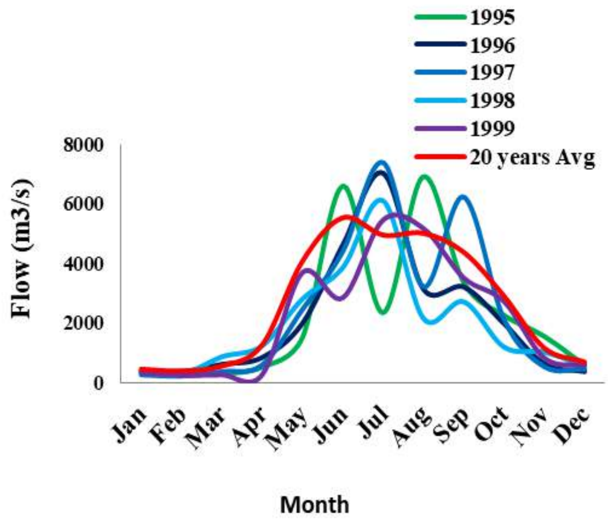


Fig. 5.13(b). Discharge of River Manu

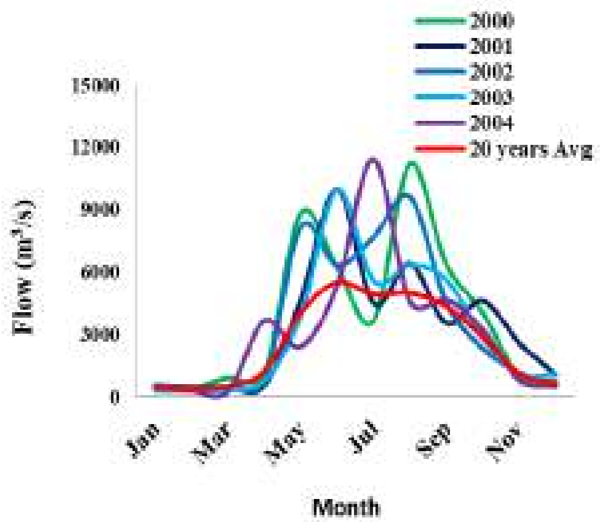


Fig. 5.13(c). Discharge of River Manu

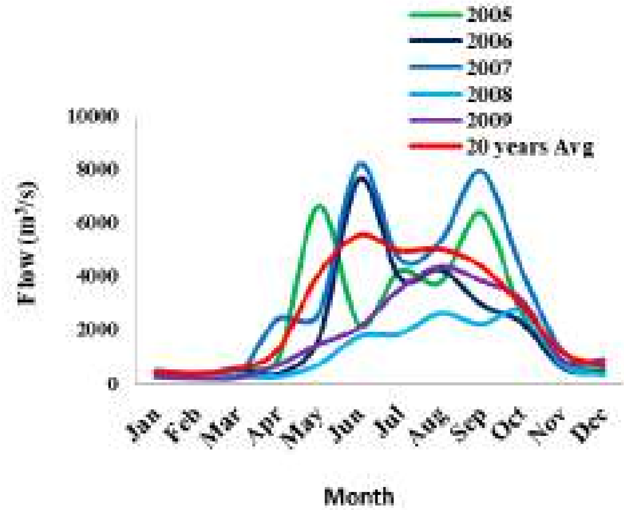


Fig. 5.13(d). Discharge of River Manu

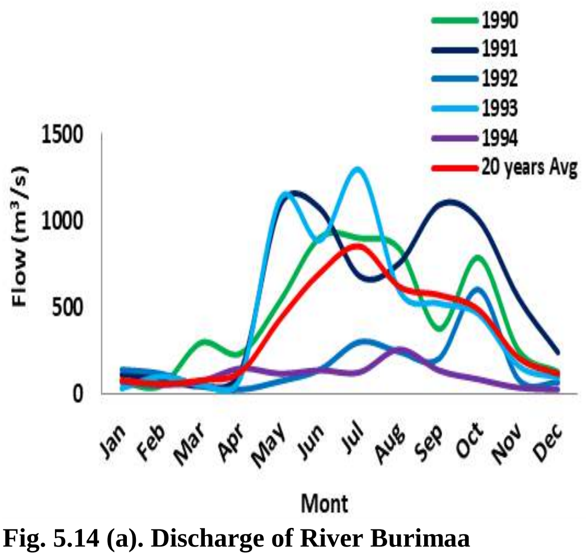


Fig. 5.14 (a). Discharge of River Burimaa

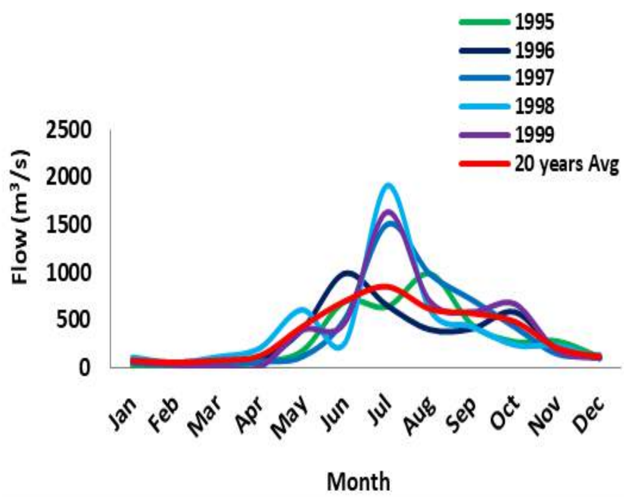


Fig. 5.14 (b). Discharge of River Burimaa

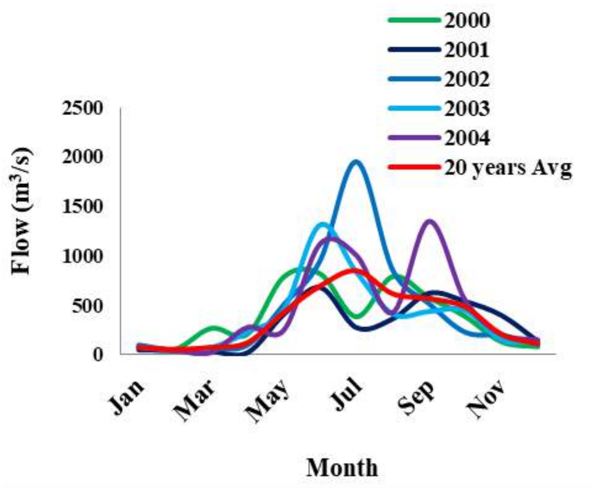


Fig. 5.14 (c). Discharge of River Burimaa

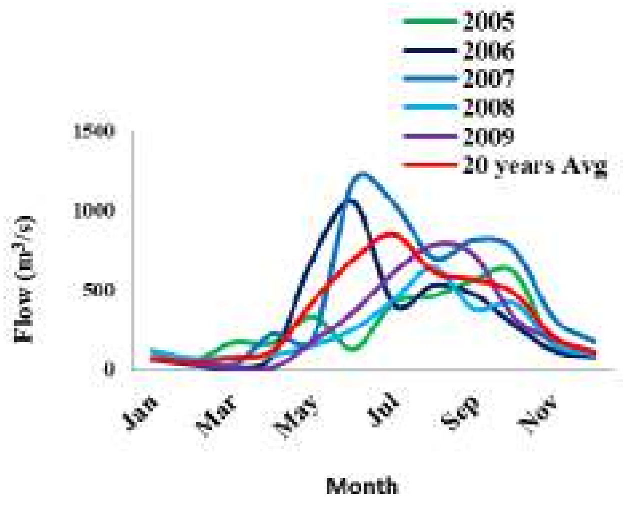


Fig. 5.14 (d). Discharge of River Burimaa

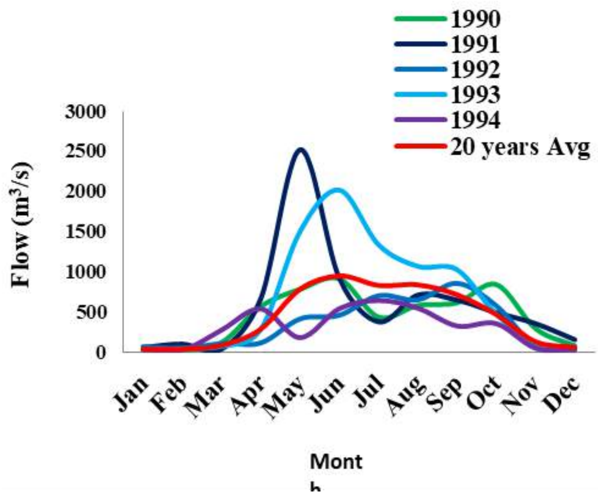


Fig. 5.15.(a).Discharge of River Juri

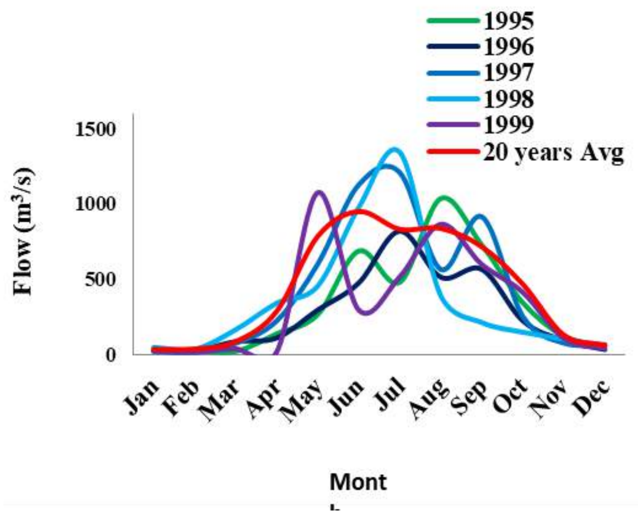


Fig. 5.15.(b).Discharge of River Juri

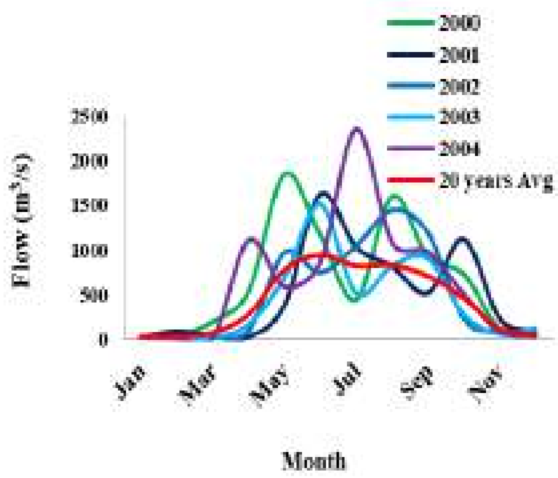


Fig. 5.15.(c).Discharge of River Juri

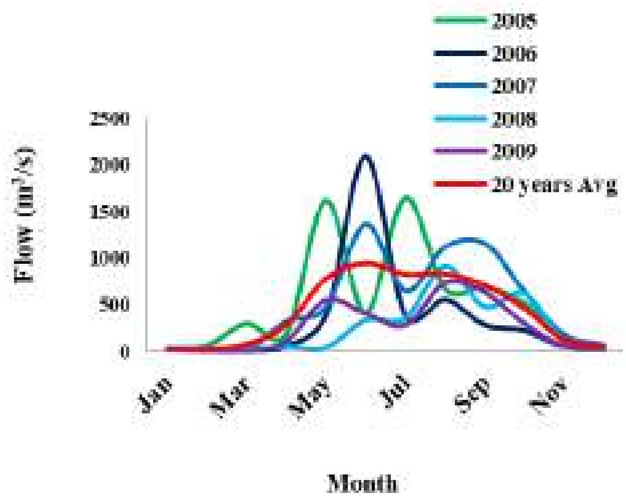


Fig. 5.15.(d).Discharge of River Juri

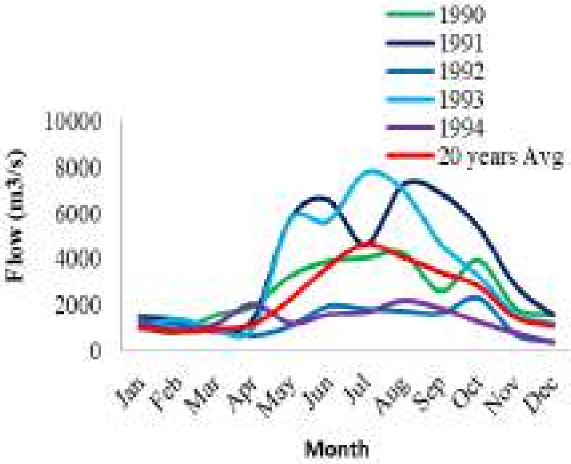


Fig. 5.16 (a) Discharge of River Gumati

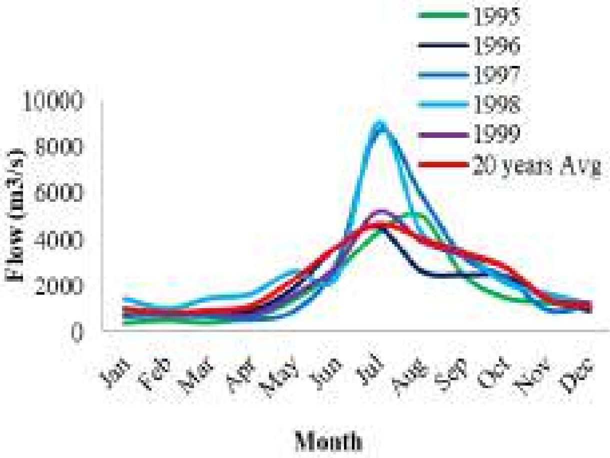


Fig. 5.16 (a) Discharge of River Gumati.

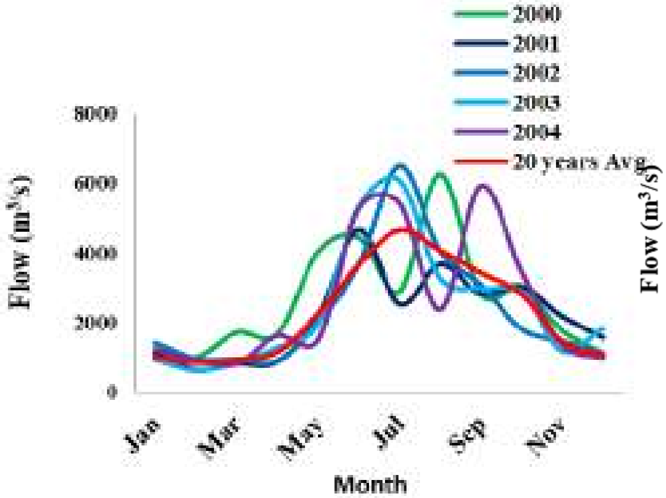


Fig. 5.16 (a) Discharge of River Gumati

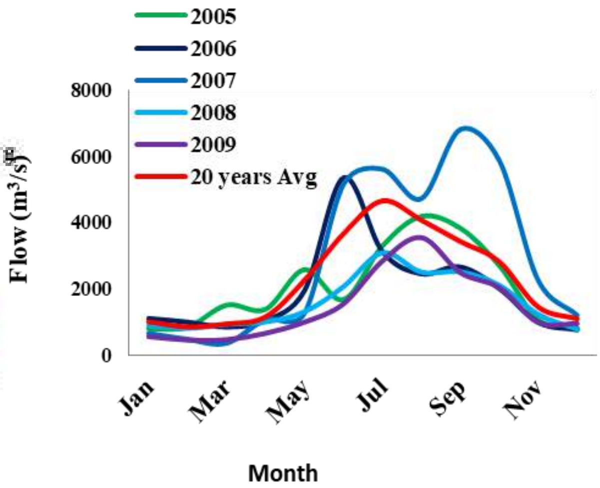


Fig. 5.16 (a) Discharge of River Gumati

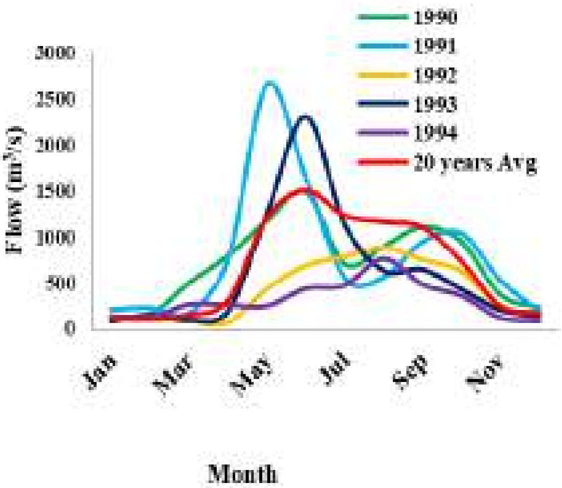


Fig. 5.17 (a). Discharge of River Dhalai

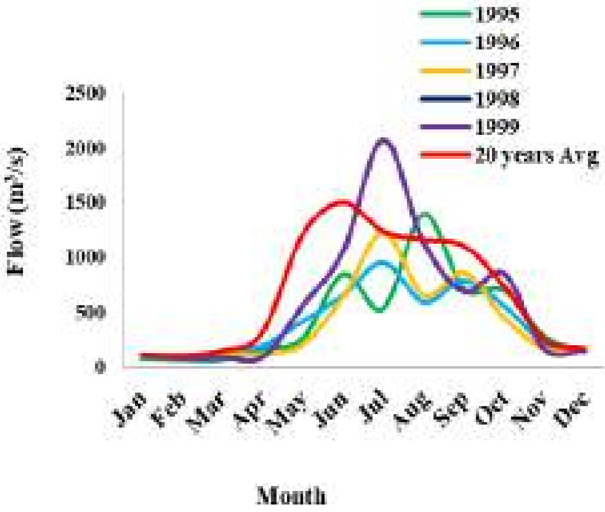


Fig. 5.17(a). Discharge of River Dhalai

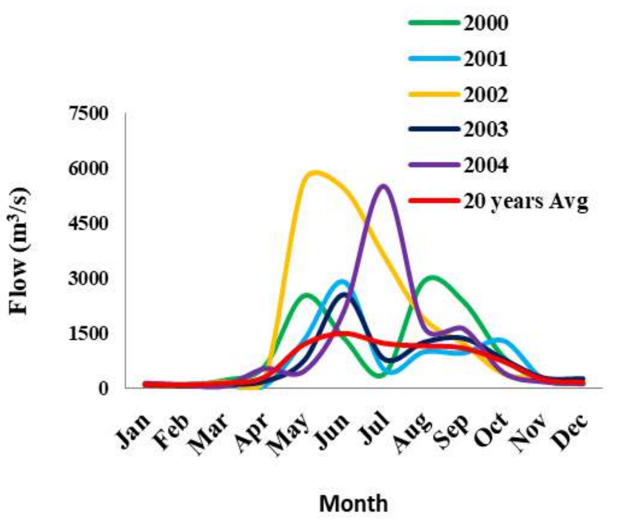


Fig. 5.17 (c). Discharge of River Dhalai

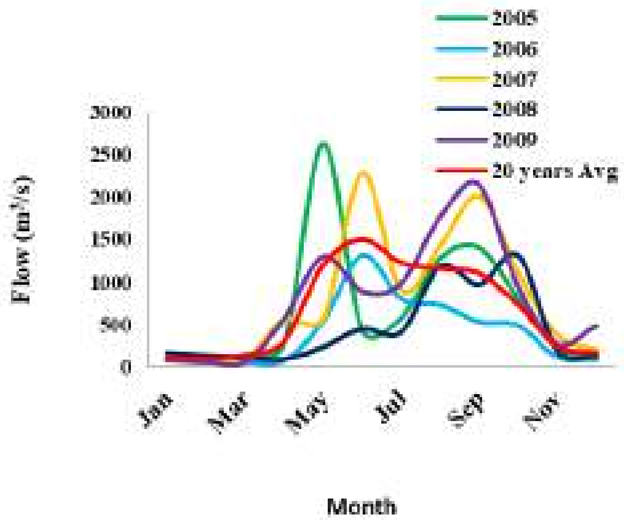


Fig. 5.17(d). Discharge of River Dhalai

5.4. Analysis of Aquifer: Groundwater Level

Historical data has been collected from Central Ground Water Board to analyze the aquifer level in different period and district wise the water tables are reflected in different figures.

Dhalai District

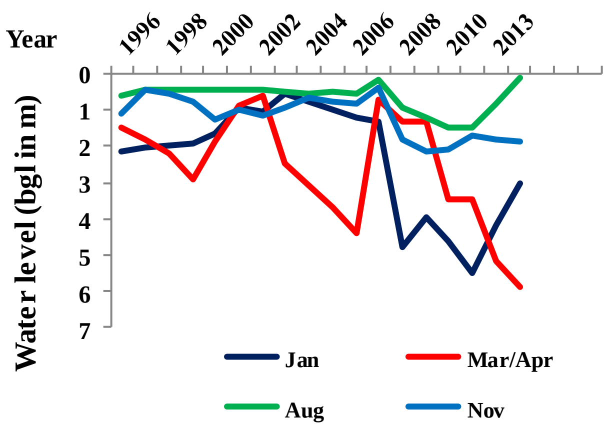
The groundwater levels in eight districts have been depicted in Figs. 5.18- 5.56. There are four towns located at different places mentioned in Fig. 5.18-%.21. In pre-monsoon the average water table drops down in the tune of 2.63 m at Avanga in Dhalai district whereas it is found to be 1.31 m in case of post-monsoon and the same area it is observed as 0.89 m in monsoon season (Fig. 5.18 (a)). The average maximum drawdown of groundwater is considerably high as 5.43 m in pre-monsoon whereas about 2.12 m has dropped down in case of post-monsoon and in the same area it is near about 1.93 m during monsoon season (Fig. 5.18 (b)).

In pre-monsoon the average water table drops down in the tune of 2.0 m at Ambasa in Dhalai district whereas it is found to be 1.2 m in case of post-monsoon and the same area it is observed as 0.5 m in monsoon season (Fig. 5.19 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 4 m in pre-monsoon whereas about 2.4 m has dropped down in case of post-monsoon and in the same area it is near about 1.2 m during monsoon season (Fig. 5.19 (b)).

In pre-monsoon the average water table drops down in the tune of 2.37 m at Kamalpur in Dhalai district whereas it is found to be 1.95 m in case of post-monsoon and the same area it is observed as 1.69 m in monsoon season (Fig. 5.20 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 3.02 m in pre-monsoon whereas about 2.53m has dropped down in case of post-monsoon and in the same area it is near about 1.97 m during monsoon season (Fig. 5.20 (b)).

The average water table is found to be dropped down in the tune of 5.33 m at Manu in pre-monsoon whereas in case of post-monsoon it is found to be as 4.5 m and the same area it is observed as 4.1 m in monsoon season (Fig. 5.21 (a)). The maximum average drawdown is considerably high in the tune of 6.22 m in pre-monsoon whereas about 5.08 m has dropped down in case of post-monsoon and in the same area it is observed as 5.12 m during monsoon season (Fig. 5.21 (b)).

DHALAI DISTRICT



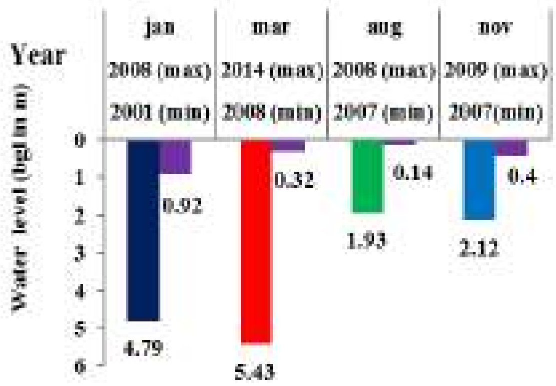
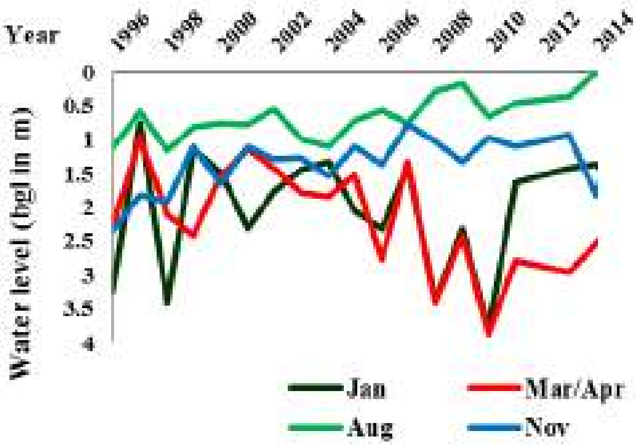


Fig.5.18 (a). Season wise Groundwater at Avanga

Fig.5.18.(b). Season wise Maximum and minimum ground water level at Avanga



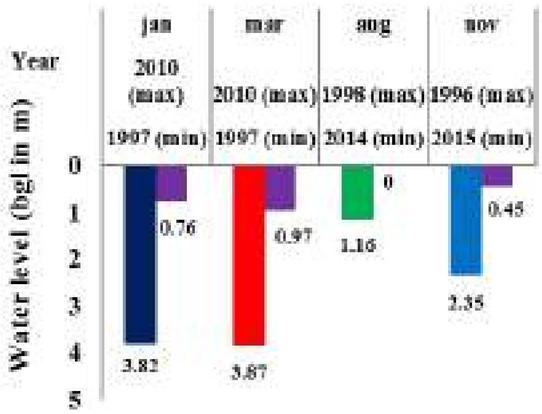
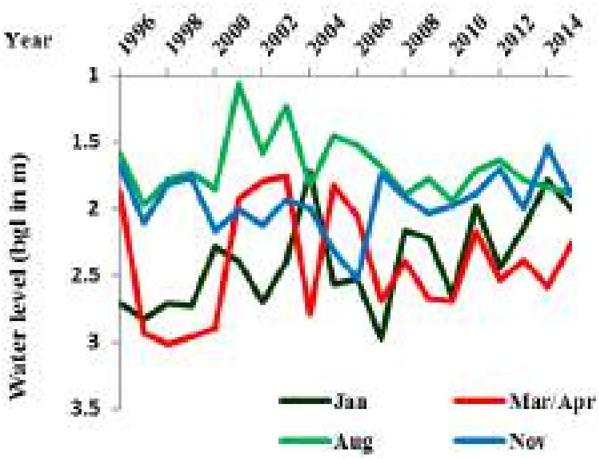


Fig. 5.19 (a). Season wise Groundwater level at Ambassa

Fig.5.19 (b). Season wise Maximum and minimum ground water level at Ambassa



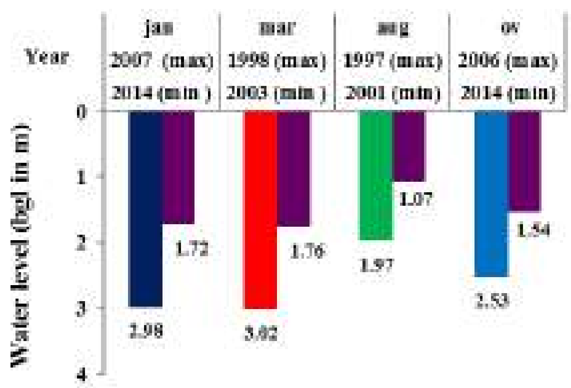


Fig. 5. 20 (a). Season wise Groundwater level at Kamalpur

Fig. 5.20 (b). Season wise Maximum and minimum ground water level at Kamalpur

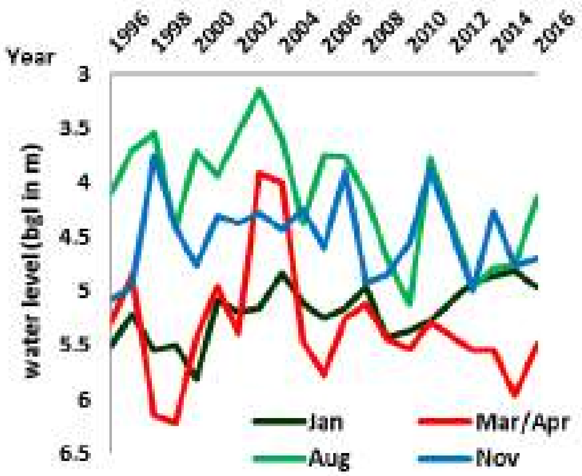


Fig.5.21 (a). Season wise Groundwater level at Manu

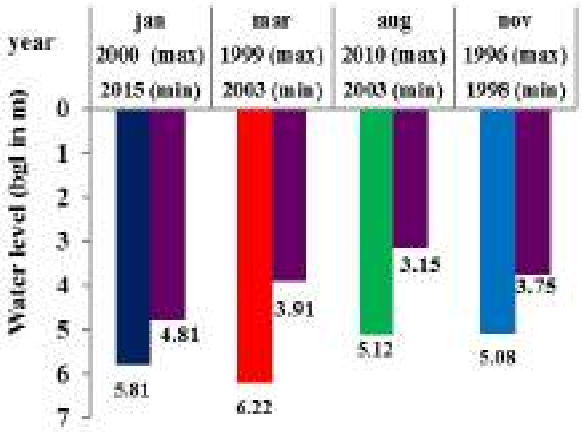


Fig. 5.21 (b). Season wise Maximum and minimum ground water level at Manu

Gomati District

In Gumati, there are four towns namely Dhawajnagar, Gaptali, Garjii and Udaipur. In pre-monsoon the average water table is dropped down in the tune of 4.48 m at Dhawajnagar in Gumati district whereas it is found to be 2.8 m in case of post-monsoon and the same area it is observed as 2.71 m in monsoon season (Fig. 5.22 (a)). The average maximum drawdown of groundwater is considerably high as 4.93 m in pre-monsoon whereas about 3.91 m has dropped down in case of post-monsoon and in the same area it is near about 3.59 m during monsoon season (Fig. 5.22 (b)).

In pre-monsoon the average water table drops down in the tune of 2.54 m at Gaptali in Gumati district whereas it is found to be 2.47 m in case of post-monsoon and the same area it is observed as 1.98 m in monsoon season (Fig. 5.23 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 2.98 m in pre-monsoon whereas about 2.98 m has dropped down in case of post-monsoon and in the same area it is near about 2.27 m during monsoon season (Fig. 5.23 (b)).

In pre-monsoon the average water table has dropped down in the tune of 2.95 m at Garjii in Gumati district whereas it is found to be 1.78 m in case of post-monsoon and the same area it is observed as 1.48 m in monsoon season (Fig. 5.24 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 3.96 m in pre-monsoon whereas about 2.74 m has dropped down in case of post-monsoon and in the same area it is near about 2.22 m during monsoon season (Fig. 5.24 (b)).

The average water table is found to be dropped down in the tune of 2.06 m at Udaipur in pre-monsoon whereas in case of post-monsoon it is found to be as 1.62 m and the same area it is observed as 1.07 m in monsoon season (Fig. 5.25 (a)). The maximum average drawdown is considerably high in the tune of 3.17 m in pre-monsoon whereas about 2.42 m has dropped down in case of post-monsoon and in the same area it is observed as 1.39 m during monsoon season (Fig. 5.25 (b)).

GOMATI DISTRICT

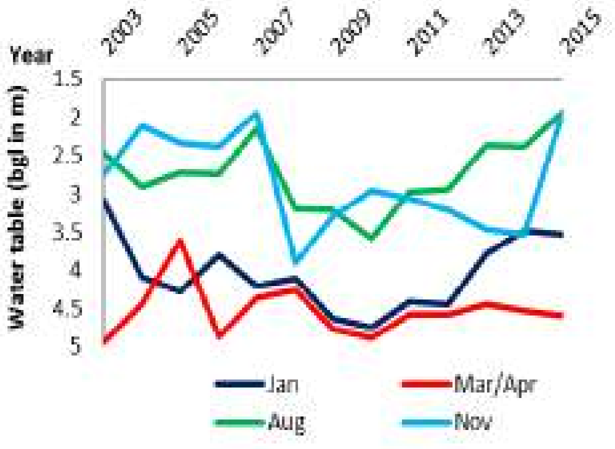


Fig. 5.22 (a). Season wise Groundwater level at Dhajanagar

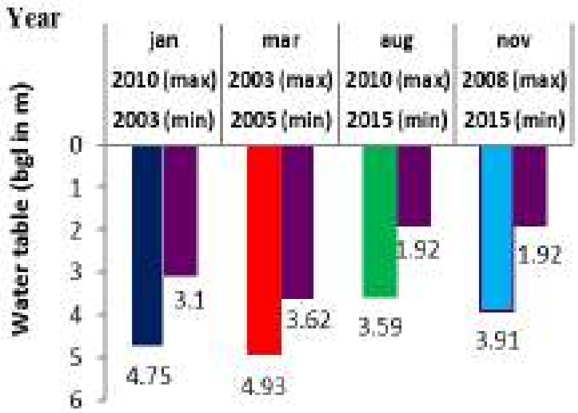


Fig.5.22 (b). Season wise Maximum and minimum ground water level at Dhajanagar

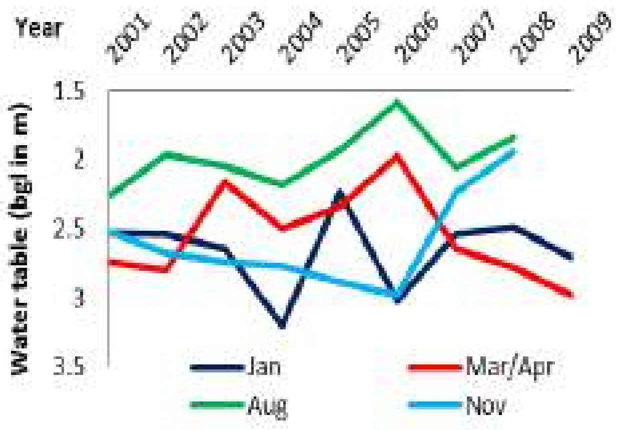


Fig. 5.23 (a). Season wise Groundwater level at Gaptali

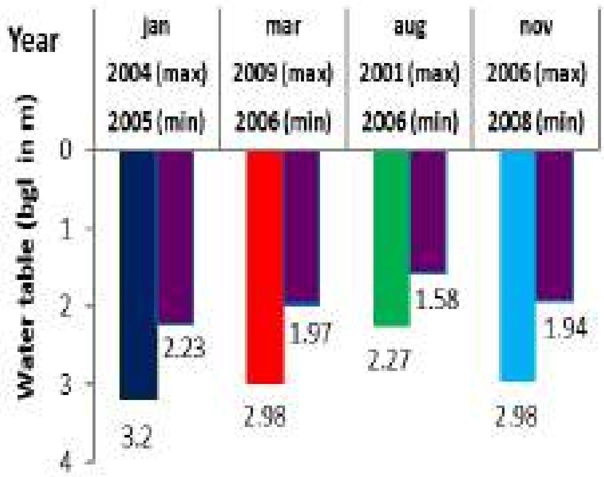


Fig. 5.23 (b). Season wise Maximum and minimum ground water level at Gaptali

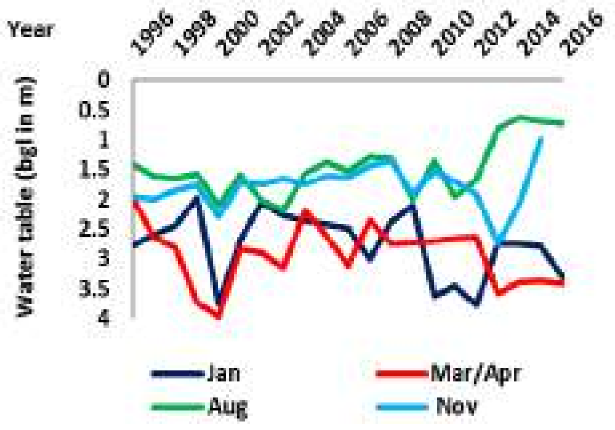


Fig. 5.24 (a). Season wise Groundwater level at Garjee

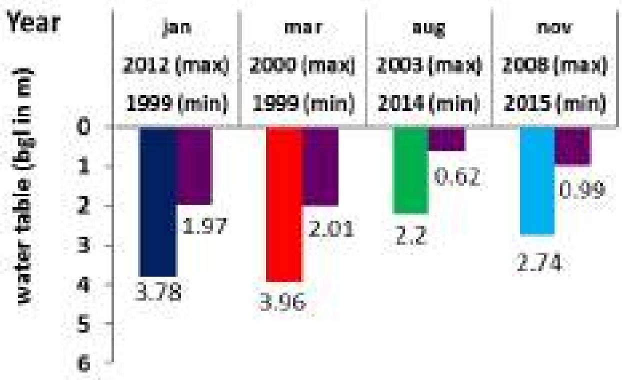


Fig. 5.23 (b). Season wise Maximum and minimum ground water level at Garjee

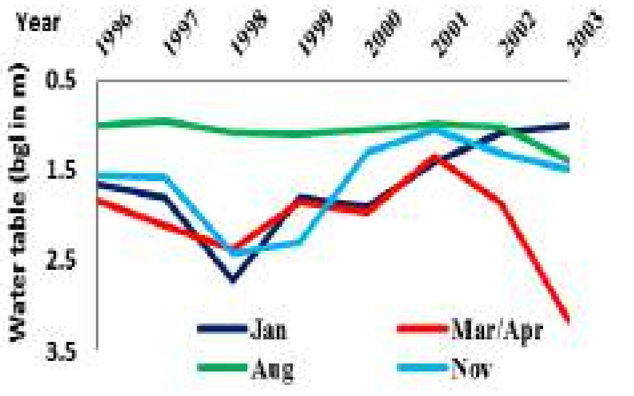


Fig. 5.25 (a). Season wise Groundwater fluctuating trend in different year at Udaipur

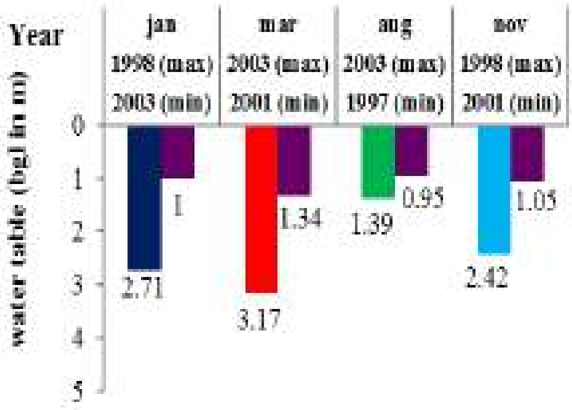


Fig. 5.25 (a). Season wise Groundwater fluctuating trend in different year at Udaipur

Fig. 5.25 (b). Season wise Maximum and minimum ground water level at Udaipur

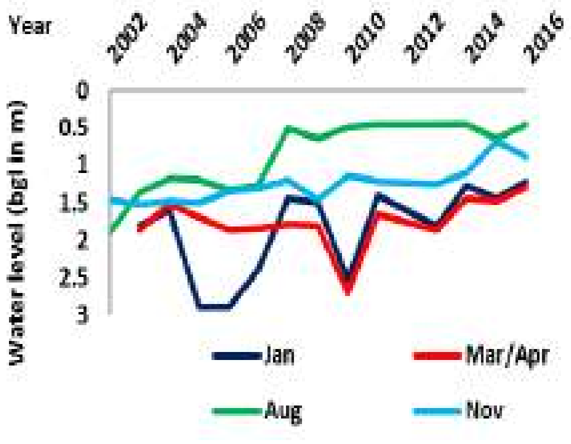
North Tripura District

In North Tripura, there are three towns namely Bagbassa, Dharmanagar and Panisagar. In pre-monsoon the average water table is dropped down in the tune of 1.75 m at Bagbassa in North Tripura district whereas it is found to be 1.24 m in case of post-monsoon and the same area it is observed as 0.81 m in monsoon season (Fig. 5.26 (a)). The average maximum drawdown of groundwater is considerably high as 2.7 m in pre-monsoon whereas about 1.52 m has dropped down in case of post-monsoon and in the same area it is near about 1.91 m during monsoon season (Fig. 5.26 (b). Thus it is to be noticed that since it is a plain land and the water flows from hilly area to plain land and resulting more water is recharged during post-monsoon and ultimately the water table is found to be lower in case of monsoon period.

In pre-monsoon the average water table has dropped down in the tune of 4.69 m at Dharmanagar in North Tripura district whereas it is found to be 4.5 m in case of post-monsoon and the same area it is observed as 3.97 m in monsoon season (Fig. 5.27 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 5.36 m in pre-monsoon whereas about 5.34 m has dropped down in case of post-monsoon and in the same area it is near about 4.68 m during monsoon season (Fig. 5.27 (b).

In pre-monsoon the average water table has dropped down in the tune of 4.12 m at Panisagari in North Tripura district whereas it is found to be 2.73 m in case of post-monsoon and the same area it is observed as 2.36 m in monsoon season (Fig. 5.28 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 4.84 m in pre-monsoon whereas about 3.34 m has dropped down in case of post-monsoon and in the same area it is near about 3.37 m during monsoon season (Fig. 5.28 (b). Since it is a plain land resulting more water is recharged during post-monsoon and ultimately the water table is found to be lower in case of monsoon period and it is located at the downstream portion.

NORTH TRIPURA DISTRICT



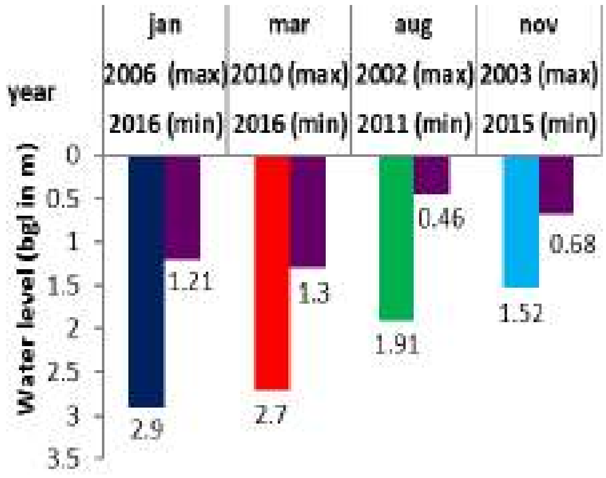
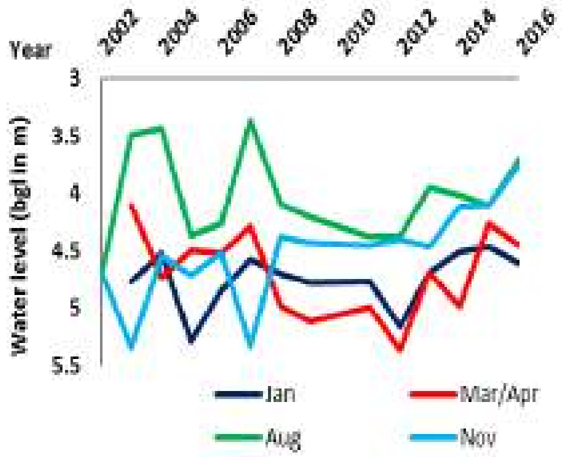


Fig. 5.26 (a). Season wise Groundwater fluctuating trend in different year at Bagbassa

Fig. 5.26 (b). Season wise Maximum and minimum ground water level at Bagbassa



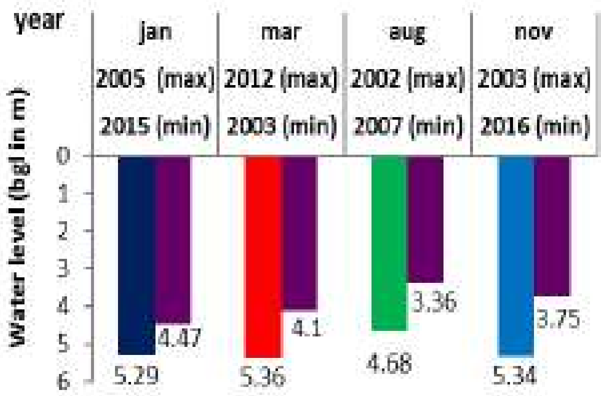


Fig. 5. 27 (a). Season wise Groundwater fluctuating trend in different year at Dharmanagar

Fig. 5.27 (b). Season wise Maximum and minimum ground water level at Dharmanagar

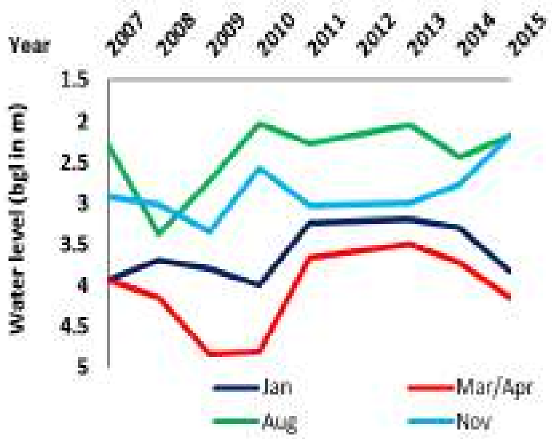


Fig. 5.28 (a). Season wise Groundwater level at Panisagar

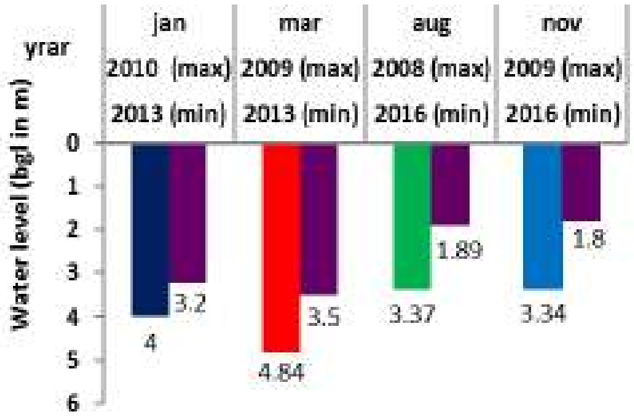


Fig. 5.28 (b). Season wise Maximum and minimum ground water level at Panisagar

Unokoti District

In Unokoti, there are four towns namely Gaurnagar, Kailasahar, Kumarghat and Pecharthal located both plain and hilly land. In pre-monsoon the average water table is dropped down in the tune of 4.41 m at Gaurnagar in Unokoti district whereas it is found to be 1.98 m in case of post-monsoon and the same area it is observed as 1.53 m in monsoon season (Fig. 5.29 (a)). The average maximum drawdown of groundwater is considerably high as 6.1 m in pre-monsoon whereas about 3.43 m has dropped down in case of post-monsoon and in the same area it is near about 2.39 m during monsoon season (Fig. 5.29 (b).

In pre-monsoon the average water table has dropped down in the tune of 2.0 m at Kailasahar in Unokoti district whereas it is found to 1.42 m in case of post-monsoon and the same area it is observed as 0.86 m in monsoon season (Fig. 5.30 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 2.91 m in pre-monsoon whereas about 1.82 m has dropped down in case of post-monsoon and in the same area it is near about 0.99 m during monsoon season (Fig. 5.30 (b).

The average water table has dropped down in the tune of 6.73 m at Kumarghat in pre-monsoon in Unokoti district whereas it is found to be 5.74 m in case of post-monsoon and the same area it is observed as 5.15 m in monsoon season (Fig. 5.31 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 9.32 m in pre-monsoon whereas 7.98 m has dropped down in case of post-monsoon and in the same area it is near about 5.71 m during monsoon season (Fig. 5.31 (b).

In pre-monsoon the average water table has dropped down in the tune of 5.65 m at Pecharthal in Unokoti district whereas it is found to 3.54 m in case of post-monsoon and the same area it is observed as 1.85 m in monsoon season (Fig. 5.32 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 7.99 m in pre-monsoon whereas about 4.88 m has dropped down in case of post-monsoon and in the same area it is near about 3.06 m during monsoon season (Fig. 5.32 (b). Since it is a hilly area, water flows towards low area. Being steep slope more water could not be entered through deep percolation and thus resulting the water scarcity problem occurs in or nearby area.

UNOKOTI DISTRICT

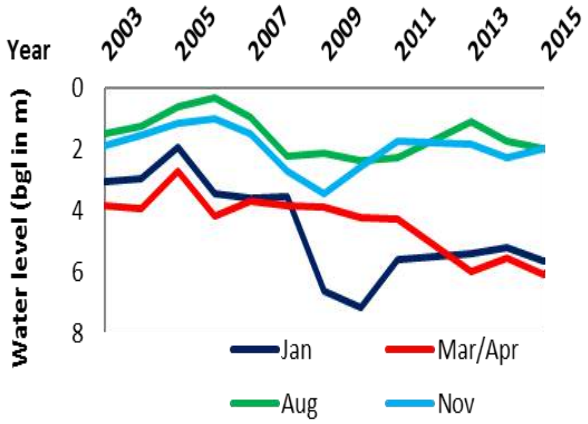


Fig. 5.29 (a). Season wise Groundwater level from 1996 to Mar, 2017 at Gournagar

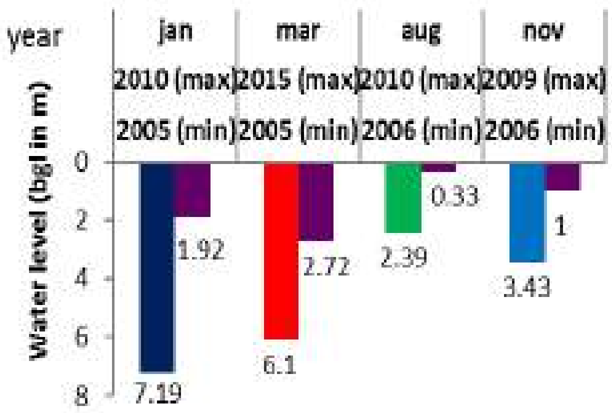


Fig. 5.29 (b). Season wise Maximum and minimum ground water level from at Gournagar

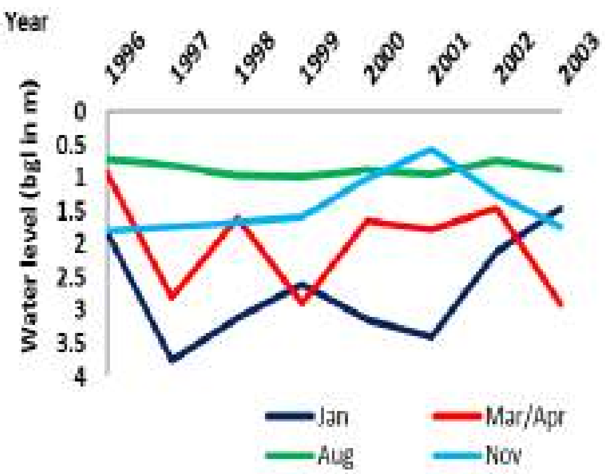


Fig. 5.30 (a). Season wise Groundwater level at Kailasahar

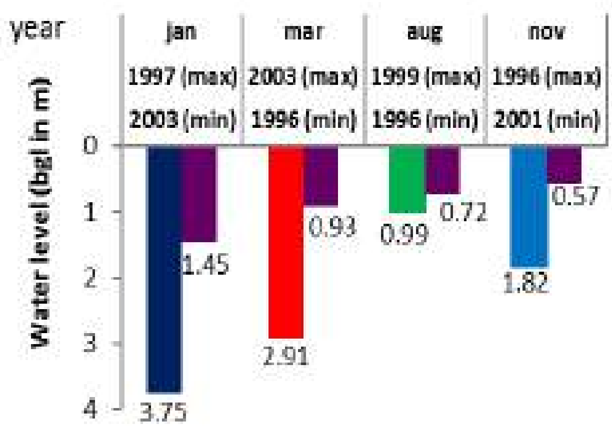


Fig. 5.30 (b). Season wise Maximum and minimum ground water level at Kailasahar

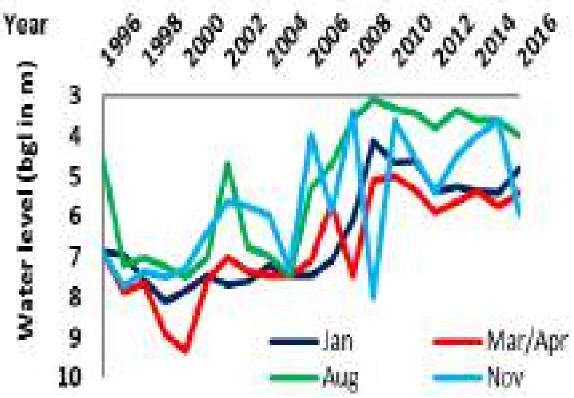


Fig.5.31 (a). Season wise Groundwater level at Kumarghat

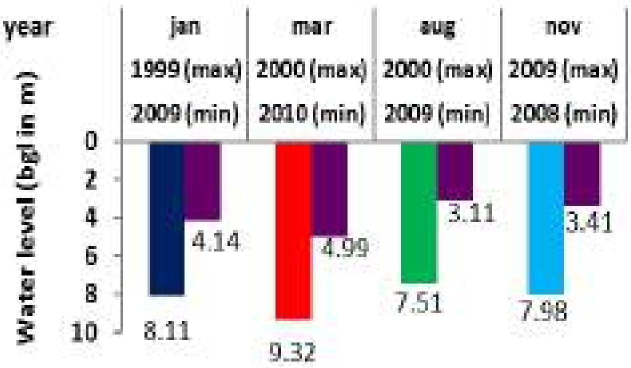
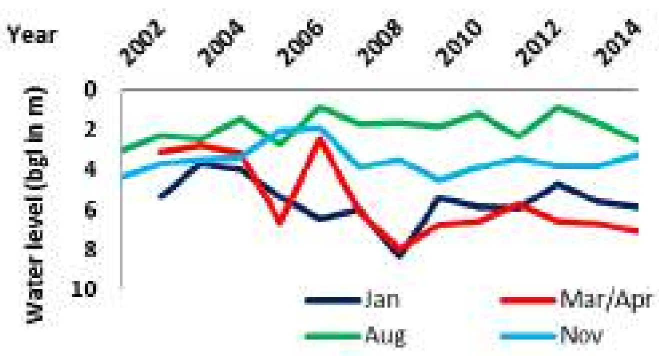


Fig. 5.31 (b). Season wise Maximum and minimum ground water level at Kumarghat



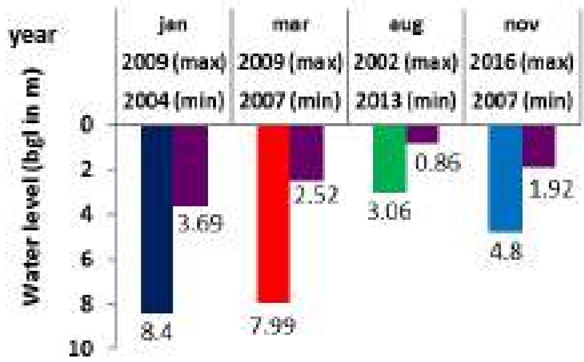


Fig. 5. 32 (a). Season wise Groundwater level at Pecharthal

Fig. 5.32 (b). Season wise Maximum and minimum ground water level at Pecharthal

South Tripura District

In South Tripura, there are five towns namely Belonia, Harishmukh, Manurmukh, Santibazar and Subroom located almost in plain land. In pre-monsoon the average water table is dropped down in the tune of 3.42 m at Belonia in South Tripura district whereas it is found to be 2.77 m in case of post-monsoon and the same area it is observed as 2.15 m in monsoon season (Fig. 5.33 (a)). The average maximum drawdown of groundwater is considerably high as 3.94 m in pre-monsoon whereas about 3.22 m has dropped down in case of post-monsoon and in the same area it is near about 3.02 m during monsoon season (Fig. 5.33 (b).

In pre-monsoon the average water table has dropped down in the tune of 5.46 m at Harishmukh in South Tripura district whereas it is found to 4.25 m in case of post-monsoon and the same area it is observed as 3.33 m in monsoon season (Fig. 5.34 (a)). The average maximum drawdown is considerably high in the tune of 7.11 m in pre-monsoon whereas about 5.92 m has dropped down in case of post-monsoon and in the same area it is near about 5.59 m during monsoon season (Fig. 5.34 (b).

The average water table has dropped down in the tune of 1.73 m at Manurmukh in pre-monsoon in South Tripura district whereas it is found to be 1.37 m in case of post-monsoon and the same area it is observed as 0.7 m in monsoon season (Fig. 5.35 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 2.57 m in pre-monsoon whereas 2.89 m has dropped down in case of post-monsoon and in the same area it is near about 0.94 m during monsoon season (Fig. 5.35 (b). As we found the water table is getting higher value in post-monsoon compared to pre-monsoon so it is concluded more water may be extracted or discharged through the connectivity of the river basin in that catchment area and also sub-surface flow may be higher in pre-monsoon.

In pre-monsoon the average water table has dropped down in the tune of 4.79 m at Santibazar in South Tripura district whereas it is found to 3.36 m in case of post-monsoon and the same area it is observed as 2.91 m in monsoon season (Fig. 5.36 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 5.46 m in pre-monsoon whereas about 4.98 m has dropped down in case of post-monsoon and in the same area it is near about 3.82 m during monsoon season (Fig. 5.36 (b).

In pre-monsoon the average water table has dropped down in the tune of 6.10 m at Subroom in South Tripura district whereas it is found to 5.03 m in case of post-monsoon and the same area it is observed as 4.36 m in monsoon season (Fig. 5.37 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 6.51 m in pre-monsoon whereas about 5.66 m has dropped down in case of post-monsoon and in the same area it is near about 5.01 m during monsoon season (Fig. 5.37 (b).

SOUTH TRIPURA DISTRICT

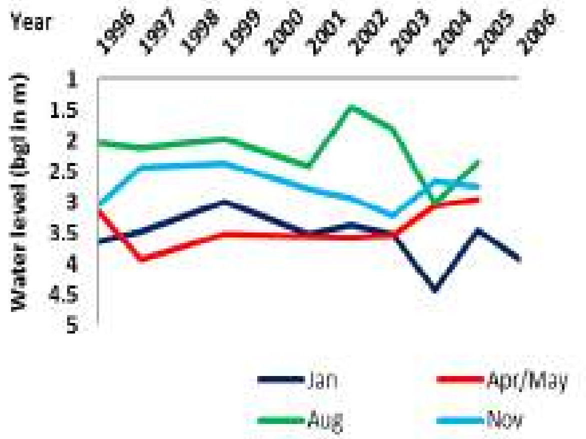


Fig. 5.33 (a). Season wise Groundwater level at Belonia

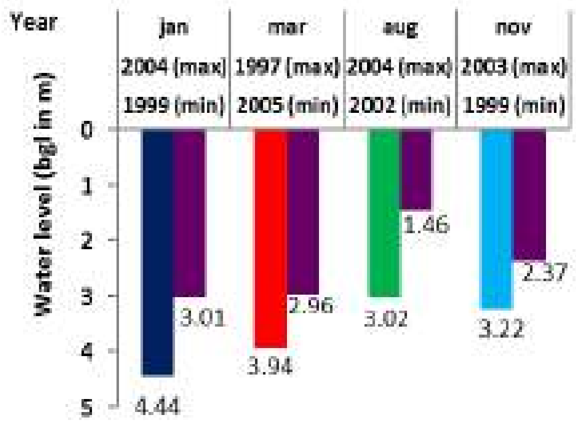


Fig. 5.33 (b). Season wise Maximum and minimum ground water level at Belonia

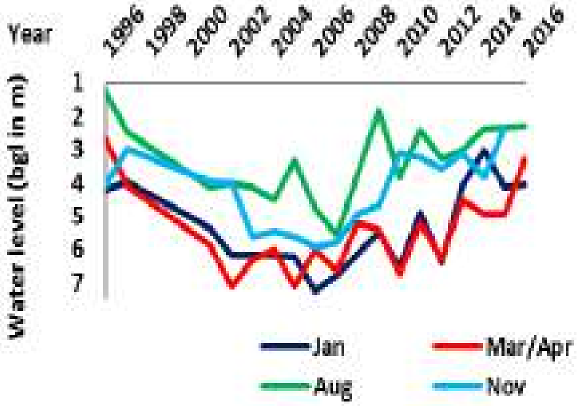


Fig. 5.34 (a). Season wise Groundwater level at Hrishyamukh

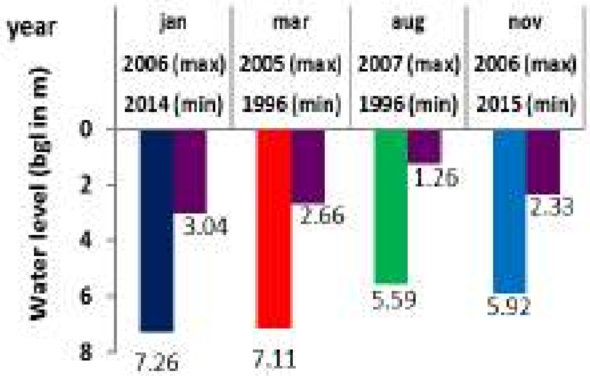


Fig. 5.34 (b). Season wise Maximum and minimum ground water level at Hrishyamukh

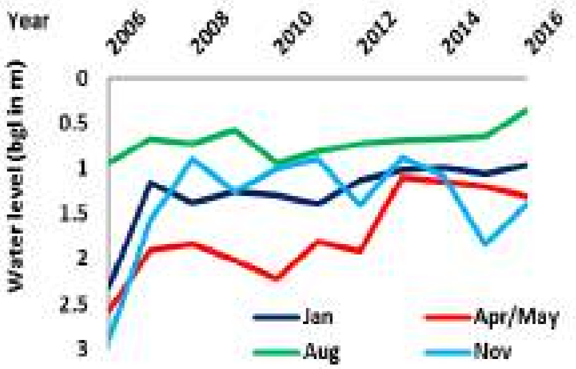


Fig. 5.35 (a). Season wise Groundwater level at Manurmukh

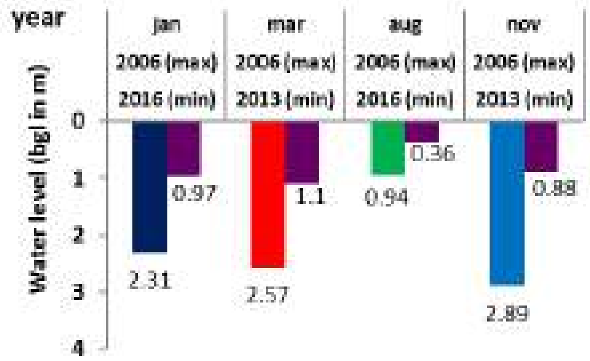


Fig. 5.35 (b). Season wise Maximum and minimum ground water level from 1996 to Mar, 2017 at Manurmukh

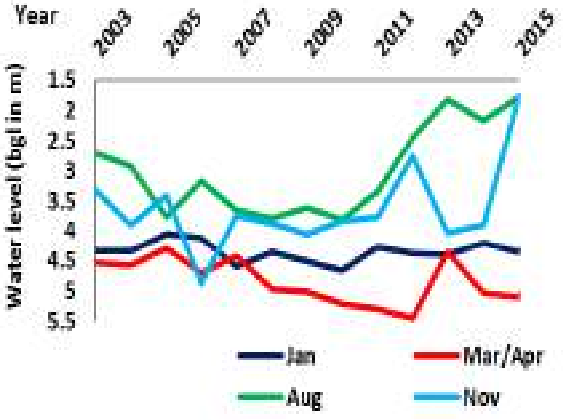


Fig. 5.36 (a). Season wise Groundwater level at Santirbazar

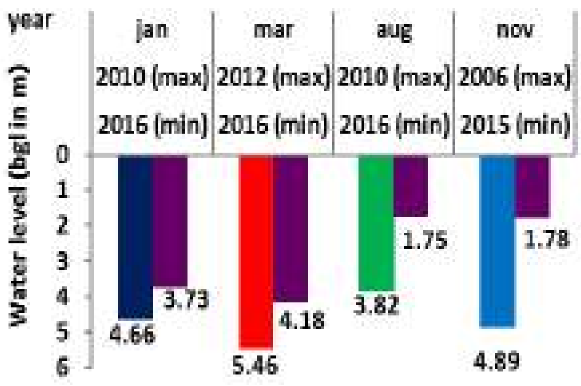


Fig. 5.36 (b). Season wise Maximum and minimum ground water level at Santirbazar

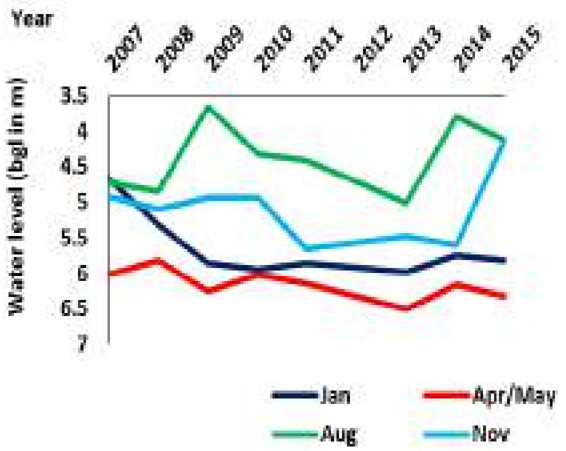


Fig. 5.37 (a). Season wise Groundwater level at Sabroom

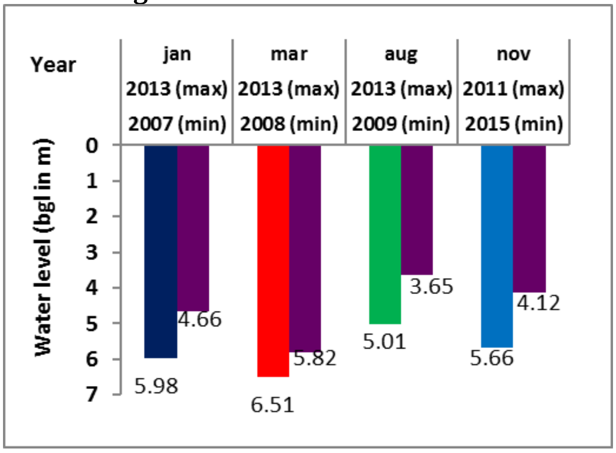


Fig. 5.37 (b). Season wise Maximum and minimum ground water level at Sabroom

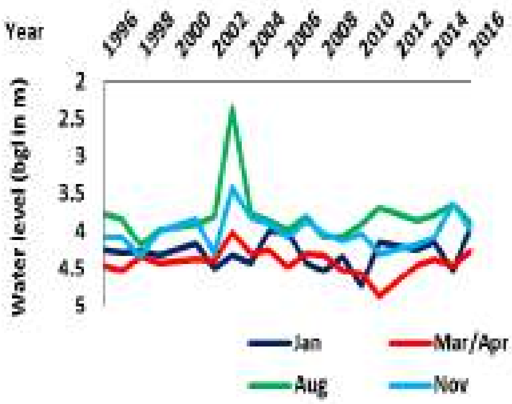
Khowai District

In Khowai, there are three towns namely Kalyanpur, Khowai and Telaimura located in hilly as well as plain land. In pre-monsoon the average water table is dropped down in the tune of 4.40 m at Kalyanpur in Khowai district whereas it is found to be 4.0 m in case of post-monsoon and the same area it is observed as 3.80 m in monsoon season (Fig. 5.38 (a)). The average maximum drawdown of groundwater is considerably high as 4.87 m in pre-monsoon whereas about 4.35 m has dropped down in case of post-monsoon and in the same area it is near about 4.19 m during monsoon season (Fig. 5.38 (b).

In pre-monsoon the average water table has dropped down in the tune of 2.30 m at Khowai in Khowai district whereas it is found to 2.12 m in case of post-monsoon and the same area it is observed as 1.83 m in monsoon season (Fig. 5.39 (a)). The average maximum drawdown is considerably high in the tune of 3.60 m in pre-monsoon whereas about 3.20 m has dropped down in case of post-monsoon and in the same area it is near about 2.40 m during monsoon season (Fig. 5.39 (b). As we understand, all three areas are in overflow zone and there is no scope further for recharging in those areas.

The average water table has dropped down in the tune of 3.33 m at Telaimura in pre-monsoon in Khowai district whereas it is found to be 2.58 m in case of post-monsoon and the same area it is observed as 2.12 m in monsoon season (Fig. 5.40 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 4.54 m in pre-monsoon whereas 3.2 m has dropped down in case of post-monsoon and in the same area it is near about 2.64 m during monsoon season (Fig. 5.40 (b).

KHOWAI DISTRICT



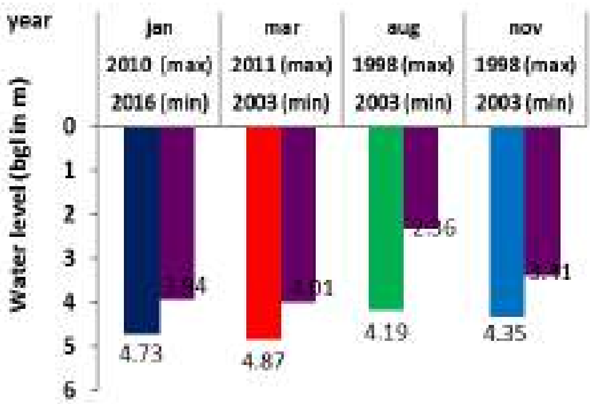
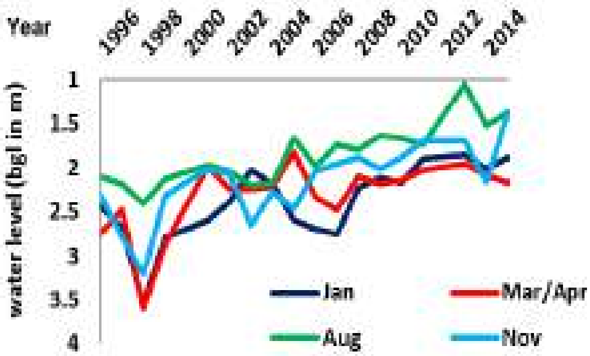


Fig. 5.38 (a). Season wise Groundwater level at Kalyanpur

Fig. 5.38 (b). Season wise Maximum and minimum ground water level at Kalyanpur



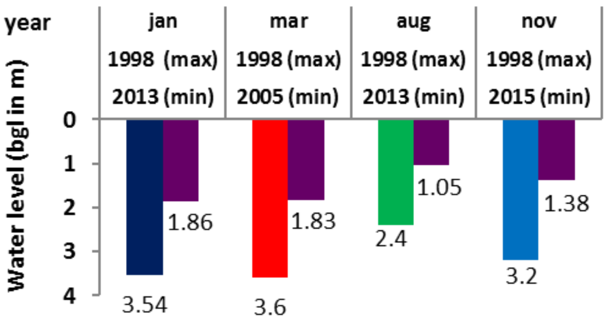
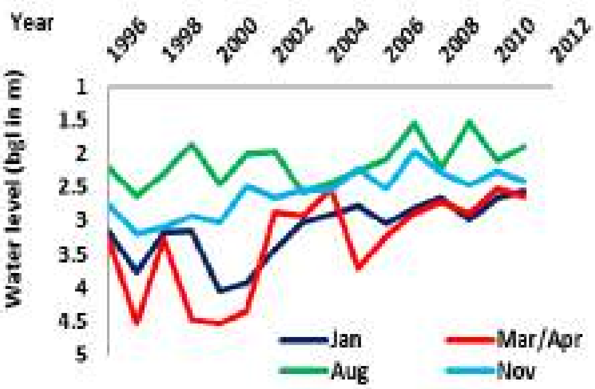


Fig. 5.39 (a). Season wise Groundwater level at Khowai.

Fig. 5.39 (b). Maximum and minimum groundwater level at same season in different year at Khowai.



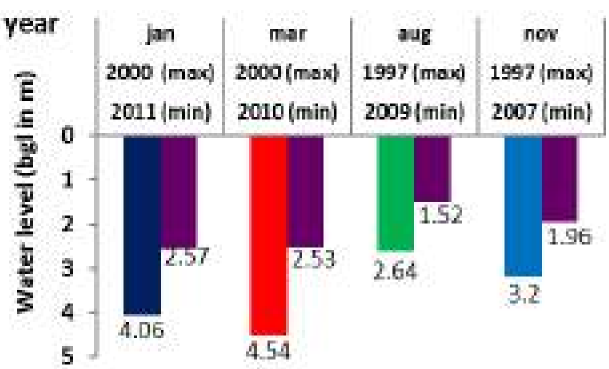


Fig. 5. 40 (a). Season wise Groundwater level at Teliamura

Fig. 5.40 (b). Season wise Maximum and minimum ground water level at Teliamura

Sipahijala District

In Sipahijala, there are seven towns namely Bishalgarh, Kalamcherra, Kathaliya, Nalchar, Sipahijala, Sonamura and Sonamura-1 located almost in plain land but in few places a hip has formed. In pre-monsoon the average water table is dropped down in the tune of 3.47 m at Bishalgarh in Sipahijala district whereas it is found to be 2.90 m in case of post-monsoon and the same area it is observed as 2.35 m in monsoon season (Fig. 5.41 (a)). The average maximum drawdown of groundwater is considerably high as 4.65 m in pre-monsoon whereas about 4.12 m has dropped down in case of post-monsoon and in the same area it is near about 3.33 m during monsoon season (Fig. 5.41 (b).

In pre-monsoon the average water table has dropped down in the tune of 1.79 m at Kalamcherra in Sipahijala district whereas it is found to 1.67 m in case of post-monsoon and the same area it is observed as 1.33 m in monsoon season (Fig. 5.42 (a)). The average maximum drawdown is considerably high in the tune of 2.19 m in pre-monsoon whereas about 2.56 m has dropped down in case of post-monsoon and in the same area it is near about 1.64 m during monsoon season (Fig. 5.42 (b). As we found the water table is getting higher value in post-monsoon compared to pre-monsoon so it is assumed that more water may be extracted or discharged through in that catchment area and also sub-surface flow may be higher in pre-monsoon.

The average water table has dropped down in the tune of 3.07 m at Kathaliya in pre-monsoon in Sipahijala district whereas it is found to be 2.31 m in case of post-monsoon and the same area it is observed as 1.88 m in monsoon season (Fig. 5.43 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 3.78 m in pre-monsoon whereas 3.25 m has dropped down in case of post-monsoon and in the same area it is near about 2.89 m during monsoon season (Fig. 5.43 (b).

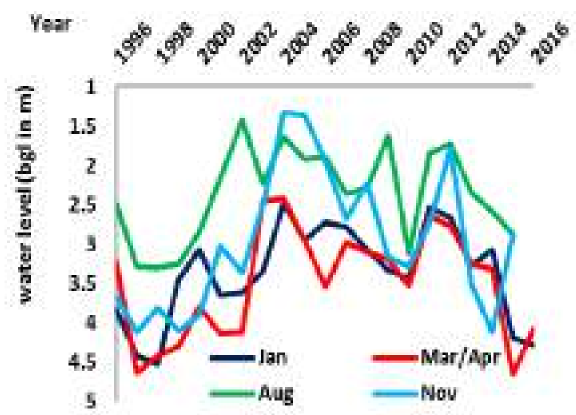
The average water table has dropped down in the tune of 4.53 m at Nalchar in pre-monsoon in Sipahijala district whereas it is found to be 2.74 m in case of post-monsoon and the same area it is observed as 2.50 m in monsoon season (Fig. 5.44 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 5.22 m in pre-monsoon whereas 3.74 m has dropped down in case of post-monsoon and in the same area it is near about 3.57 m during monsoon season (Fig. 5.44 (b).

The average water table has dropped down in the tune of 2.71 m at Sipahijala in pre-monsoon in Sipahijala district whereas it is found to be 2.25 m in case of post-monsoon and the same area it is observed as 2.09 m in monsoon season (Fig. 5.45 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 3.65 m in pre-monsoon whereas 2.76 m has dropped down in case of post-monsoon and in the same area it is near about 2.46 m during monsoon season (Fig. 5.45 (b).

The average water table has dropped down in the tune of 2.63 m at Sonamura in pre-monsoon in Sipahijala district whereas it is found to be 1.62 m in case of post-monsoon and the same area it is observed as 1.11 m in monsoon season (Fig. 5.46 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 3.68 m in pre-monsoon whereas 2.38 m has dropped down in case of post-monsoon and in the same area it is near about 1.65 m during monsoon season (Fig. 5.46 (b).

The average water table has dropped down in the tune of 2.86 m at Sonamura-1 in pre-monsoon in Sipahijala district whereas it is found to be 1.65 m in case of post-monsoon and the same area it is observed as 1.11 m in monsoon season (Fig. 5.47 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 3.70 m in pre-monsoon whereas 2.12 m has dropped down in case of post-monsoon and in the same area it is near about 1.32 m during monsoon season (Fig. 5.47 (b). Thus, it is observed that in this area a magnitude of 1.58 m of water table rose during monsoon whereas the considerable amount of water got discharged and the net amount with a magnitude of 0.36 m of water against depth is getting discharged from the catchment area.

SIPAHIJALA DISTRICT



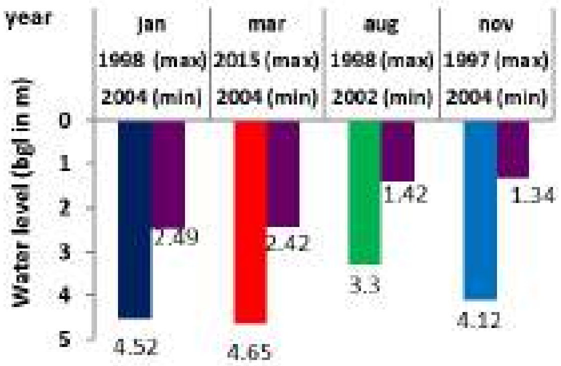
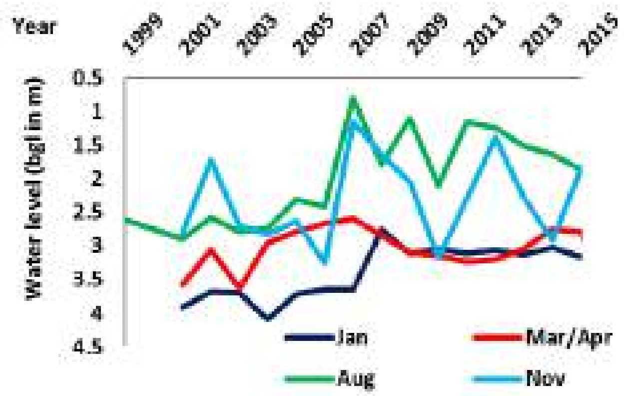


Fig. 5.41 (a). Season wise Groundwater level at Bishalgarh

Fig. 5.41 (b). Season wise Maximum and minimum ground water level at Bishalgarh



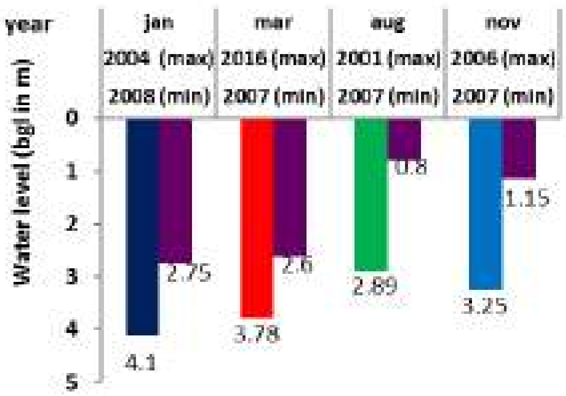
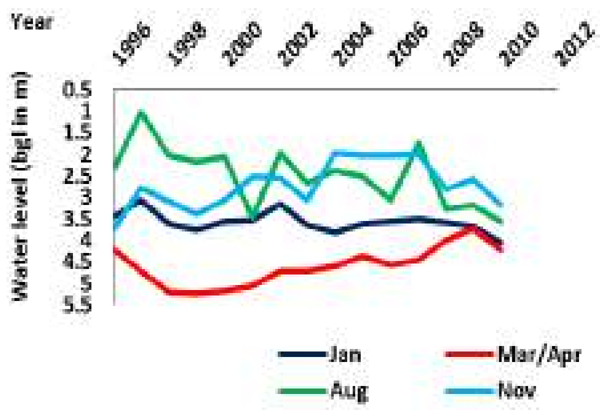


Fig. 5.42 (a). Season wise Groundwater level at Kathalia

Fig. 5.42 (b). Season wise Maximum and minimum ground water level at Kathalia



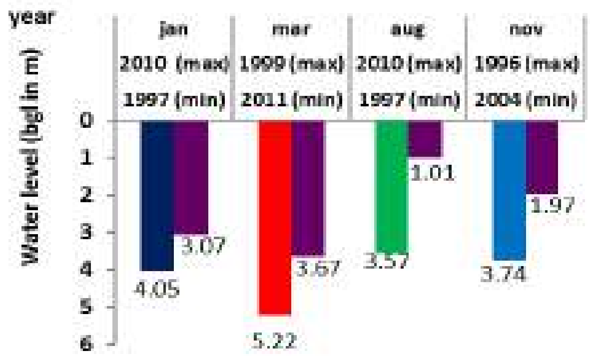
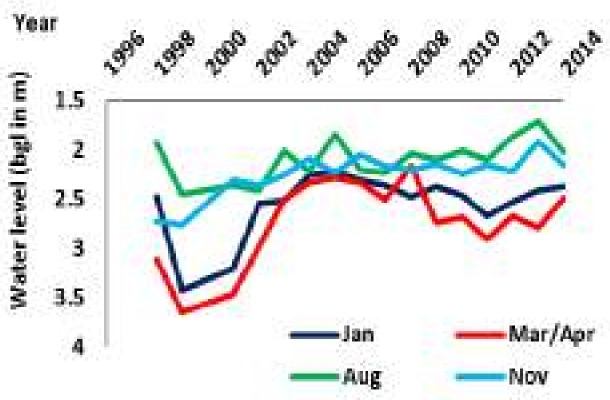


Fig. 5. 43 (a). Season wise Groundwater level at Nalchar

Fig. 5. 43 (b). Season wise Maximum and minimum ground water level at Nalchar



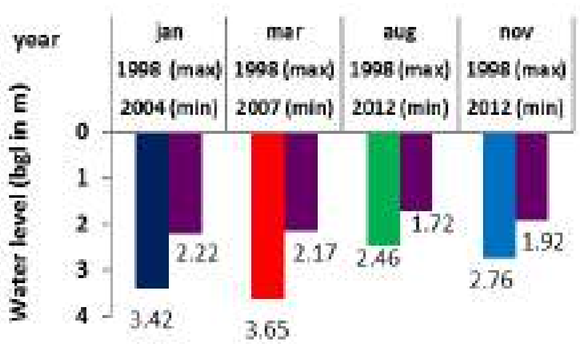
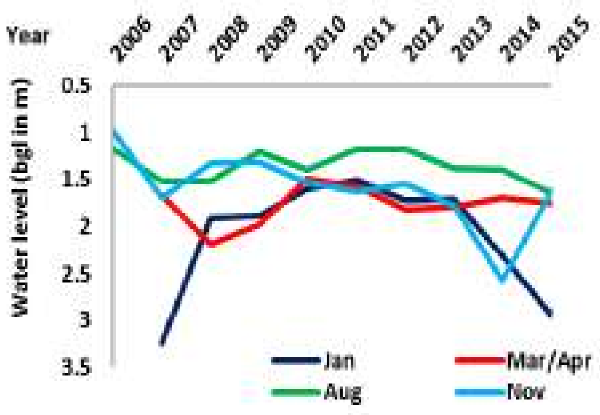


Fig. 5.44 (a). Season wise Groundwater level at Sipahijala

Fig. 5.44 (b). Season wise Maximum and minimum ground water level at Sipahijala



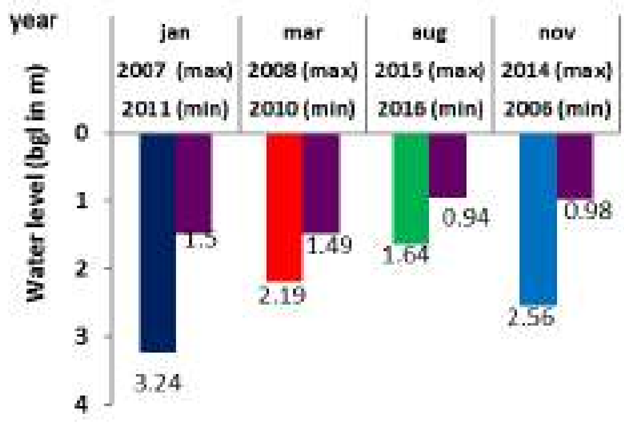
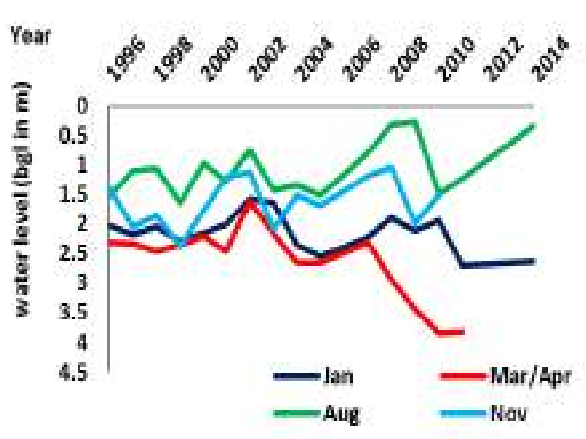


Fig. 5.45 (a). Season wise Groundwater level at Dakshin Kalamcherra

Fig. 5.45 (b). Season wise Maximum and minimum ground water level at Dakshin Kalamcherra



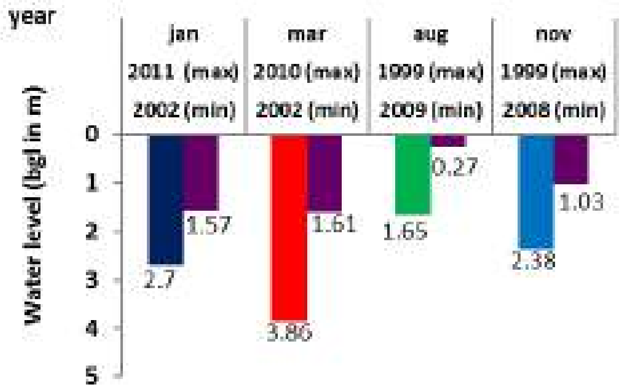
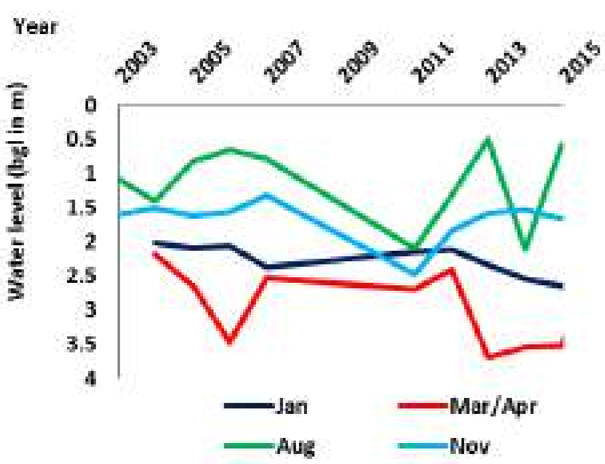


Fig. 5.46 (a). Season wise Groundwater level at Sonamura

Fig. 5.46 (b). Season wise Maximum and minimum ground water level at Sonamura



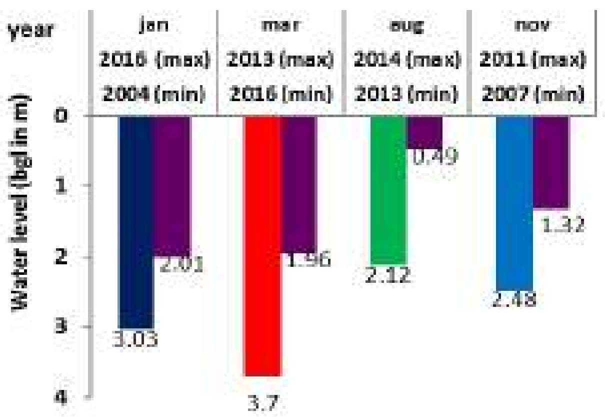


Fig. 5.47 (a). Season wise Groundwater level at Sonamura 1.

Fig. 5. 47 (b). Season wise Maximum and minimum ground water level at Sonamura 1

West Tripura District

In West Tripura, there are six towns namely Agartala, Badharghat, Champaknagar, Mohnpur, Narshingrah, and Simna located almost all in plain land. In pre-monsoon the average water table is dropped down in the tune of 8.0 m at Agartala in West Tripura district whereas it is found to be 5.7 m in case of post-monsoon and the same area it is observed as 5.6 m in monsoon season (Fig. 5.48 (a)). The average maximum drawdown of groundwater is considerably high as 10.44 m in pre-monsoon whereas about 7.53 m has dropped down in case of post-monsoon and in the same area it is near about 8.91 m during monsoon season (Fig. 5.48 (b). Normally in plain land the water table is ranged between 2 m and 3 m whereas in this zone the higher amount of water table is found ranged between 8 m and 10 m. So, it is observed that more water is extracted due to more habitations and thus results the water table is declined at a higher rate.

In pre-monsoon the average water table has dropped down in the tune of 3.20 m at Badharghat in West Tripura district whereas it is found to 1.87 m in case of post-monsoon and the same area it is observed as 1.68 m in monsoon season (Fig. 5.49 (a)). The average maximum drawdown is considerably high in the tune of 3.73 m in pre-monsoon whereas about 2.06 m has dropped down in case of post-monsoon and in the same area it is near about 1.97 m during monsoon season (Fig. 5.49 (b).

The average water table has dropped down in the tune of 3.90 m at Champaknagar in pre-monsoon in West Tripura district whereas it is found to be 2.80 m in case of post-monsoon and the same area it is observed as 2.12 m in monsoon season (Fig. 5.50 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 5.50 m in pre-monsoon whereas 3.99 m has dropped down in case of post-monsoon and in the same area it is near about 3.50 m during monsoon season (Fig. 5.50 (b).

The average water table has dropped down in the tune of 2.69 m at Mohanpur in pre-monsoon in West Tripura district whereas it is found to be 1.97 m in case of post-monsoon and the same area it is observed as 0.80 m in monsoon season (Fig. 5.51 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 4.32 m in pre-monsoon whereas 3.44 m has dropped down in case of post-monsoon and in the same area it is near about 2.56 m during monsoon season (Fig. 5.51 (b).

The average water table has dropped down in the tune of 6.10 m at Narshingarh in pre-monsoon in West Tripura district whereas it is found to be 4.16 m in case of post-monsoon and the same area it is observed as 4.07 m in monsoon season (Fig. 5.52 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 8.5 m in pre-monsoon whereas 4.6 m has dropped down in case of post-monsoon and in the same area it is near about 4.39 m during monsoon season (Fig. 5.52 (b).

The average water table has dropped down in the tune of 5.73 m at Simna in pre-monsoon in West Tripura district whereas it is found to be 4.80 m in case of post-monsoon and the same area it is observed as 4.62 m in monsoon season (Fig. 5.53 (a)). The average maximum drawdown of groundwater is considerably high in the tune of 6.10 m in pre-monsoon whereas 5.61 m has dropped down in case of post-monsoon and in the same area it is near about 4.91 m during monsoon season (Fig. 5.53 (b).

WEST TRIPURA DISTRICT

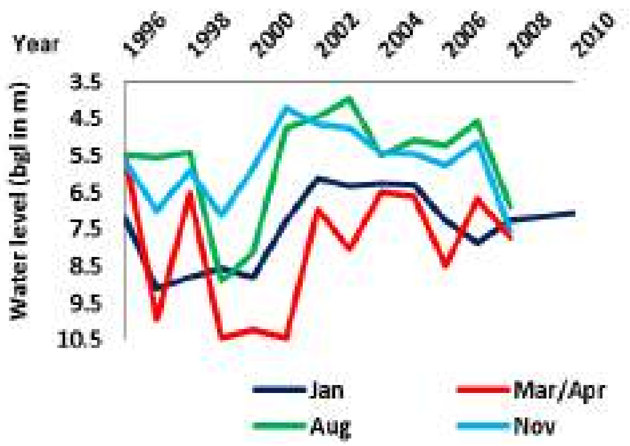


Fig. 5.48 (a). Season wise Groundwater level at Agartala

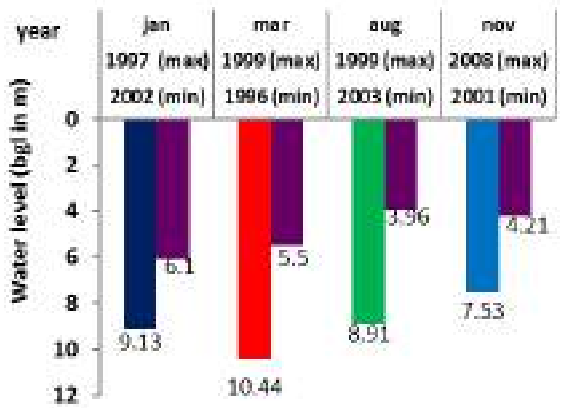


Fig. 5.48 (b). Season wise Maximum and minimum ground water level at Agartala

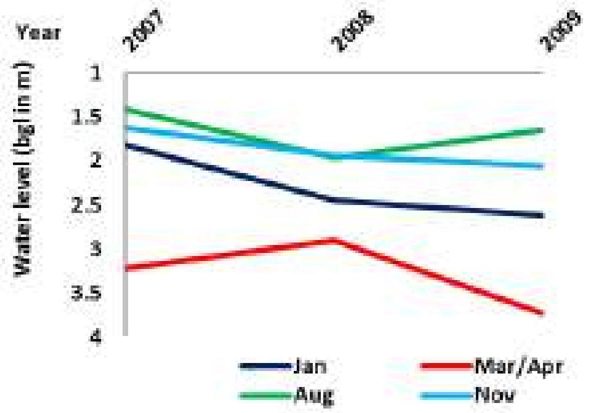


Fig. 5.49 (a). Season wise Groundwater level at Badharghat STW

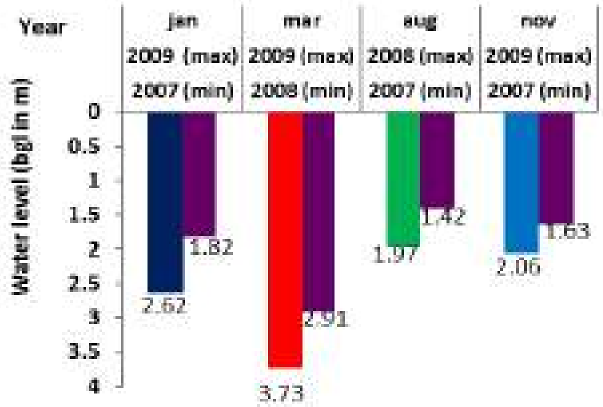


Fig. 5. 49 (b). Season wise Maximum and minimum ground water level Badharghat STW

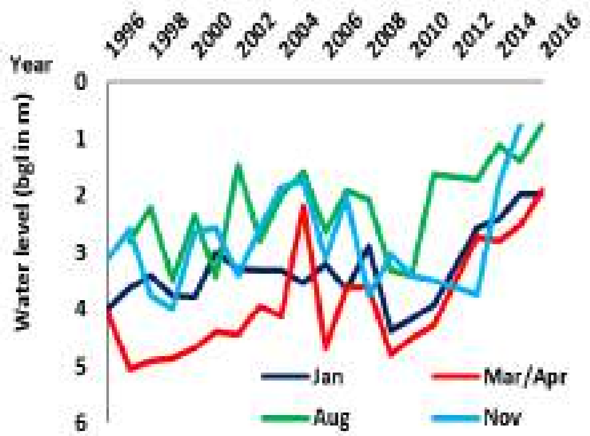


Fig. 5.50 (a). Season wise Groundwater level at Champaknagar

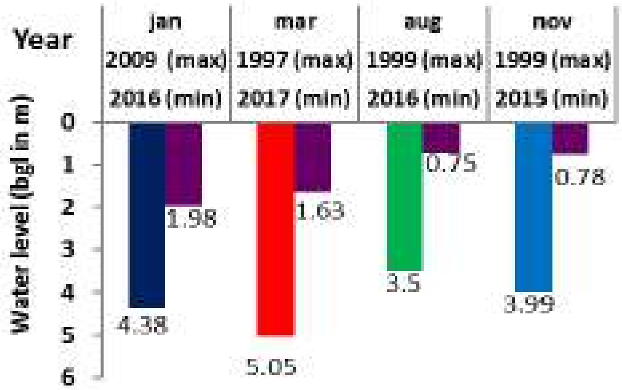


Fig. 5.50 (b). Season wise Maximum and minimum ground water level at Champaknagar

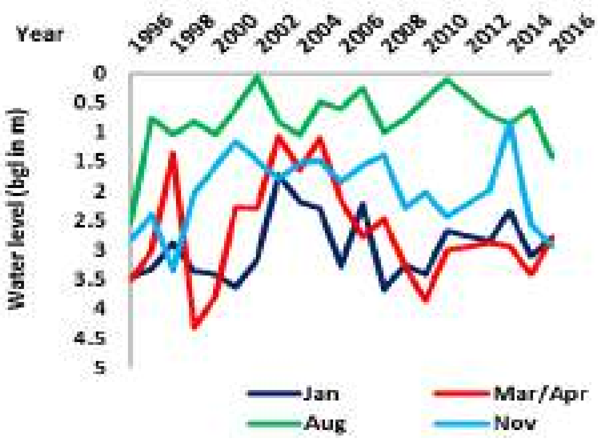


Fig. 5.51 (a). Season wise Groundwater level at Mohanpur

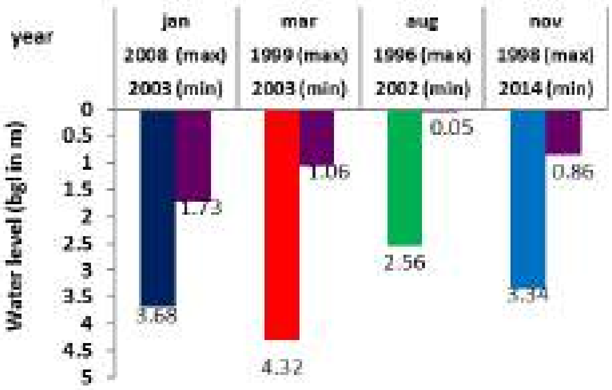
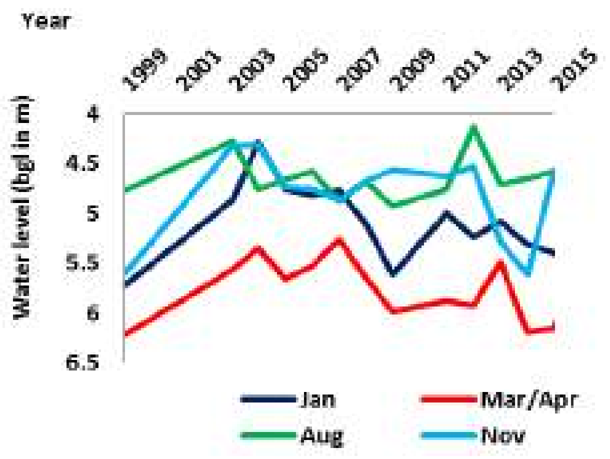


Fig. 5.51 (b). Season wise Groundwater level at Mohanpur



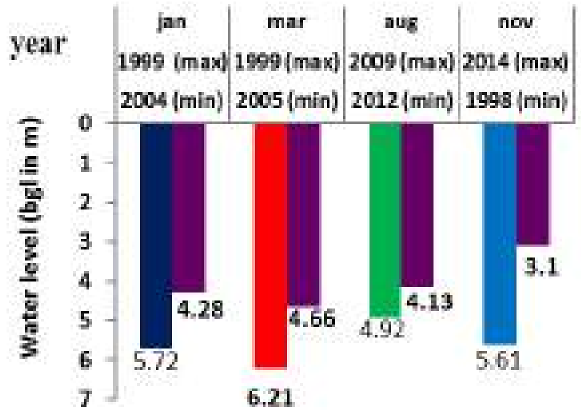
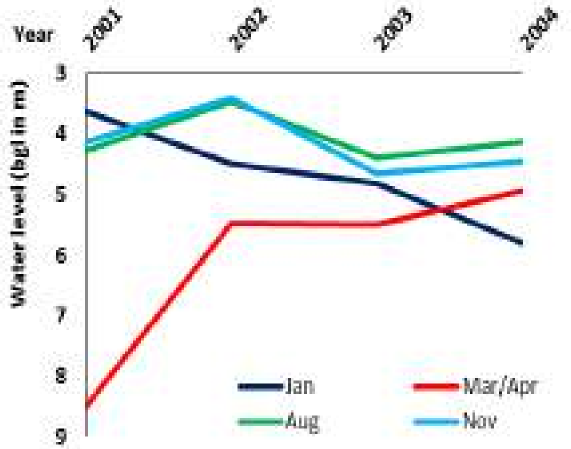


Fig. 5.52 (a). Season wise Groundwater level at Simna

Fig. 5.52 (b). Season wise Maximum and minimum ground water level at Simna



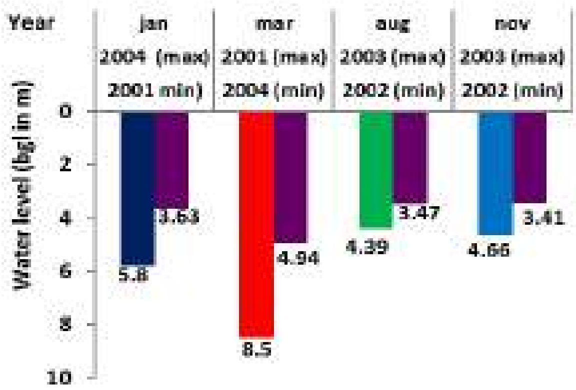


Fig. 5.53 (a).Season wise Groundwater level at Narshingrah

Fig. 5. 53 (b). Season wise Maximum and minimum ground water level at Narshingrah

5.5 Assessment of Static Groundwater in Tripura State

The position of wells and sub-surface geological sections are collected from hundred observation points based on primary and secondary data selected for the research study. A map is produced based on all primary and secondary data represented as Fig. 5.54. The maximum static water level is found to be 67.1 m below ground surface at Champari under Ambassa. The average discharge is found ranging between 11.35 m^3/hr. and 126.36 m^3/hr. for eight districts of Tripura state.

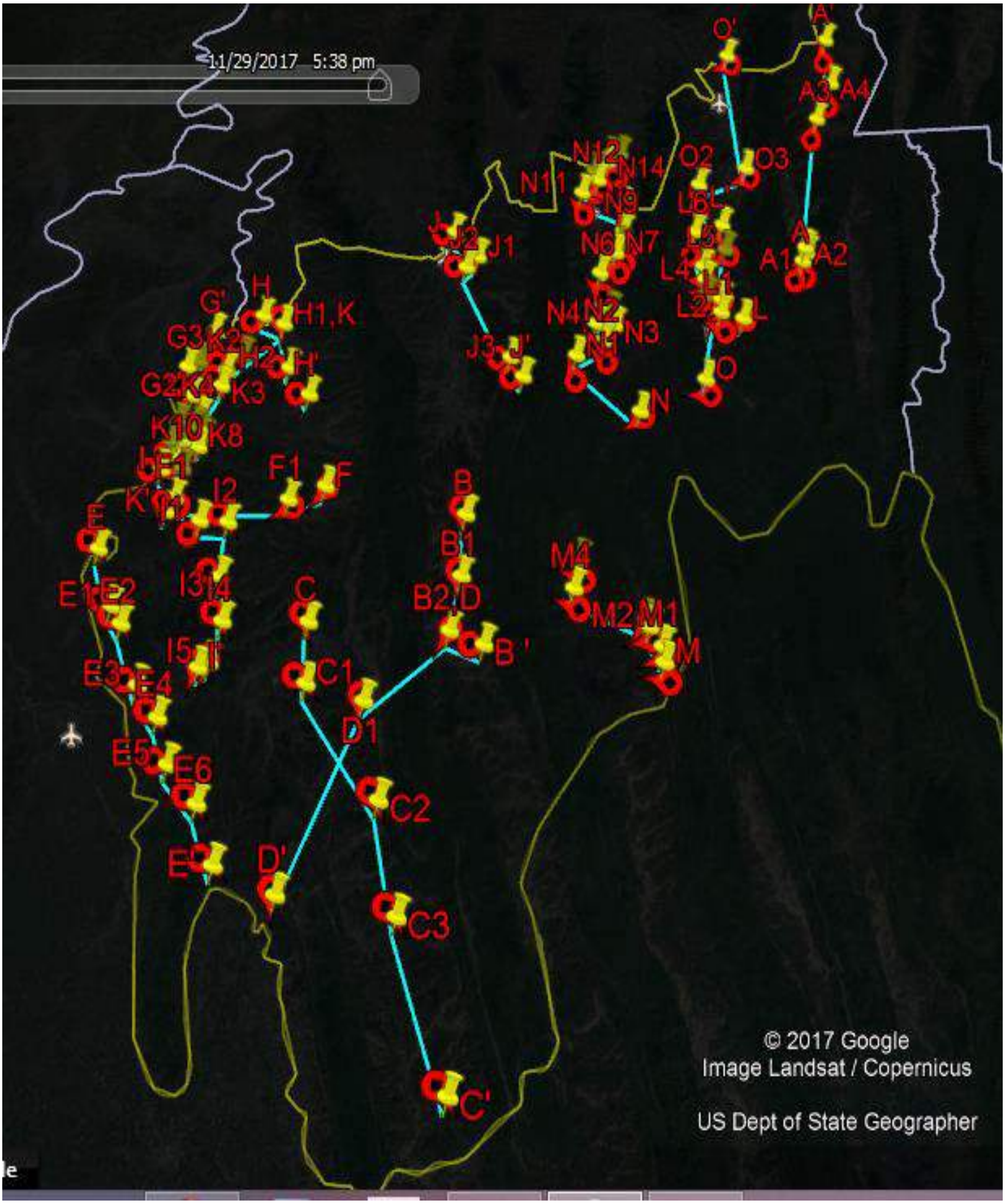


Fig .5.54. Sub -surface geology map of various section of Tripura in static condition

Table 5.4(a) Position of tubewell covering Tripura State describing GPS point with Block

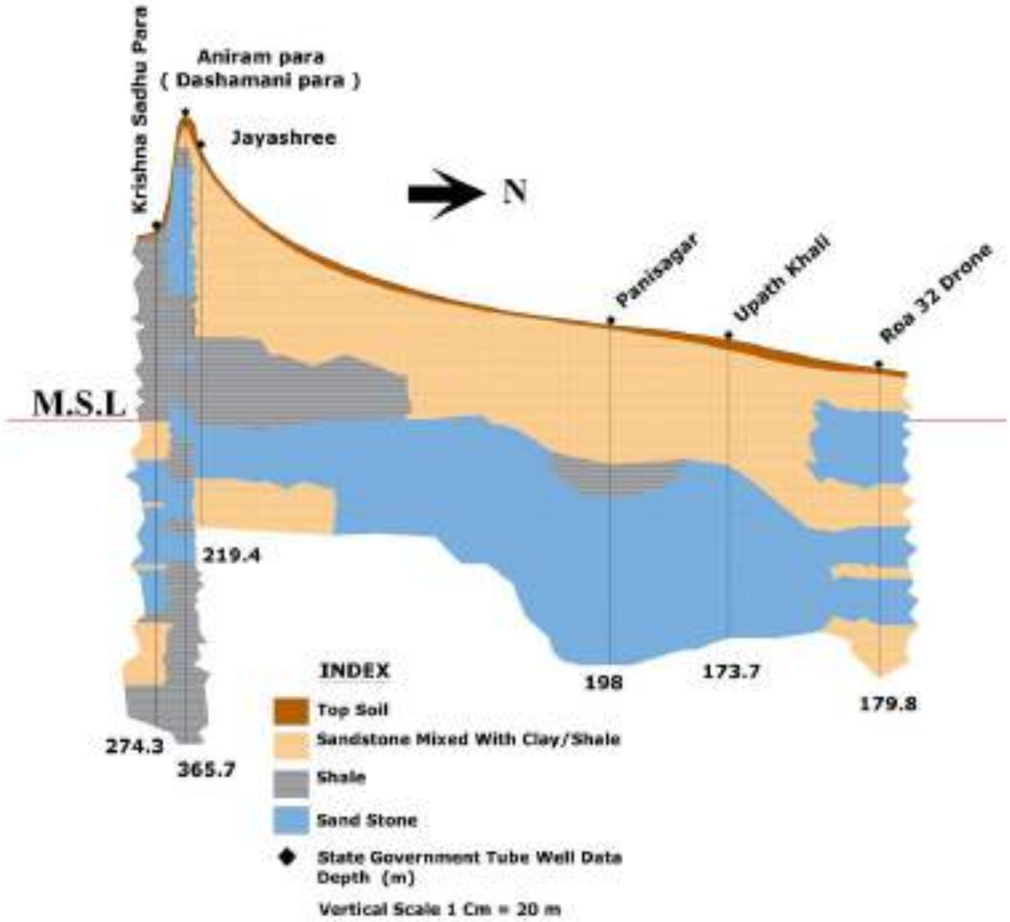
Sl	Location	Block	Place mark	Latitude	Longitude
1	Krishna Sadhu para	Dasda	**A**	N24° 1'1.18"	E 92° 7'16.07"
2	Aniram Para under dashamani para		**A1**	N24° 1'49.57"	E92° 7'40.26"
3	Jayashree		**A2**	N24° 2'18.32"	E92° 7'32.58"
4	Panisagar	panisagar	**A3**	N24°15'17.76"	E92° 9'2.84"
5	Upath khali	Dharmanagar	**A4**	N24°19'06"	E92°10'31"
6	Roa 32 drone		**A'**	N24°23'58.82"	E92°10'11.52"
1	Chhechuya ADC Village	Ompi	**B**	N 23°40'24.97"	E91°39'37.93"
2	West Sharbang ADC Village	Amarpur	**B1**	N23°35'37.57"	E91°39'41.38"
3	Thalbhanga para		**B2**	N 23°31'35.35"	E 91°39'8.61"
4	Dalak ADC Village		**B'**	N23°30'25.55"	E91°41'52.58"
1	Salghara (Ghoratilla)	Matabari	**C**	N23°32'45.86"	E 91°28'6.24"
2	Paratia (Halakhet)		**C1**	N23°28'15.82"	E91°28'32.52"
3	Bagafa	Bagafa	**C2**	N 23°19'57.41"	E91°35'1.79"
4	Nabaidya para (Garifa)	Rupaichari	**C3**	N 23°12'31.72"	E 91°37'8.42"
5	Jalefa Market	Satchand	**C'**	N23° 1'56.24"	E91°41'41.72"
1	Thalbhanga para (East Sarbang ADC Village)	Amarpur	**D**	N23°31'35.35"	E91°39'8.61"
2	Maidabari (Purba mock puskarini)	Matabari	**D1**	N23°26'49.67"	E 91°33'6.08"
3	East Sarashima (Sarkar tilla)	Hrishyamukh	**D'**	N23°14'13.5"	E91°28'20.7"
1	Rahimpur (RWS)	Baxanagar	**E**	N 23°39'10.41"	E91°10'24.36"
2	Kalam Chowra		**E1**	N23°34'41.57"	E 91°12'22.84"
3	Kamalanagar		**E2**	N23°33'19.10"	E 91°13'25.55"
4	Tamshabari W/S(Rept.)	Sonamura	**E3**	N 23°28'44.21"	E91°15'38.63"
5	Sobhapur		**E4**	N 23°26'18.74"	E91°17'39.76"
6	Nirbhoypur(M.I)	Khatalia	**E5**	N23°23'4.97"	E91°19'1.78"
7	Manai Pathar	Sonamura	**E6**	N23°20'20.58"	E91°21'39.07"
8	I C Nagar	**Rajnagar**	**E'**	N23°16'17.51"	E91°23'33.64"
1	East Jarulbachai	Jampaijala	**F**	N23°43'15.92"	E91°27'59.92"
2	Takarjala		**F1**	N23°42.336	E91°25.128
3	South Gokul Nagar	Sonamura	**F'**	N 23°42'54.98"	E91°15'46.58"
1	Charipara(BADP)	Dukli	**G**	N 23°47.68	E 091°14.566
2	Gajaria (Replacement)		**G1**	N 23.82061	E 091.24779
3	West Bhubanban	AMC	**G2**	N23°51'31.17"	E91°15'36.82"
4	Narayanpur Labour Colony(WR)	Mohanpur	**G3**	N 23°54'5.90"	E91°14'44.19"
5	P.T.C.Narsingarh.		**G4**	N 23.90843	E 91.26149
6	Dakshin Ranguti		**G'**	N 23.95311°	E 091.27547°

Table 5.4(b) Position of tubewell covering Tripura State describing GPS point with Block

S.l	Location	Block	Place mark	Latitude	Longitude
1	Mohinipur	Mohanpur	H	N23°58'24.27"	E91°20'31.20"
2	Mohanpur Hospital		H1	N 23°57'31.11"	E91°22'25.66"
3	Rajchantai (Ramchandranagar)	Mandai	H2	N23°53'32.25"	E91°23'30.06"
4	Biman Kobra Para		H'	N 23°51.081	E 91°25.529
1	Isha Ch. Nagar	Madhupur	I	N23°45'22.77"	E91°14'13.65"
2	chandra nagar	Bishalgarh	I1	N 23°41'0.20"	E91°18'10.87"
3	Bikram Nagar - II		I2	N 23°40'45.51"	E91°20'29.68"
4	Vivekananda Palli (Ramkrishna)	Bishramganj gh	I3	N 23°36'30.45"	E91°20'35.01"
5	Nalchar (South)	Melaghar	I4	N 23°33'8.51"	E91°21'20.86"
6	Chandigarh		I5	N 23°30'9.84"	E91°20'50.61"
7	Melaghar (W/S) sc		I'	N 23°29'49.62"	E91°20'3.95"
1	Singi chara near BSF camp	Khowai	J	N24'05.490"	E091'36.438"
2	East Ganki		J1	N24'02.953"	E091'38.731"
3	Ramani mohan palli Sonatala		J2	N24'02.002"	E91'37.778"
4	Malay Najak	Mungia Kami	J3	N23°53'28.12"	E91°42'16.68"
5	Taksha Para		J'	N23°51'41.48"	E91°43'27.57"
1	Mohanpur Hospital	Mohanpur	K	N23°57'31.11"	E91°22'25.66"
2	Lembucharra Agriculture.		K1	N 23.91433	E 91.32285
3	Mekliband (MI)	AMC	K2	N 23.89316	E 91.30275
4	Rubber Board Bhalukia Tilla		K3	N 23.87092	E 091.29927
5	City Centre Agartala		K4	N23.82825	E91.27785
6	A.D.Nagar police Line		K5	N 23.81344	E 91.27311
7	Matinagar	Dukli	K6	N23°47'58.00"	E91°17'4.10"
8	Dukali II(w/s)		K7	N 23°47'48.40"	E91°17'13.12"
9	Hapania Hospital Medical college		K8	N 23.78470	E 91.28251
10	Madhuban		K9	23°46'42.05"	E 91°15'20.18"
11	Khash Madhupur		K10	N 23°46.163	E 091°15.552
12	University complex (surjamaninagar)		K11	N 23°45'19.61"	E91°15'57.77"
13	Harishnagar Tea estate.	Bishalgarh	K'	N23°42'54.98"	E91°15'46.58"
1	Lalchara	Chowmanu	L	N23.9323	E92.03361
2	Chailengta - II (ST)		L1	N23.9438	E92.00219
3	Khetuicherra		L2	N23°57'47.96"	E92° 0'7.81"
4	Karathicherra		L3	N23°58'16.23"	E 91°58'47.49"
5	Jamir cherra		L4	N23°59'45.01"	E91°58'43.78"
6	Marakpara(W/S)	Manu	L5	N24° 1'0.06"	E91°58'33.04"
7	Nepaltila- II	Chowmanu	L6	N24.07319	E91.96424
8	82 Mile	Manu	L'	N24.0812	E92.00355

Table 5.4(c) Position of tubewell covering Tripura State describing GPS point with Block

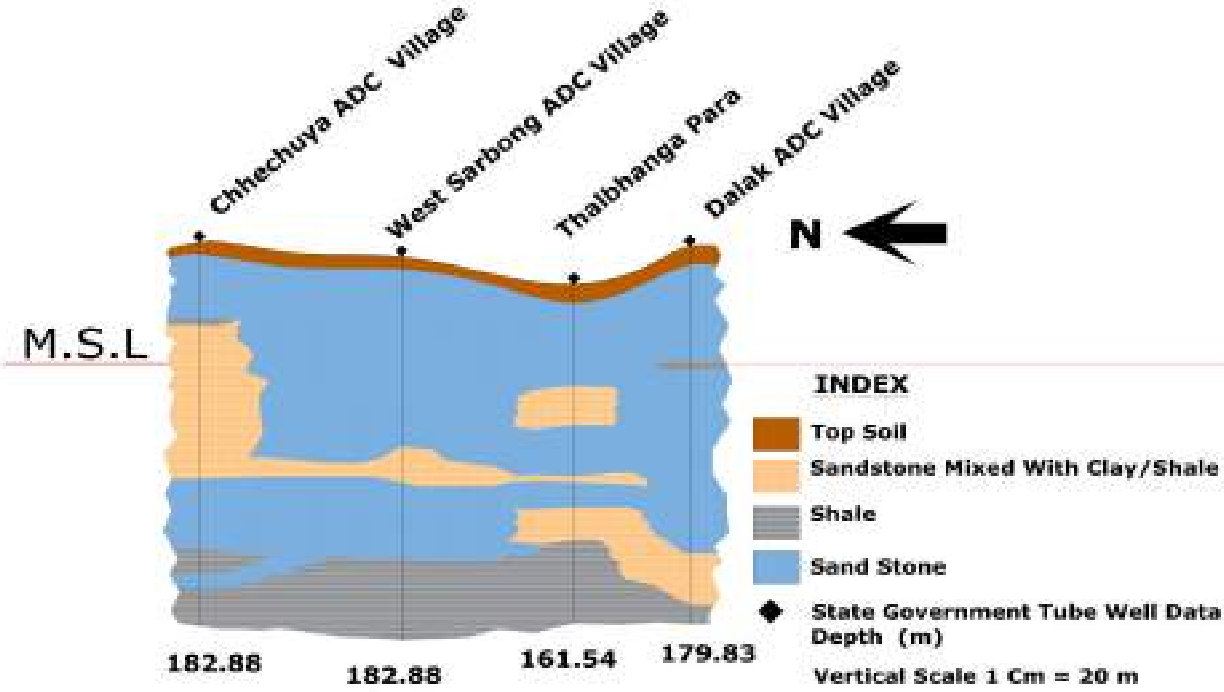
S.l	**Location**	**Block**	**Place mark**	**Latitude**	**Longitude**
1	Tuichakma	Dumburnagar	**M**	N23°28'29.62"	E91°55'44.29"
2	Raima Cherra		**M1**	N23°29'39.59"	E 91°55'34.30"
3	Boul Khali		**M2**	N23°31'8.22"	E91°54'33.24"
4	Madanjoy Para, Raima V.C.		**M3**	N23°31'39.49"	E91°54'17.29"
5	Ram Nagar		**M4**	N23°34'16.80"	E91°48'35.66"
6	Gandacherra		**M'**	N23°36'26.90"	E91°48'52.94"
1	Champarai Para	Ambassa	**N**	N23.80267	E91.88996
2	Hadukalak Para (Kulai RF Extn.)		**N1**	N23.88883	E91.79763
3	Kamalacherra- II		**N2**	N23.91006	E91.83533
4	Ramratan Para		**N3**	N23°55'52.65"	E91°50'59.69"
5	Gantachara		**N4**	N23.93556	E91.82289
6	Harinmara		**N5**	N23.95475	E91.84291
7	Maharani	Salema	**N6**	N24° 0'49.02"	E 91°49'33.96"
8	Mechurai Para		**N7**	N 24.04474	E 91.84786
9	Jamthum		**N8**	N 24.05619	E 091.85375
10	Chankap		**N9**	N 24.07854	E 91.85753
11	Purba Tilla, Mahabir G.P, Kamalpur, Dhalai	Durga Chowmuhani	**N10**	N 24.11309	E 91.86094
12	Srirampur		**N11**	N24.14641	E91.79326
13	Kalachari		**N12**	N 24.16646	E91.81682
14	Mayachari		**N13**	N 24.18255	E91.81007
15	Kamalpur		**N14**	N 24°11'54.09"	E91°49'51.33"
16	Ganga Nagar		**N15**	N 24.20893	E91.83188
17	mohonpur		**N'**	N 24.21014	E91.84882
1	Chowmanu	Chowmanu	**O**	N23°50'38.45"	E91°58'49.55"
2	West Karamchara		**O1**	N24°02‘30‘	E92°00‘30‘
3	Unakoti (Paschim Ratachara)	Pecharthal	**O2**	N24° 9'1.38"	E91°58'8.32"
4	Unakoti (kukidhar)		**O3**	N24.174444	E92.03944
5	Khawrabil	Kailashahar	**O'**	N24°22'41.36"	E92° 0'44.81"



Sl. No	Place mark	Location	Block	Depth of bore hole (m- bgl)	Depth of pipe lowering (m-bgl)	Filter layer depth (m-bgl)	Thickness of Strainer (m)	Discharge (m3/h)	static water level (m)
1	**A**	Krishna Sadhu para	Dasda	274.32	241.46	175.93-194.2 218.69-237	36.6	56.82	18.3
2	**A1**	Aniram Para under dashamani para		365.76	263	213.30-230.14 243.78-259	36.69	11.35	27.4
3	**A2**	Jayashree		219.45	210.63	164.77-201.11	36.63	45.46	12.2
4	**A3**	Panisagar	panisagar	198	175	83-89 100-137 143-149 162-168	55	66	23
5	**A4**	Upath khali	Dharmanagar	173.73	155.4	115.53-151.9	36.59	45.46	3
6	**A'**	Roa 32 drone		178.88	147.28	42.24-54.24 60.77-66.74, 100.87-112.87 138.18-144.45	36	45.46	3.5

Fig. 5.55 (a). Panel Diagram of Sub-Surface Geology from KrishnaSadhu Para (Dasda) to Roa 32 Drone (Dharmanagar), (ref. Section A-A')

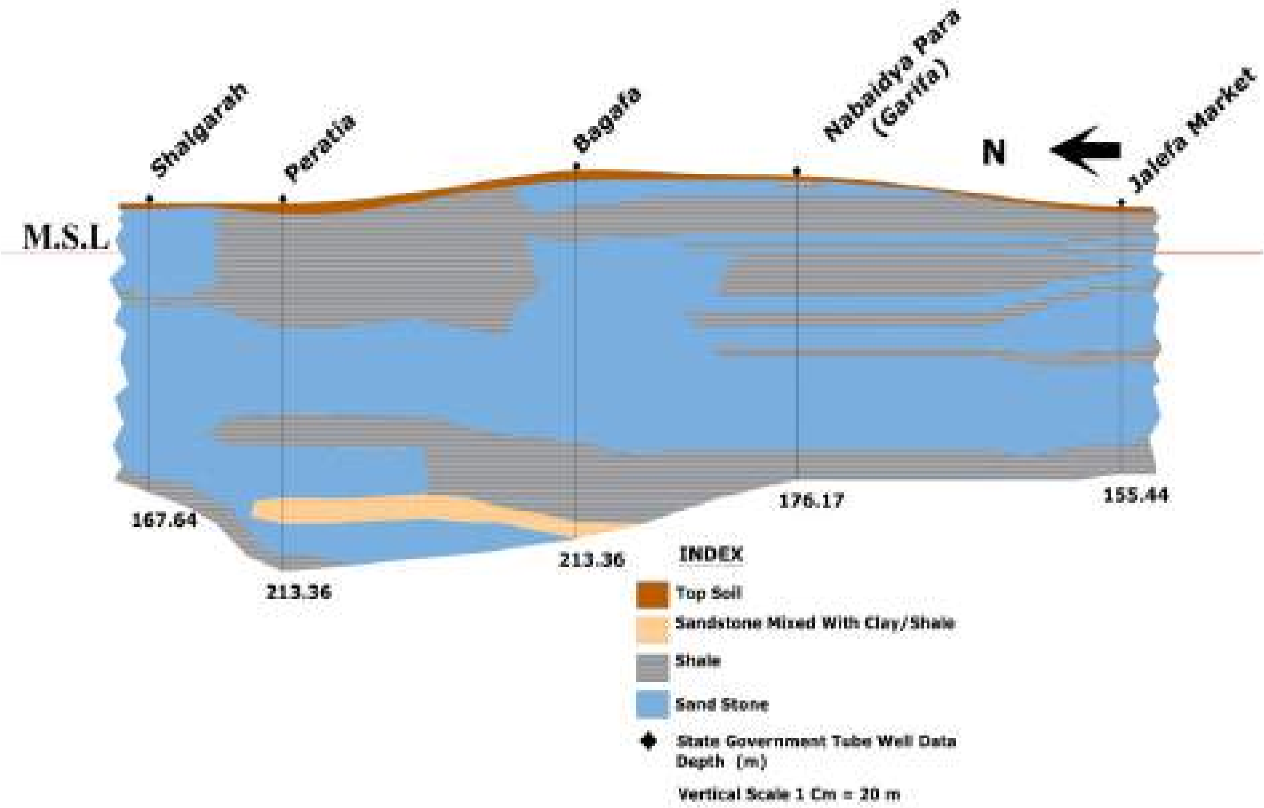
Values of static water level decrease in the hilly and valley areas to 27.4 m, 23.0 m, 18.3 m, 12.2 m, 3.5 m and 3.0 m for Anirampara, Panisagar, Krishnasadhupara, Joyasree, Roa 32 and Upathkhali respectively depicted in Fig. 5.55 (a) and the direction of flow is from south to north. The thickness of filter layer is found to be ranged between 36 m and 55 m as highlighted in the figure. The depth of pipe lowering is observed in the study area varied from 147 m to 263 m.



Sl. No	Place mark	Location	Block	Depth of bore hole (m-bgl)	Depth of pipe lowering (m-bgl)	Filter layer depth (m-bgl)	Thickness of Strainer (m)	Discharge (m3/h)	static water level (m)
1	B	Chhechuya ADC Village	Ompi	182.88	167.64	115.82-46.30 158.49-64.59	36.58	70.23	3.05
2	B1	West Sharbang ADC Village	Amarpur	182.88	146.3	67.05-79.24 118.87-43.25	36.57	46.46	4.57
3	B2	Thalbhanga para		161.54	109.72	67.05-91.44 94.48-106.68	36.59	45.46	3.66
4	B'	Dalak ADC Village		179.83	149.35	109.76-46.30	36.54	45.46	7.62

Fig .5.55.(b) Sub-Surface Geology Panel Diagram of Chhechuya ADC Village **(Ompi) to** Dalak ADC Village **(Amarpur), (Ref Section B-B')**

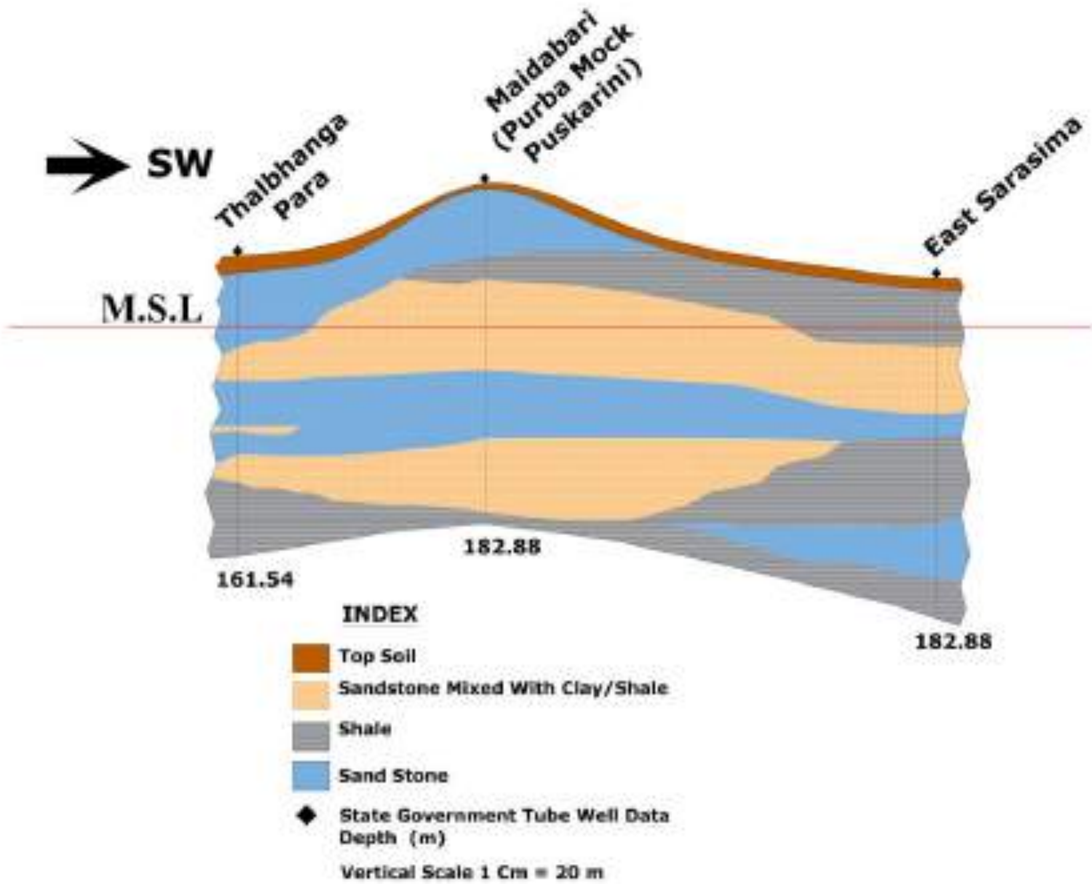
Values of static water level decrease in the hilly and valley areas to 7.62 m, 4.57 m, 3.66 m, and 3.05 m for Dalak, West Sarbang, Thalbhanga and Chhechuya respectively depicted in Fig. 5.55 (b) and the direction of flow is from Central to South. The average thickness of filter layer is found as 37 m as highlighted in the figure. The depth of pipe lowering is observed in the study area varied from 109 m to 167 m.



Sl. No	Place mark	Location	Block	Depth of bore hole (m- bgl)	Depth of pipe lowering (m-bgl)	Filter layer depth (m-bgl)	Thickness of Strainer (m)	Discharge (m3/h)	static water level (m)
1	**C**	Salghara (Ghoratilla)	Matabari	167.6	161.54	88.39-106.68 140.20-158.49	36.58	89.55	3.6
2	**C1**	Paratia (Halakhet)		213.4	173.73	103.63-134.11 152.40-170.68	36.57	45.46	3.3
3	**C2**	Bagafa	Bagafa	213.4	202.07	163.63-199.52	35.89	68.19	Artesian flow
4	**C3**	Nabaidya para (Garifa)	Rupaichari	176.2	153.49	114.78-151.49	36.71	68.19	12.1
5	**C'**	Jalefa Market	Satchand	155.5	144.93	105.05-141.83	36.78	68.65	5.4

Fig .5.55.(c) Sub-Surface Geology Panel Diagram of Salghara (Ghoratilla) **(Matabari) to** Jalefa Market **(Satchand), (Ref Section C-C')**

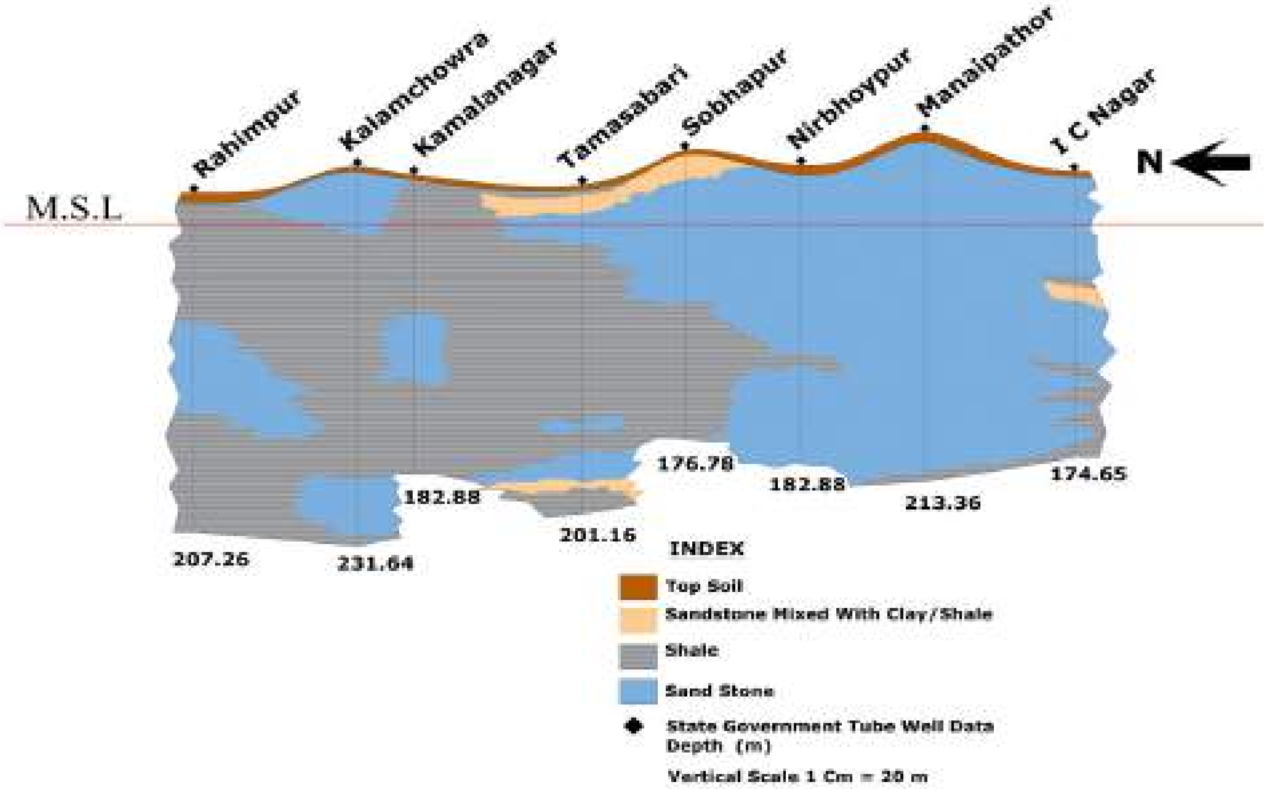
Values of static water level decrease in the hilly and valley areas to 12.2 m, 5.49 m, 3.66 m and 3.35 for Jelefa, Nabaidyapara, Salgara and Perapia respectively depicted in Fig. 5.55 (c) and the direction of flow is from north to south. The average thickness of filter layer is found as 37 m as highlighted in the figure. The depth of pipe lowering is observed in the study area varied from 144 m to 202 m. There is one overflow zone which indicates the high water pressure and the sand bed thickness is found to be more.



Sl. No	Place mark	Location	Block	Depth of bore hole (m-bgl)	Depth of pipe lowering (m-bgl)	Filter layer depth (m-bgl)	Thickness of Strainer (m)	Discharge (m3/h)	static water level (m)
1	**D**	Thalbhanga para (East Sarbang ADC Village)	Amarpur	161.54	109.72	67.05-91.44 94.49-06.68	36.57	45.59	3.66
2	**D1**	Maidabari (Purba mock puskarini)	Matabari	182.88	140.2	100.58-137.1	36.58	45.46	Artisian flow
3	**D'**	East Sarashima (Sarkar tilla)	Hrishyamukh	182.88	161.54	73.15-82.29 131.06-158.4	36.57	50.01	4.42

Fig .5.55 (d) Sub-Surface Geology Panel Diagram of Thalbhanga para (East Sarbang ADC Village) **(**Amarpur**) to** East Sarashima (Sarkar tilla) **(**Hrishyamukh**), (Ref Section D-D').**

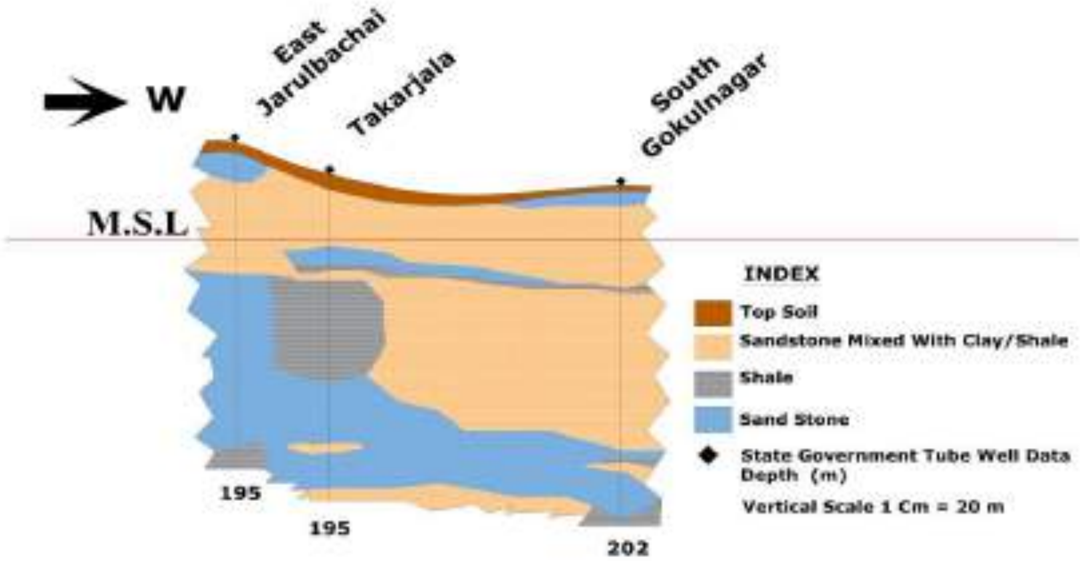
Values of static water level decrease in the hilly and valley areas to 4.42 m and 3.66 m for East Sarashina and Thalbhangapara respectively depicted in Fig. 5.55 (d) and the direction of flow is from north to south-west. The average thickness of filter layer is found as 37 m as highlighted in the figure. The depth of pipe lowering is observed in the study area varied from 109 m to 161 m. There is one overflow zone which indicates the high water pressure zone and the sand bed thickness is found to be more.



Sl. No	Place mark	Location	Block	Depth of bore hole (m-bgl)	Depth of pipe lowering (m-bgl)	Filter layer depth (m-bgl)	Thickness of Strainer (m)	Discharge (m3/h)	static water level (m)
1	**E**	Rahimpur (RWS)	Baxanagar	207.3	131.97	86.20-128.87	42.67	68.64	9.14
2	**E1**	Kalam Chowra		231.6	219.45	36.57-42.67 192.02-216.40	29.50	68.64	4.57
3	**E2**	Kamalanagar		182.9	126.23	81.24-117.03	33.52	68.64	4.57
4	**E3**	Tamshabari W/S(Rept.)	Sonamura	201.2	186.00	30.48-36.57 167.64-182.88	21.33	51.23	5.79
5	**E4**	Sobhapur		176.8	92.25	53.22-83.05	29.82	68.65	8.08
6	**E5**	Nirbhoypur(M.I)	Khatalia	182.9	176.78	137.16-173.73	36.52	34.10	7.62
7	**E6**	Manai Pathar	Sonamura	213.4	203.36	157.23-193.96	36.73	29.55	9.14
8	**E'**	I C Nagar	(Rajnagar)	174.7	165.50	95.51-105.94 115.09-121.26 131.90-141.10 145.63-156.30	36.49	45.46	4.57

Fig. 5.55.(e). Sub-Surface Geology Panel Diagram of Rahimpur (RWS) **(**Baxanagar**) to** I C Nagar (Rajnagar)**,(Ref Section E-E')**

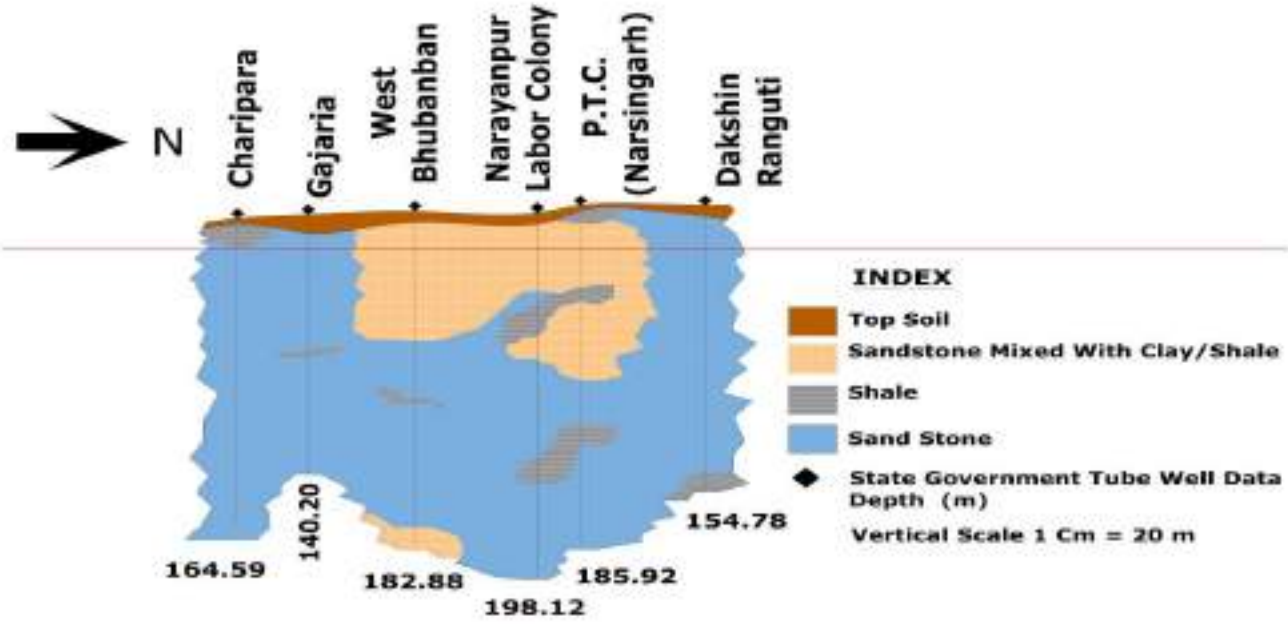
Values of static water level decrease in the hilly and valley areas to 9.14, 8.08 m, 7.62 m, 5.79 m and 4.57 for Rahimpur/Monaipathar, Sovapur, Nirbhoypur, Tamasabari and Kalamchowra/Kamalanagar/Icenagar respectively depicted in Fig. 5.55 (e) and the direction of flow is from north to south. The thickness of filter layer is found to be ranged between 21 m and 43 m as highlighted in the figure. The depth of pipe lowering is observed in the study area varied from 131 m to 220 m.



Sl. No	Place mark	Location	Block	Depth of bore hole (m-bgl)	Depth of pipe lowering (m-bgl)	Filter layer depth (m-bgl)	Thickness of Strainer (m)	Discharge (m3/h)	static water level (m)
1	**F**	East Jarulbachai	Jampaijala	195	186.83	147.05-183.78	36.73	54.09	1.52
2	**F1**	Takarjala		195	185.81	133.99-155.33 167.52-182.76	38.85	46.59	artesian flow
3	**F'**	South Gokul Nagar	Sonamura	202	199.79	172.1-196.59	24.42	68.19	artesian flow

Fig .5.55.(f) Sub-Surface Geology Panel Diagram of East Jarulbachai **(**Jampaijala**) to** South Gokul Nagar **(**Sonamura**), (Ref Section F-F')**

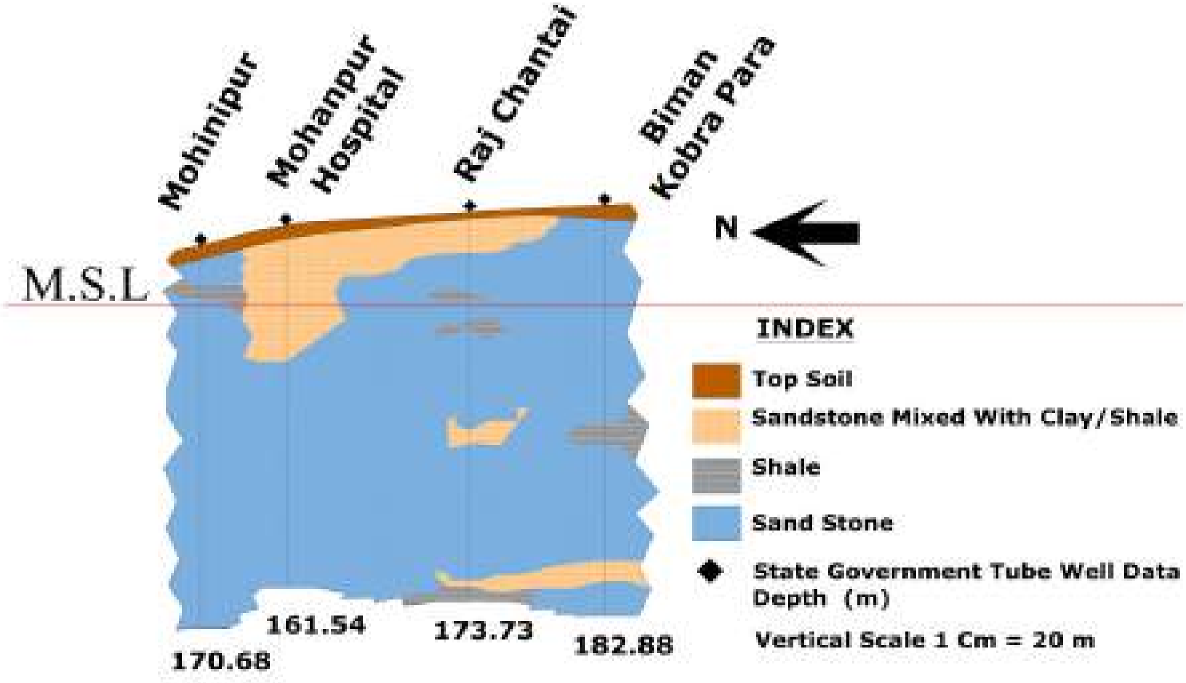
Values of static water level decrease in the hilly and valley areas to 1.52 m to zero for East Jarulbachai depicted in Fig. 5.55 (f) and the direction of flow is from east to west. The thickness of filter layer is found to as 37 m as highlighted in the figure. The depth of pipe lowering is observed as 195 m in the study area. Two overflow zones are found resulted high pressure zone observed even there is no sand bed thickness. The sub-surface geology of this area is getting sandy-clay with shale up to the depth of 202 m of pipe lowering.



Sl. No	Place mark	Location	Block	Depth of bore hole (m-bgl)	Depth of pipe lowering (m-bgl)	Filter layer depth (m-bgl)	Thickness of Strainer (m)	Discharge (m3/h)	static water level (m)
1	**G**	Charipara	Dukli	164.59	158.22	122.35-158.7	36.35	80.92	5.48
2	**G1**	Gajaria		140.24	125.08	86.47-122.01	35.54	68.19	4.57
3	**G2**	West Bhubanban	AMC	182.88	172.27	133.36-169.19	35.83	80.92	6.71
4	**G3**	Narayanpur Labour Colony	Mohanpur	198.25	191.45	149.30-187.95	38.65	77.74	9.14
5	**G4**	P.T.C.Narsingarh.		185.92	181.17	141.58-178.67	37.09	90.92	7.32
6	**G'**	Dakshin Ranguti		154.78	146.39	107.39-143.35	35.96	89.55	7.62

Fig .5.55.(g) Sub-Surface Geology Panel Diagram of Charipara **(**Dukli**) to** Dakshin Ranguti **(**Mohanpur**), (Ref Section G-G').**

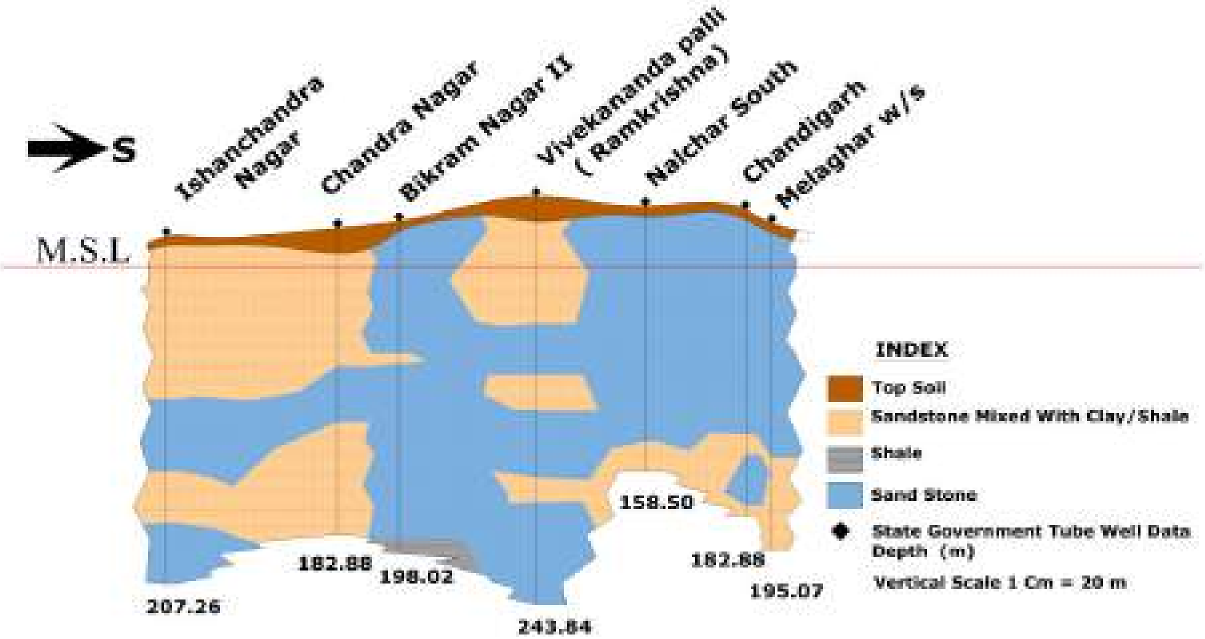
Values of static water level decrease in the hilly and valley areas to 9.14, 7.62 m, 7.32 m, 6.71 m, 5.48 m, and 4.57 for Narayanpur, Dakhin Ranguti, PTC Narsingarh, West Bhubanban, Charipara and Gajaria respectively depicted in Fig. 5.55 (g) and the direction of flow is from north to south. The average thickness of filter layer is found as 37 m as highlighted in the figure. The depth of pipe lowering is observed in the study area varied from 125 m to 192 m.



Sl. No	Place mark	Location	Block	Depth of bore hole (m- bgl)	Depth of pipe lowering (m-bgl)	Filter layer depth (m-bgl)	Thickness of Strainer (m)	Discharge (m3/h)	static water level (m)
1	**H**	Mohinipur	Mohanpur	170.68	163.8	124.21-160.73	36.52	59.55	9.14
2	**H1**	Mohanpur Hospital		161.54	154.92	115.26-151.88	36.62	59.55	12.2
3	**H2**	Rajchantai	Mandai	170.74	164.89	124.31-160.79	36.48	68.55	4.57
4	**H'**	Biman Kobra Para		182.88	158.11	119.48-156.01	36.53	68.19	7.92

Fig .5.55.(h). Sub-Surface Geology Panel Diagram of Mohinipur **(**Mohanpur) **to** Biman Kobra Para **(**Mandai**), (Ref Section H-H')**

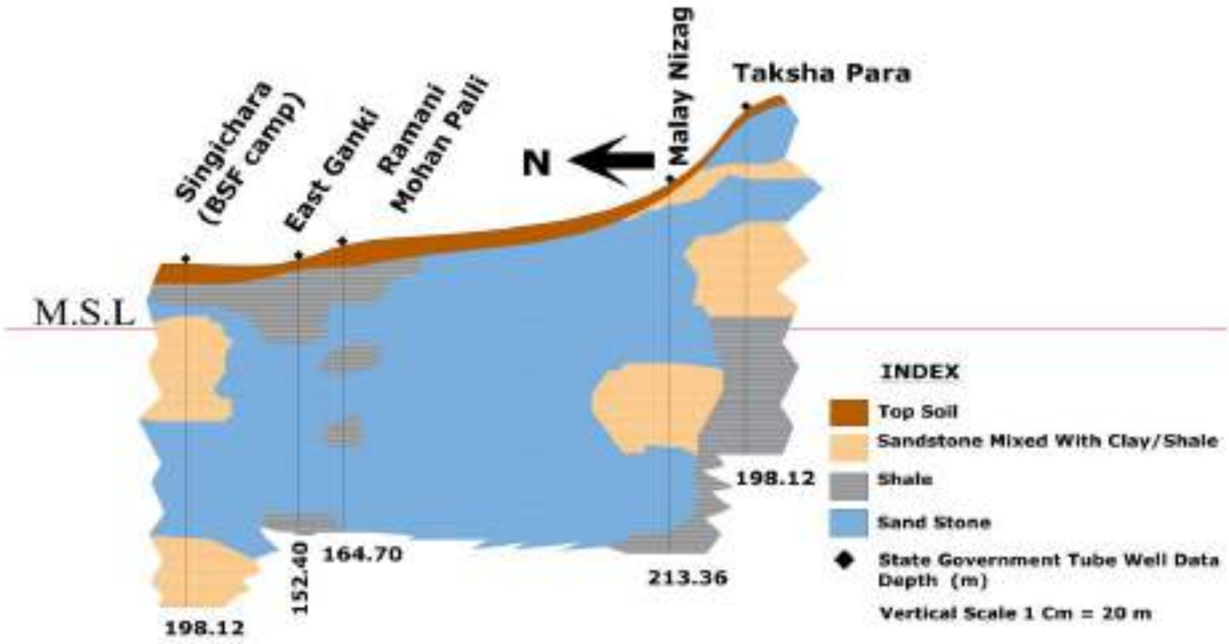
Values of static water level decrease in the valley areas to 12.2 m, 9.14 m, 7.92 m and 4.57 m for Mohanpur, Mohinipur, Bimancobrapara and Rajchantai respectively depicted in Fig. 5.55 (h) and the direction of flow is from north to south. The average thickness of filter layer is found as 37 m as highlighted in the figure. The average depth of pipe lowering is observed as 160 m n the study area.



Sl. No	Place mark	Location	Block	Depth of bore hole (m-bgl)	Depth of pipe lowering (m-bgl)	Filter layer depth (m-bgl)	Thickness of Strainer (m)	Discharge (m3/h)	static water level (m)
1	**I**	Isha Ch. Nagar	Madhupur	207.26	147.82	101.74-138.52	36.78	80.92	2.44
2	**I1**	chandra nagar	Bishalgarh	182.88	156.82	111.20-150.22	38.99	90.90	4.57
3	**I2**	Bikram Nagar - II		198.02	176.78	134.48-171.18	36.7	54.48	4.1
4	**I3**	Vivekananda Palli (Ramkrishna)	Bisramganj	243.84	167.64	124.01-159.44	35.43	80.90	6.09
5	**I4**	Nalchar ,South	Melaghar	158.49	143.40	104.83-140.35	35.52	36.30	1.52
6	**I5**	Chandigarh		182.88	174.20	73.02-94.84	36.98	24.50	8.53
						101.04-106.94			
						161.90-171.16			
7	**I'**	Melaghar (W/S)		195.07	147.14	106.68-143.25	36.57	46.50	5.9

Fig .5.55.(i) Sub-Surface Geology Panel Diagram of Isha Ch. Nagar **(**Madhupur**) to** Melaghar (W/S) **(**Melaghar**), (Ref Section I-I')**

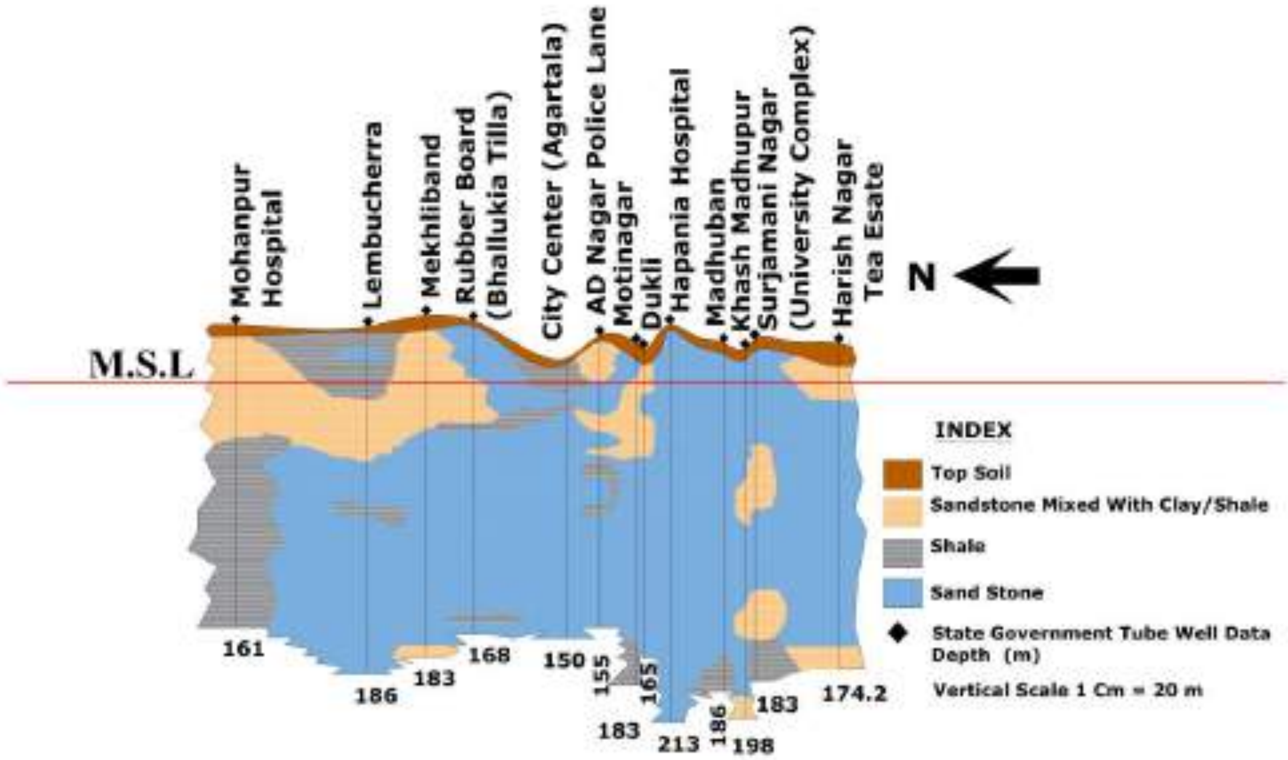
Values of static water level decrease in the valley areas to 8.53 m, 6.09 m, 5.90 m, 4.57 m, 4.10 m, 2.44 m and 1.52 m for Chandigarh, Vivekananda Polly, Melaghar, Chandranagar, Bikramnagar, Ishanchandranagar and Nalchar respectively depicted in Fig. 5.55 (i) and the direction of flow is from south to north. The thickness of filter layer is found ranging between 43 m and 35 m as highlighted in the figure. The depth of pipe lowering is observed in the study area varied from 143 m to 177 m.



Sl. No	Place mark	Location	Block	Depth of bore hole (m- bgl)	Depth of pipe lowering (m-bgl)	Filter layer depth (m-bgl)	Thickness of Strainer (m)	Discharge (m3/h)	static water level (m)
1	**J**	Singi chara (BSF camp)	Khowai	198.12	157.96	121-157.96	36.96	113.65	Artesian flow
2	**J1**	East Ganki		152.4	146.42	106.72-143.2	36.5	109.86	5.49
3	**J2**	Ramani mohan palli		164.7	155.55	115.3-152.5	37.14	126.36	3
4	**J3**	Malay Najak	Mungia Kami	213.36	201.31	162.49-198.2	35.77	45.46	4.57
5	**J'**	Taksha Para		198.12	133.64	84.8-115.3	36.46	46.59	1.52

Fig .5.55.(j) Sub-Surface Geology Panel Diagram of Singi chara (BSF camp) **(**Khowai**) to** Taksha Para **(**Mungia Kami**), (Ref Section J-J')**

Values of static water level decrease in the hilly and plain areas to 5.49 m, 4.57 m, 3.0 and 1.52 m for East Ganki, Malaynajak, Romonimohan and Taksapara respectively depicted in Fig. 5.55 (j) and the direction of flow is from north to south. The average thickness of filter layer is found to as 36 m as highlighted in the figure. The depth of pipe lowering is observed ranging between 133 m and 201 m in the study area. One overflow zone is found resulted high pressure zone as well as high discharge as observed in the area.

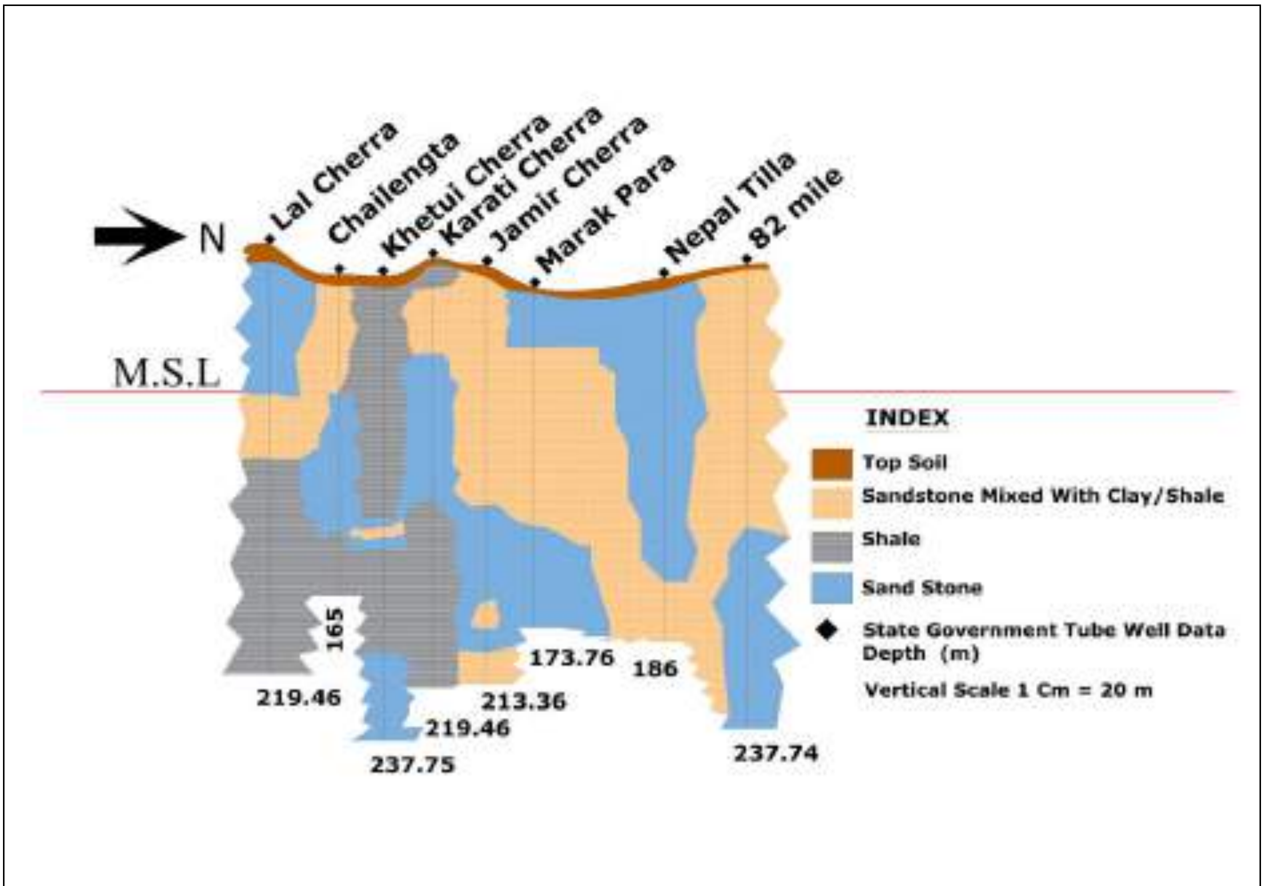


Sl . No	Plac e mark	Location	Block	Depth of bore hole (m-bgl)	Depth of pipe lowering (m-bgl)	Filter layer depth (m-bgl)	Thicknes s of Strainer (m)	Discharg e (m3/h)	static water level (m)
1	**K**	Mohanpur Hospital	Mohanpur Block	161.6	154.92	115.2-151.8	36.62	59.55	12.19
2	**K1**	Lembucharra Agriculture.		186.0	108.35	68.3-105.3	36.95	55.69	18.28
3	**K2**	Mekliband (MI)	AMC	182.9	176.6	136.4-172.9	36.45	61.37	3.048
4	**K3**	Rubber Board Bhalukia Tilla		176.8	170.5	129.6-166.1	36.46	30.00	9.14
5	**K4**	City Centre Paradise Chowmohoni Agartala		154.0	148.32	108.8-145.3	36.45	120.47	1.52
6	**K5**	A.D.Nagar police Line	Dukli Block	155.5	148	107.9-144.4	36.42	45.40	9.14

7	**K6**	Matinagar		182.88	151.21	111.7-148.1	36.46	45.40	7.62
8	**K7**	Dukali II(w/s)		164.59	159.51	119.7-156.4	36.68	68.19	7.92
9	**K8**	Hapania Hospital Medical college		213.36	204.14	158.4-201.0	42.65	90.92	6.096
10	**K9**	Madhuban		182.88	168.95	128.6-165.8	37.23	34.10	18.288
11	**K10**	Khash Madhupur		198.12	138	100.1-134.5	34.40	68.19	4.572
12	**K11**	University complex (surjamaninagar)		182.88	139.1	94.9-135.45	40.55	94.79	16.76
13	**K'**	Harishnagar Tea estate.	Bishalgarh	202.69	199.79	172.1-196.5	24.42	68.19	artesian flow

Fig .5.55.(k) Sub-Surface Geology Panel Diagram of Mohanpur Hospital **(**Mohanpur**) to** Harishnagar Tea estate **(**Bishalgarh**), (Ref Section K-K')**

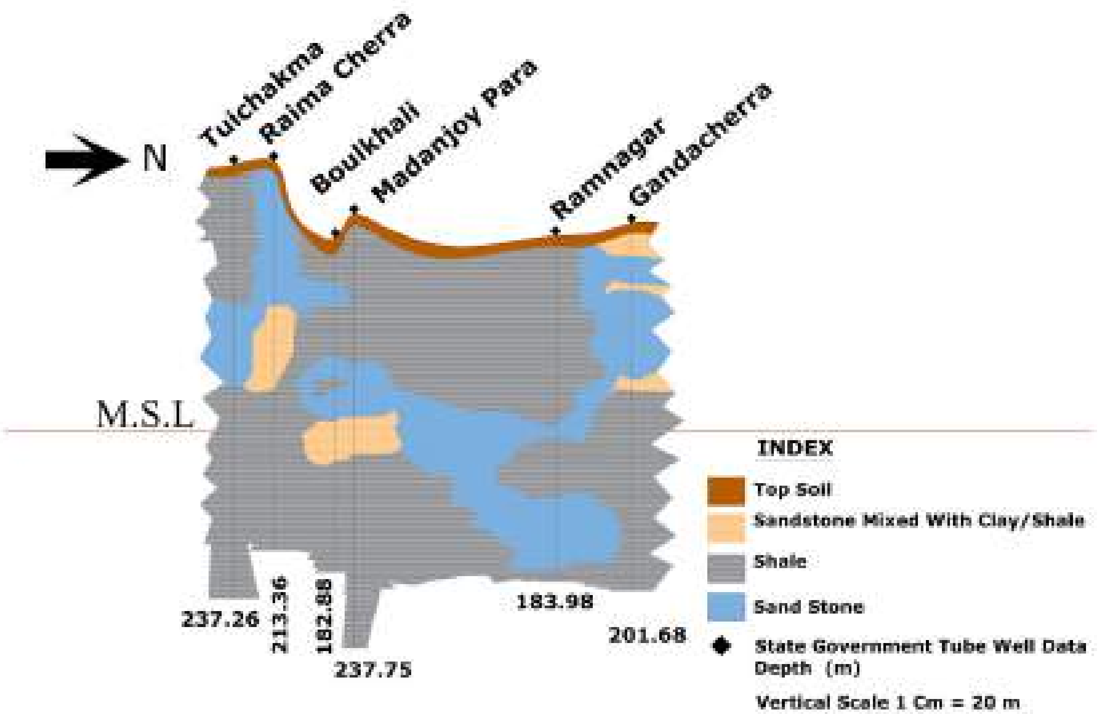
Values of static water level decrease in the hilly and valley areas to 18.3 m, 16.8 m, 12.2 m, 9.14 m, 7.92 m, 7.62 m, 6.1 m, 3.05 m, and 1.52 m depicted in Fig. 5.55 (k) and the direction of flow is from north-east to south-west. The thickness of filter layer is found ranging between 24 m and 43 m highlighted in the figure. The depth of pipe lowering is observed varied from 108 m to 205 m in the study area. There is one overflow zone where the sand bed layer is found as higher value and it is belonging as higher pressure zone.



Sl. No	Place mark	Location	Block	Depth of bore hole (m-bgl)	Depth of pipe lowering (m-bgl)	Filter layer depth (m-bgl)	Thickness of Strainer (m)	Discharge (m3/h)	static water level (m)
1	**L**	Lalchara	Chowmanu	219.5	79.4	42.33-75.84	33.5	13.6	21.3
2	**L1**	Chailengta - II (ST)		164.6	134.6	97.9-130.93	33.0	37.7	7.6
3	**L2**	Khetuicherra		237.8	231.6	198.24-227.93	29.7	22.8	
4	**L3**	Karathicherra		219.6	121.9	81.78-118.24	36.5	45.5	2.7
5	**L4**	Jamir cherra	Manu	213.8	200.9	125.98-137.90 153.20-171.32 191.72-197.75	36.1	68.1	6.7
6	**L5**	Marakpara(W/S)		182.9	173.9	134.60-170.79	36.2	113.5	0.3
7	**L6**	Nepaltila- II	Chowmanu	186.1	159.5	118.91-156.37	37.5	45.5	4.6
8	**L'**	82 Mile	Manu	237.7	180.5	140.84-177.43	36.6	94.7	7.6

Fig .5.55.(l) Sub-Surface Geology Panel Diagram of Lalchara **(**Chowmanu**) to** 82 Mile **(**Manu**), (Ref Section L-L')**

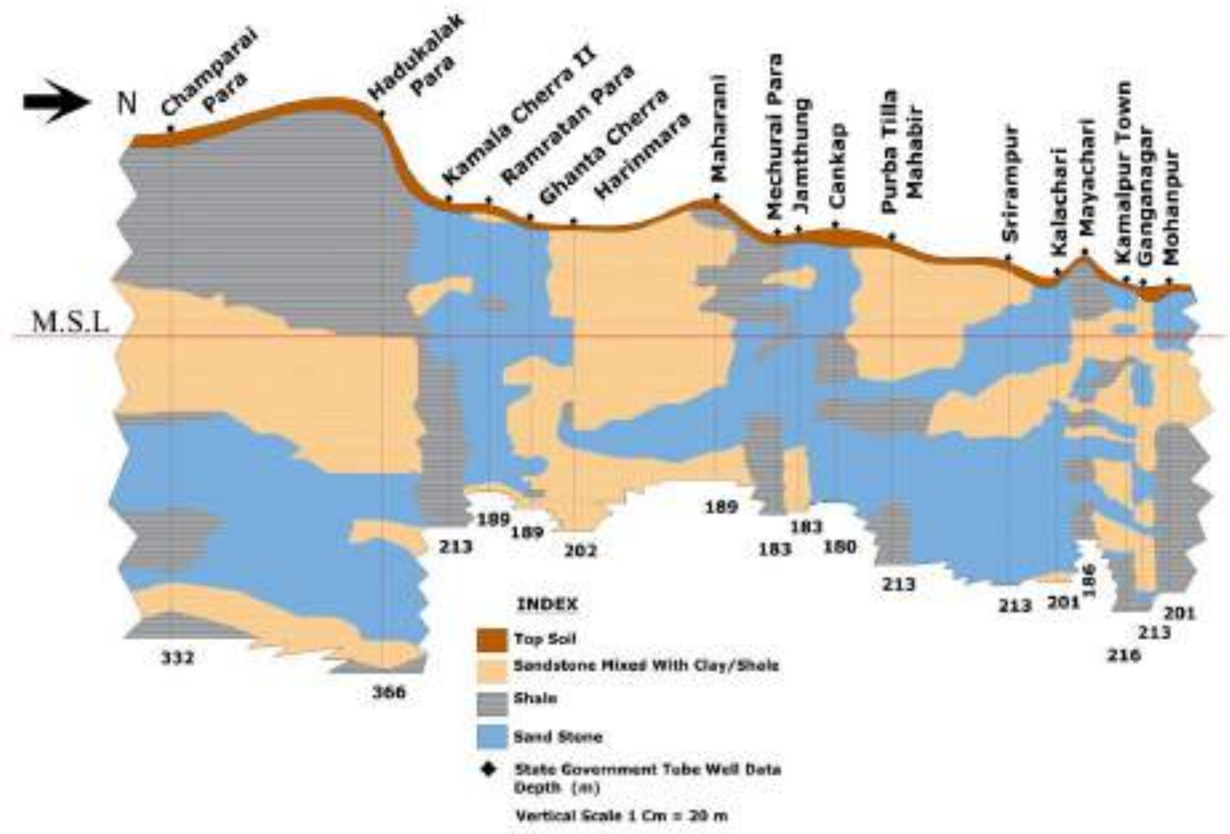
Values of static water level decrease in the hilly areas to 21.3 m, 7.62 m, 6.71 m, 4.57 m, 2.74 m and 0.3 m depicted in Fig. 5.55 (l) and the direction of flow is from north to south. The average thickness of filter layer is found as 36 m highlighted in the figure. The depth of pipe lowering is observed varied from 79 m to 231 m in the study area.



Sl. No	Place mark	Location	Block	Depth of bore hole (m- bgl)	Depth of pipe lowering (m-bgl)	Filter layer depth (m-bgl)	Thickness of Strainer (m)	Discharge (m3/h)	static water level (m)
1	**M**	Tuichakma	Dumburnagar	237.26	122.12	71.62-118.87	47.24	37.73	6.1
2	**M1**	Raima Cherra		213.36	76.26	48.83-72.97	24.14	20.46	6.1
3	**M2**	Boul Khali		182.88	109.72	64.00-76.20 82.30-100.58	30.48	27.28	3.05
4	**M3**	Madanjoy Para,		237.75	143.23	115.56-140.13	24.48	11.77	6.1
5	**M4**	Ram Nagar		183.98	182.51	149.51-179.41	29.9	22.73	3.05
6	**M'**	Gandacherra		201.16	80.68	48.58-77.58	29	56.75	2.44

Fig.5.55.(m) Sub-Surface Geology Panel Diagram of Tuichakma to Gandacherra under (Dumburnagar), (Ref Section M-M')

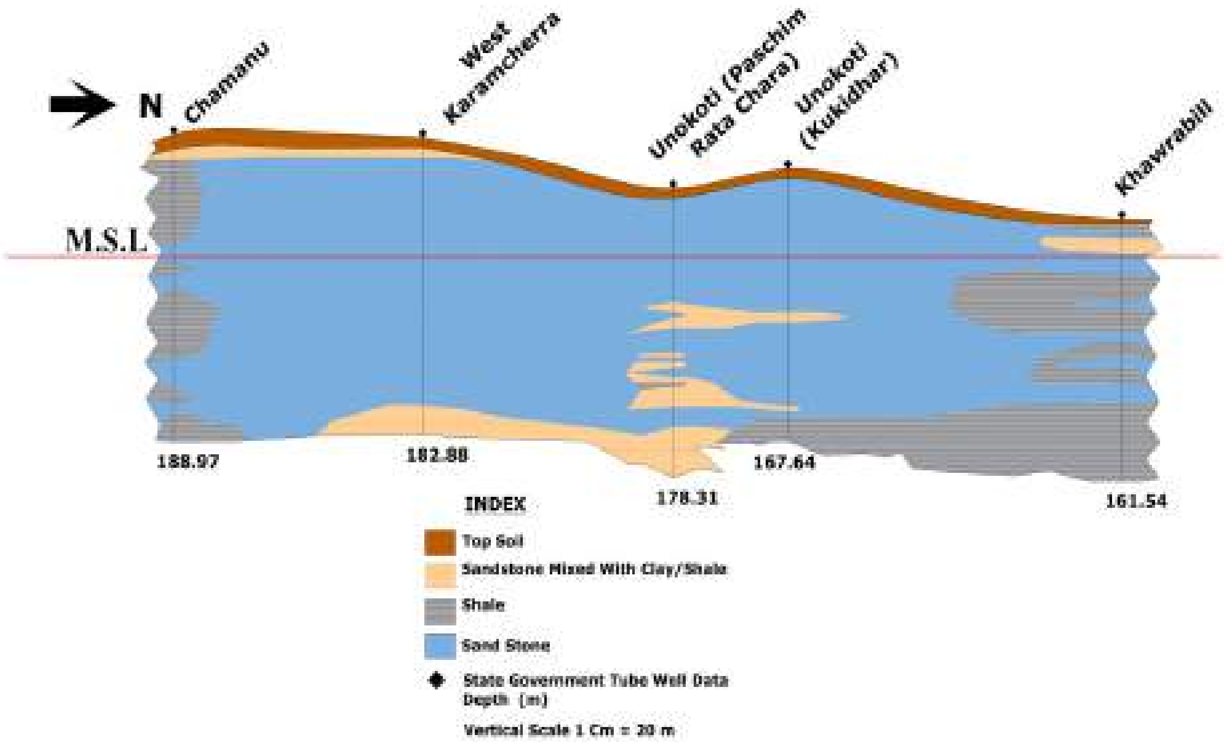
Values of static water level decrease in the hilly areas to 6.1 m, 3.05 m and 2.44 m depicted in Fig. 5.55 (m) and the direction of flow is from north to south. The thickness of filter layer is found ranging between 29 m and 47 m highlighted in the figure. The depth of pipe lowering is observed varied from 76 m to 183 m in the study area.



Sl. No	Place mark	Location	Block	Depth of bore hole (m-bgl)	Depth of pipe lowering (m-bgl)	Filter layer depth (m-bgl)	Thickness of Strainer (m)	Discharge (m3/h)	static water level (m)
1	**N**	Champarai Para	Ambassa	332	249.73	200.76-243.65	42.89	29.55	67.1
2	**N1**	Hadukalak Para (Kulai RF Extn.)		366	277.36	207.26-231.64, 249.93-268.22.	42.67	46.60	36.6
3	**N2**	Kamalacherra - II		213	105.69	53.95-77.43 93.77-102.93	32.64	59.10	artesian flow
4	**N3**	Ramratan Para		189	182.81	142.98-179.71	36.76	59.47	7.62
5	**N4**	Gantachara		189	155.62	113.3-149.59	36.29	23.64	7.01
6	**N5**	Harinmara		202	168.91	71.96-103 148.83-154.47 160.51-165.91	45.69	34.10	2.43
7	**N6**	Maharani	Salema	189	164.19	124.75-161.09	36.34	81.83	artesian flow
8	**N7**	Mechurai Para		183	121.32	82.30-118.22	35.92	15.91	18.3
9	**N8**	Jamthum		183	143.16	95.95-121.95 128.05-140.09	38.04		2.43
10	**N9**	Chankap		180	204.74	168.35-201.7	33.35	68.19	3.04
11	**N10**	Purba Tilla, Mahabir G.P, Kamalpur,		213	170.07	130.71-166.97	36.26	11.37	12.1
12	**N11**	Srirampur	Durga Chowmuhani	213	205.15	167.09-202.05	34.96	68.10	artesian flow
13	**N12**	Kalachari		201	150.17	110.69-147.09	36.4	29.31	artesian flow
14	**N13**	Mayachari		186	159.68	68.58-83.82 117.35-126.49 146.91-156.97	34.44	37.68	7.9
15	**N14**	Kamalpur		216	176.78	124.95-138.68 147.82-164.56	30.48	56.75	4.88
16	**N15**	Ganga Nagar		213	78.33	48.33-75.23	26.9	26.10	2.2
17	**N'**	Mohonpur		201	137.4	80.4-101.78 129.56-132.78	26.4	29.60	3.1

Fig .5.55.(n) Sub-Surface Geology Panel Diagram of Champarai Para **(**Ambassa**) to** Mohonpur **(**Durga Chowmuhani**), (Ref Section N-N')**

The static water level values decrease in the hilly and valley areas to 67.1 m and 2.43 m depicted in Fig. 5.55 (n) and the direction of flow is from north to south. The thickness of filter layer is found ranging between 27 m and 46 m highlighted in the figure. The depth of pipe lowering is observed varied from 78 m to 277 m in the study area. There are four overflow zones where the land slope is found as higher value towards north to south direction and the flow rate is getting higher value due to movement of groundwater in the same direction. The sub-surface geology up to 366 m is covered by sandy-clay/shale and still no water is accumulated in the same area.



<table>
<tr><th>Sl. No</th><th>Place mark</th><th>Location</th><th>Block</th><th>Depth of bore hole (m- bgl)</th><th>Depth of pipe lowering (m-bgl)</th><th>Filter layer depth (m-bgl)</th><th>Thickness of Strainer (m)</th><th>Discharge (m3/h)</th><th>static water level (m)</th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">O</td><td rowspan="3">Chowmanu</td><td rowspan="4">Chowmanu</td><td rowspan="3">188.97</td><td rowspan="3">160.21</td><td>68.58-77.72</td><td rowspan="3">32.01</td><td rowspan="3">37.73</td><td rowspan="3">7.62</td></tr>
<tr><td>86.86-92.96</td></tr>
<tr><td>140.20-156.97</td></tr>
<tr><td>2</td><td>O1</td><td>West Karamchara</td><td>182.88</td><td>164.89</td><td>125.23-161.81</td><td>36.58</td><td>90.92</td><td>artesian flow</td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">O2</td><td rowspan="3">Unakoti (Paschim Ratachara)</td><td rowspan="3">Kumarghat</td><td rowspan="3">178.31</td><td rowspan="3">147.98</td><td>48.74-67.09</td><td rowspan="3">36.45</td><td rowspan="3">37.85</td><td rowspan="3">7.62</td></tr>
<tr><td>90.16-96.26</td></tr>
<tr><td>109.30-115.23</td></tr>
</table>

						138.32-144.42			
4	**O3**	Unakoti (kukidhar)		167.64	152.95	111.45-147.83	36.38	37.85	6.1
5	**O'**	Khawrabil	Kailashar	161.54	120.18	58.91-60.96	21.62	94.64	5.49
						76.2-82.30			
						91.44-97.53			
						106.68-112.78			

Fig .5.55.(o) Sub-Surface Geology Panel Diagram of Chowmanu **(**Chowmanu**) to** Khawrabil **(**Kailashar**), (Ref Section O-O')**

Hundred nos. of soil starta done by rig boring are represented in Annexure A. Values of static water level decrease in the hilly and valley areas to 7.62 m, 6.10 m and 5.49 m for Chamonu/Unokoti, Kukidhar and Khawrabill respectively depicted in Fig. 5.55 (o) and the direction of flow is from north to south. The thickness of filter layer is found ranging between 21 m and 37 as highlighted in the figure. The depth of pipe lowering is observed varied from 120 m to 165 m in the study area. A high value of sand-bed zone with high discharge is observed as overflow zone in this area.

Thus it concluded that artesian conditions prevail in places where a thick clay sequence completely seals the underlying sandy aquifer over a long lateral distance with sufficient confining pressure with high discharge at Singichara BSF Camp low discharge observed as Dasda or in the perched aquifers at the end of the valley at all directions of the study area. The resultant flow path eventually joins and feeds the major regional north-northwest-west-southwest-south flow direction. This flow pattern (local and regional) is generally consistent with the geology and stratigraphy of the area.

5.5.1. Groundwater Movement Direction and Speed of Groundwater Movement

Ground water moves from higher elevations to lower elevations and from locations of higher pressure to locations of lower pressure. Typically, this movement is quite slow, on the order of less than one meter per day to a few tens of centimeter per day. In groundwater hydraulics (the science of groundwater movement), water pressure surface and water table elevation are referred to as the hydraulic head. Hydraulic head is the driving force behind groundwater movement.

Groundwater movement is always in the downward direction of the hydraulic head gradient (Figure 5.56 (a)-(c)). If there is no hydraulic head gradient, there is no flow. The hydraulic gradient is often but not always similar to that of the land surface. In most valleys and basins the hydraulic gradient is in the range of 0.5 to 10 feet per thousand meter (0.05 to 1.0 percent). Groundwater movement in gravels and sands is relatively rapid, whereas it is exceedingly slow in clay or in tiny rock fractures. The ability of geologic material to move ground water is called hydraulic conductivity. It is measured in m^3 per day per square meter (m^3/m^2) or in meter per day (m/day). The amount of groundwater flow is greater with higher hydraulic conductivity, even if the hydraulic gradient is the same. The hydraulic conductivity of sandy or gravelly aquifers typically ranges from 100 to 10,000 gallons per day (gpd) per square foot (approximate equivalent: 10 to 1,000 ft/day). On the other hand, the hydraulic conductivity of clays, which consist of tiny particles that stick together and block water movement, is a tiny fraction of the hydraulic conductivity of a sandy aquifer: 0.001 gallon per day per square foot or less. The hydraulic conductivity of fractured rock depends greatly on the degree of fracturing. It may be as high as 10 to 100 gpd per square foot (approximately 1 to 10 ft/day).

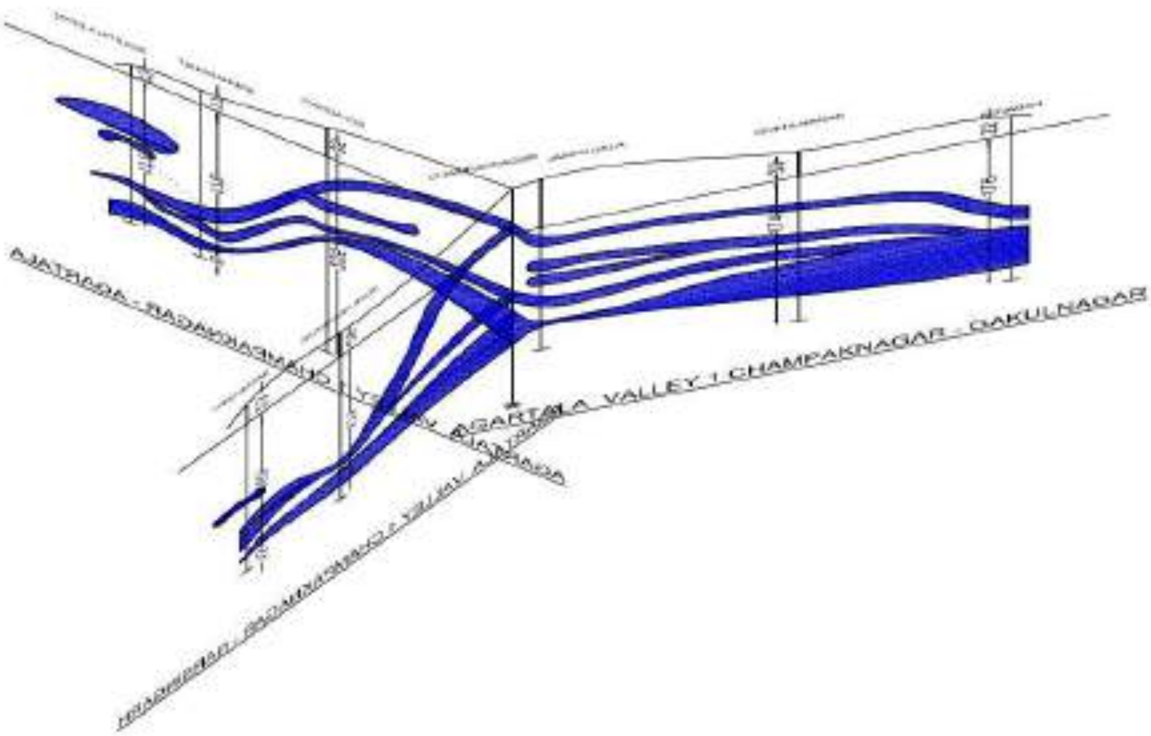


Fig. 5.56.(a). Groundwater movement of the Study area under Agartala Valley (Champaknagar-Gakulnagar)

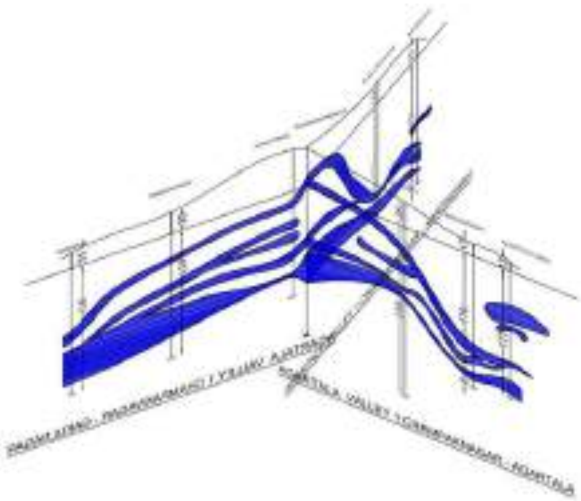


Fig. 5.56 (b). Groundwater movement of the Study area under Agartala Valley (Champaknagar-Agartala)

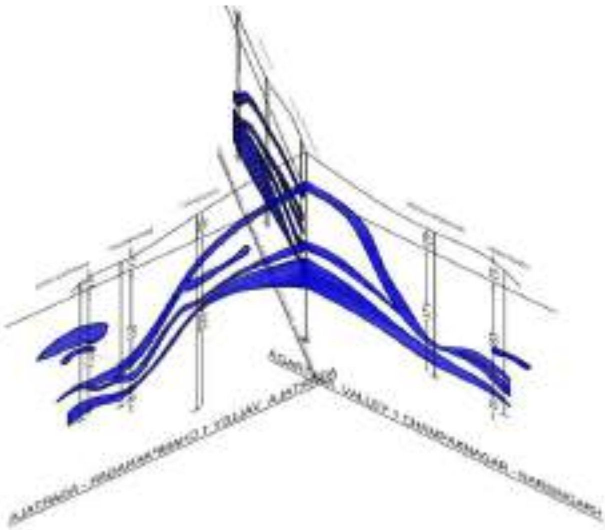


Fig. 5.56 (c). Groundwater movement of the Study area under Agartala Valley (Champaknagar-Narsingarh)

5.6. Calculation of Static and Dynamic Groundwater of Tripura

The static and dynamic groundwater is calculated using GEC, 97, 2004, 2009 and 2015 (Water level fluctuation method) considered overflow zone area for static but not for dynamic condition. The depth ranges from 30-35 m is considered for replenishable dynamic groundwater recharge and storage as well. The specific yield is considered as 0.08 referred by Central Ground Water Board, Govt. of India for estimation of dynamic groundwater recharge. But for static it is considered starting 30 m onwards up to 300 m bgl. So, the total static groundwater storage is estimated as 11.75 BCM with the help of total available boring depth. Again, the dynamic groundwater replenishable as well as storage would be received as 2.03 BCM referred in Tables 5.6 (a), (b) and (c).

All standard empirical formulae have been considered to estimate all kind of losses given in Fig.5.57.(a). Accordingly replenishable dynamic groundwater is calculated based on all collected data given in Table 5.56 (a), (b) and (c) and it is validated with the estimated value which is about 2.52% higher than the average value. The result is also very close to the value found by the Central Ground Water Board (CGWB), Govt. of India considered the period of 1996-2014. The deviated average value of 10.6% is observed compared to CGWB Fig.5.57.(b) which is a good agreement as close to 20% error prescribed by any past literature. The detail calculation steps of dynamic groundwater is represented in **Annexure B.**

Table 5.6 (a). Block wise static and dynamic groundwater of Tripura-Part-I

Sl. no	GEOGRAPHICAL AREA			hilly area (ha)	plane land and recharge zone with over flow area (ha)(for static)	Over flow area from Un-cofind Zone in shallow tubewell(wthin 0-35m) (ha)	plane land and recharge zone without over flow area (for dynamic) (ha)	Total static water available (ham)	District wise Total static water available (bcm)	Replenishable net dynamic recharge ground water available	Total replenishable net dynamic recharge ground water available(bcm)
	Name of District	Name of Block	GP/VC (ha)								
1	2	3	4	5	6	7	8	9	10	11	12
1	Dhalai District	Chamanu	45829	42224	3605		3605	8117.92		1994.77	
2		Manu	46331	21001	25330		25330	59291.45		4015.48	
3		Ambasa	29079	18663	10416		10416	26121.09		6061.07	
4		Ganganagar	25624	22296	3328		3328	8053.59		1935.32	
5		Salema	22431	10314	12117	15	12102	28922.03		6135.72	
6		Durga Chawmuhani	14587	8656	5931	22	5909	14111.87		2990.68	
7		Dumburnagar	28157	14342	13815		13815	31117.44		7478.35	
8		Raishabari	16958	7840	9118		9118	20537.74		4944.16	
9		Ambassa MC	1477	114	1363		1363	3421.61		791.72	
10		Kamalpur NP	1016	0	1016		1016	2614.10		511.31	
		DISTRICT TOTAL=	231489	145450	86039	37	86002		2.02		0.37
1	North Tripura District	Kadamtala	8509	110	8399		8399	15695.46		2885.75	
2		Kalacherra	7768	102	7666		7666	16183.85		2354.65	
3		Yuvarajnagar	14386	6018	8368		8368	17976.22		3651.35	
4		Panisagar	8866	4072	4794	8	4786	9786.53		1875.29	
5		Damcherra	18510	18337	173	28	145	276.52		685.49	
6		Jampuihill	18889	15088	3801		3801	4579.67		905.29	
7		Dasda	37545	23586	13959		13959	27939.86		6366.34	
8		Laljuri	19950	9806	10144		10144	19338.89		4690.99	
9		Dharmanagar MC	1069	0	1069		1069	2296.44		365.14	
10		Panisagar NP	300	13	287		287	615.99		158.03	
		DISTRICT TOTAL=	135792	77132	58660	36	58624		1.15		0.24
1	Unakoti District	Gournagar	11576	4081	7495		7495	14517.82		2919.84	
2		Chandipur	12845	5394	7451		7451	13711.33		2859.01	
3		Kumarghat	24347	12019	12328		12328	21941.37		6349.42	
4		Pecherthal	15966	11609	4357		4357	7781.60		1128.44	
5		Kailashahar MC	619	0	619		619	1408.84		237.24	
6		Kumarghat NP	350	17	333		333	600.00		196.37	
		DISTRICT TOTAL=	65703	33120	32583		32583		0.60		0.14

Table 5.6 (b). Block wise static and dynamic groundwater of Tripura-Part-II

Sl.no	GEOGRAPHICAL AREA			hilly area (ha)	plane land and recharge zone with over flow area (ha)(for static)	Over flow area from Un-cofind Zone in shallow tubewell(wth in 0-35m) (ha)	plane land and recharge zone without over flow area (for dynamic) (ha)	Total static water available (ham)	District wise Total static water available (bcm)	refrensible net dynamic recharge ground water availabl	Total refrensible net dynamic recharge ground water availabl(bcm)
	Name of District	Name of Block	GP/VC (ha)								
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	South Tripura District	Rajnagar	20248	5040	15208		15208	26501.46		5596.57	
2		Bharat Chandra Nagar	12209	4075	8134		8134	17561.63		3020.37	
3		Hrishyamukh	18260	6195	12065	13	12052	22136.74		3285.21	
4		poyangbari	7415	4150	3265	57	3208	7488.92		926.60	
5		Rupaichari	18485	13283	5202	95	5107	9105.16		1420.13	
6		Satchand	19684	11854	7830	36	7794	15356.57		1658.92	
7		Bagafa	27525	11238	16287		16287	32243.37		5680.06	
8		Jolaibari	23601	10991	12610		12610	25537.77		4443.81	
9		Belonia MC	574	0	574	5	569	1176.15		204.32	
10		Sabroom NP	506	0	506		506	988.69		144.25	
11		Santirbazar NP	2694	0	2694		2694	5354.89		946.68	
		DISTRICT TOTAL=	151201	66826	84375	206	84169		1.63		0.27
1	Gomati District	Matabari	22270	5122	17148		17148	40213.77		4411.82	
2		Tepania	8656	2705	5951		5951	13477.23		1677.74	
3		Killa	19372	8192	11180		11180	25200.84		3355.47	
4		Kakraban	10378	4665	5713		5713	10114.30		1434.71	
5		Amarpur	40191	20255	19936	6	19930	46786.29		5236.23	
6		Ompi	30511	19432	11079		11079	24276.19		2930.60	
7		Karbook	21468	8383	13085		13085	28208.51		2240.07	
8		Silachari	7394	5230	2164		2164	4835.74		395.31	
9		Udaipur MC	610	0	610		610	1383.53		232.20	
10		Amarpur NP	855	0	855		855	1961.70		219.58	
		DISTRICT TOTAL=	161705	73984	87721	6	87715		1.96		0.22
1	West Tripura District	Dukli	10445	477	9968		9968	22035.26		6476.57	
2		Hezamara	18366	6955	11411		11411	21349.98		2570.04	
3		Mohanpur	9081	543	8538		8538	20327.27		4325.06	
4		Bamutia	5471	0	5471		5471	12755.36		2774.36	
5		Lefunga	4942	0	4942		4942	10506.15		2510.64	
6		Jirania	5035	953	4082		4082	8453.82		1963.33	
7		Old Agartala	6524	0	6524		6524	15406.03		1965.21	
8		Belbari	9655	2144	7511		7511	15901.46		1391.87	
9		Mandai	18073	6198	11875		11875	23203.75		2201.10	
10		Agartala M.C	7650	0	7650		7650	16338.87		2314.58	
11		Mohanpur MC	1805	0	1805		1805	4094.90		907.21	
12		Jirania NP	400	0	400		400	828.40		194.18	
13		Ranirbazar NP	195	0	195		195	399.20		74.24	
		DISTRICT TOTAL=	97642	17270	80372		80372		1.72		0.30

Table 5.6 (c). Block wise static and dynamic groundwater of Tripura-Part-III

Sl.no	GEOGRAPHICAL AREA			hilly area (ha)	plane land and recharge zone with over flow area (ha)(for static)	Over flow area from Un-confined Zone in shallow tubewell(wthin 0-35m) (ha)	plane land and recharge zone without over flow area (for dynamic) (ha)	Total static water available (ham)	District wise Total static water available (bcm)	Repleni shable net dynamic recharge ground water available	Total repleni shable net dynamic recharge ground water available(bcm)
	Name of District	Name of Block	GP/VC (ha)								
1	2	3	4	5	6	7	8	9	10	11	12
1	Sepahijala District	Nalchar	8172	2320	5852		5852	11829.58		2937.57	
2		Mohanbhog	8716	2576	6140		6140	12085.36		3080.37	
3		Kathalia	15167	3810	11357		11357	24295.18		3946.98	
4		Boxanagar	11806	794	11012		11012	21467.34		3558.89	
5		Bishalgarh	14083	1266	12817		12817	26621.55		5850.05	
6		Charilam	12675	1149	11526		11526	23521.17		5335.24	
7		Jampuijala	30652	5011	25641		25641	49271.75		5153.88	
8		Melaghar M.C.	1793	245	1548		1548	3161.13		775.19	
9		Bishalgarh MC	915	0	915		915	1935.41		421.20	
10		Sonamura NP	413	0	413		413	883.83		227.16	
		DISTRICT TOTAL=	104392	17171	87221		87221		1.75		0.31
1	Khowai District	Khowai	9591	187	9404	135	9269	20528.72		4382.31	
2		Padmabill	11904	5179	6725	27	6698	15068.51		2870.69	
3		Tulashikhar	26461	19102	7359		7359	16782.57		2966.61	
4		Teliamura	12887	10805	2082		2082	4330.98		511.39	
5		Mungiakami	29292	18109	11183		11183	23432.75		2762.19	
6		Kalyanpur	10153	5825	4328		4328	9034.42		4296.39	
7		Khowai MC	582	0	582	7	575	1251.66		255.32	
8		Teliamura MC	375	12	363		363	755.11		89.49	
		DISTRICT TOTAL=	101245	59219	42026	169	41857	1174726.17	0.91		0.18
STATE TOTAL=			**1049169**	**490172**	**558997**	**454**	**558543**	**1174726.17**	**11.75**	**203037.19**	**2.03**

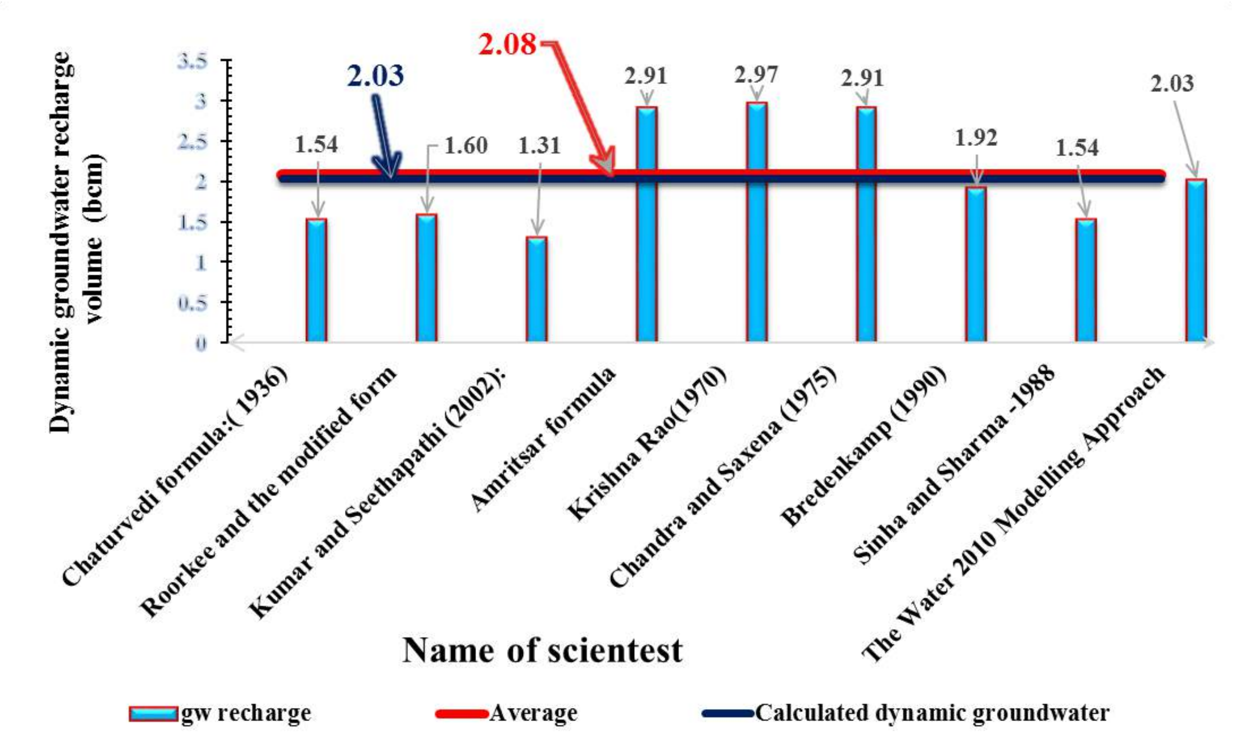


Fig.5.57. (a). recharge volume of dynamic groundwater in various Empirical methods

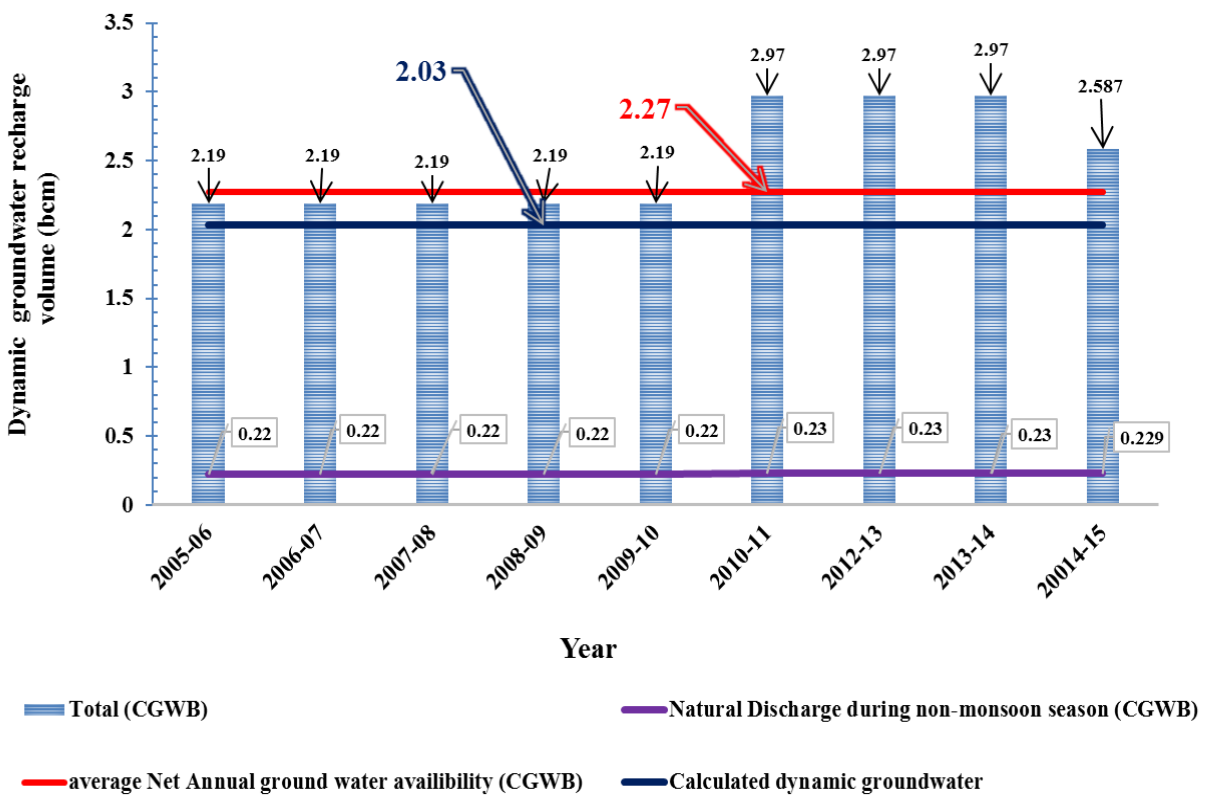


Fig.5.57 (b). CGWB year wise dynamic ground water recharge volume of the state

In Fig.5.57.(c), about 33 stations are considered and it is prepared based on Mean Sea Level and elevation. The results showed that the the water level fluctuation are varied at different physical position to assess the dynamic and static groundwater during pre-monsoon and post-monsoon. The maximum drawdown level are observed during pre and post-monsoon in study area.

Central Groundwater Water Board (CGWB), Govt. of India has constructed 58 tube wells in Tripura. In West Tripura district tube wells constructed between 42 and 255 mbgl, tapping 24 – 66 m of granular zones yielded 4 – 165 m3/hr. In South Tripura district tube wells constructed between 35 and 212 mbgl, tapping 18 – 60 m of granular zones yielded 12 – 158 m3/hr. In North Tripura district tube wells constructed between 45 and 262 mbgl, tapping 15 – 63 m of granular zones yielded 4 – 95 m3/hr. In Dhalai district tube wells constructed between 53 and 255 mbgl, tapping 32 – 57 m of granular zones yielded 38 – 211 m^3/hr. The static water table with respect to elevation of Tripura state is demarcated in Fig.5.57 (c). The dynamic groundwater levels during the period of 1996 to 2016 in two different seasons are highlighted in Fig. 5.57 (c)

Analysis of aquifer performance tests on exploratory/ deposit deep tubewells in the state have shown transmissivity ranged between 4.5 and 1577 m^2/day and permeability ranged between 0.1 and 28.4 m/day. The storage co-efficient ranged between 2.25 x 10^{-5} and 2.20 x 10^{-3} showing confined nature of the aquifer. The calculation of dynamic, static and total dynamic and static up to 300 m bgl are given in **Annexure C** respectively.

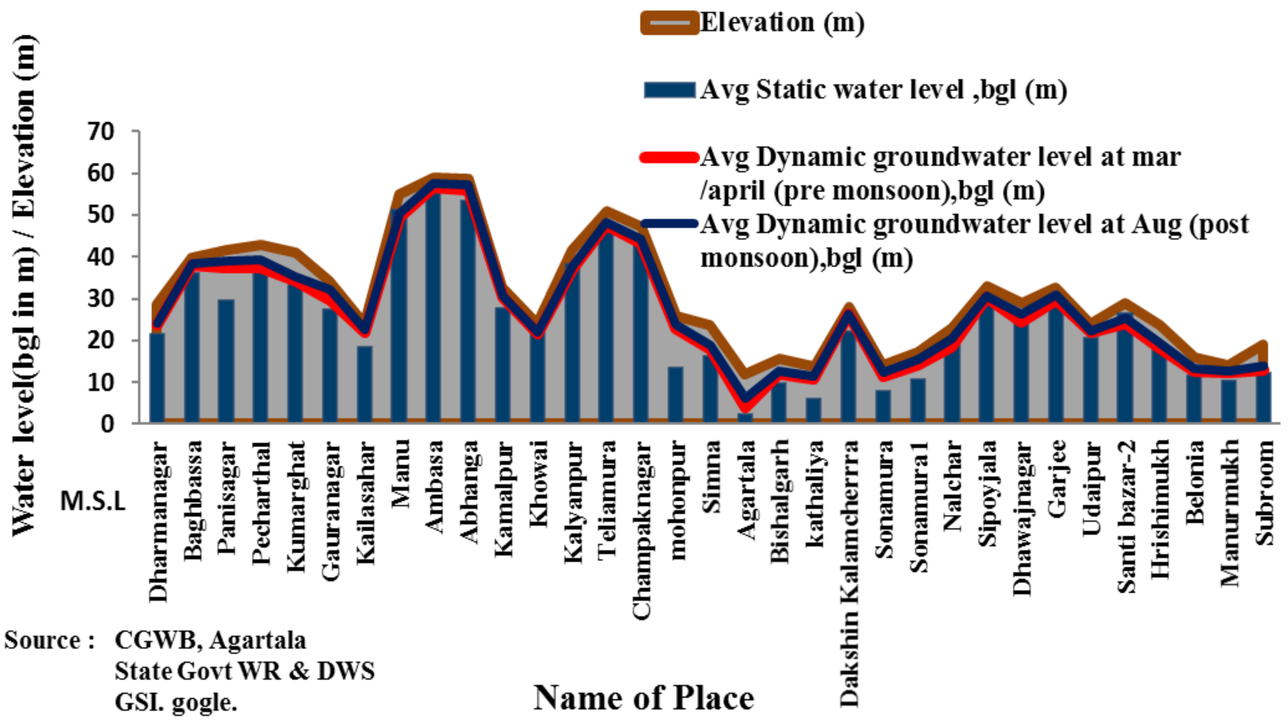


Fig. 5.57.(c) Water level scenario at different stages with respect to location along with elevation

5.7. Water Budget Components and Sectorial Demand of Tripura State

Analysis of rainfall are made using gauge station in in state by different organization as all collection have been verified using statistical methods and checked for data consisting as well. depicted in Fig .5.58 water budget.

The Population projection and calculated based (five standard methods such as percentage ratio method, arithmetical increase method, geometric mean method, incremental increase method and absolute increase methods).

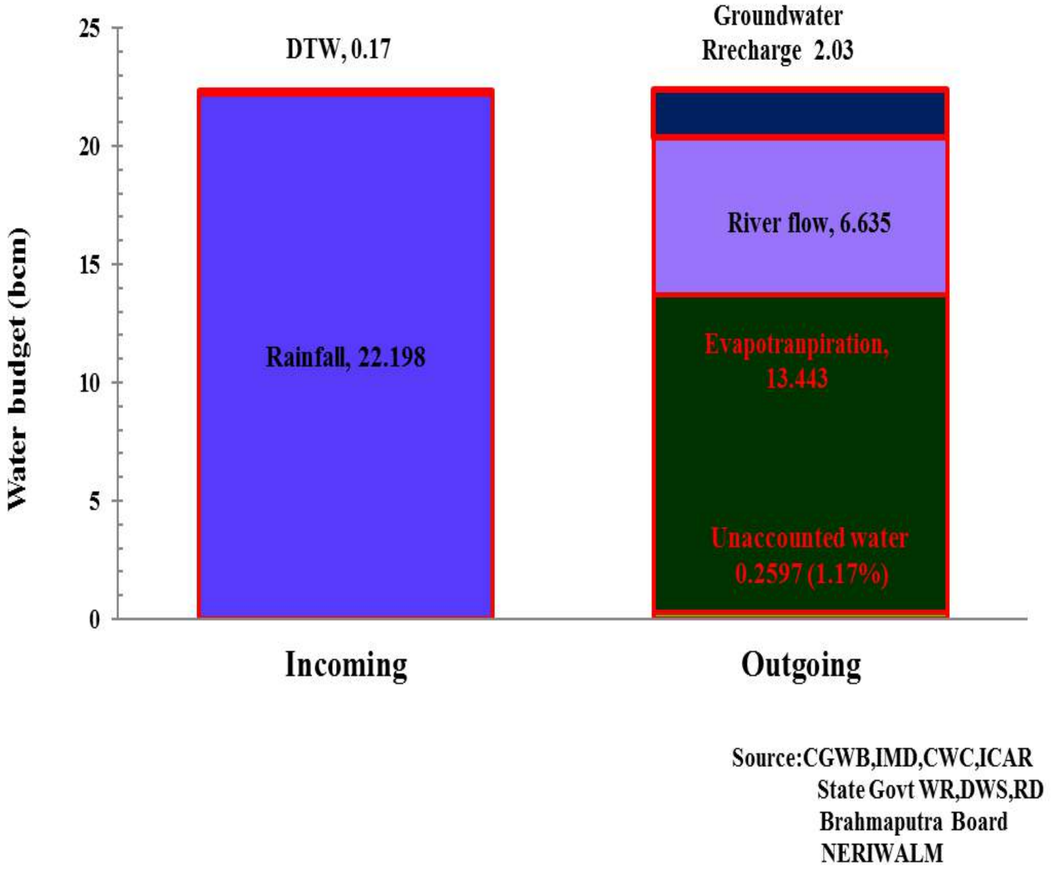


Fig.5.58. Water budget components

Out of five methods it is justified which method is more appropriate to project future population in the study area. These projected populations are used to estimate the sectorial demand as well as future water availability depicted in Fig .5.59. The results also indicate that as the year increases with an increase of sectorial water demand at a constant rate. The future demand of groundwater availability is also in the tune of 25 % of total dynamic recharge value in the year of 2050.

This figure also remark that the static water table keeping at normal no pumping condition of the State average is 11.76 bcm all sectorial demands like Domestic demand, Irrigational demand, power demand, industrial demand anf environmental demand as per Indian standard guide line (6%,78%,3%,5% and 8%)(163.4, 2125,81.7,136.2 and 218 mcm) water will be required.

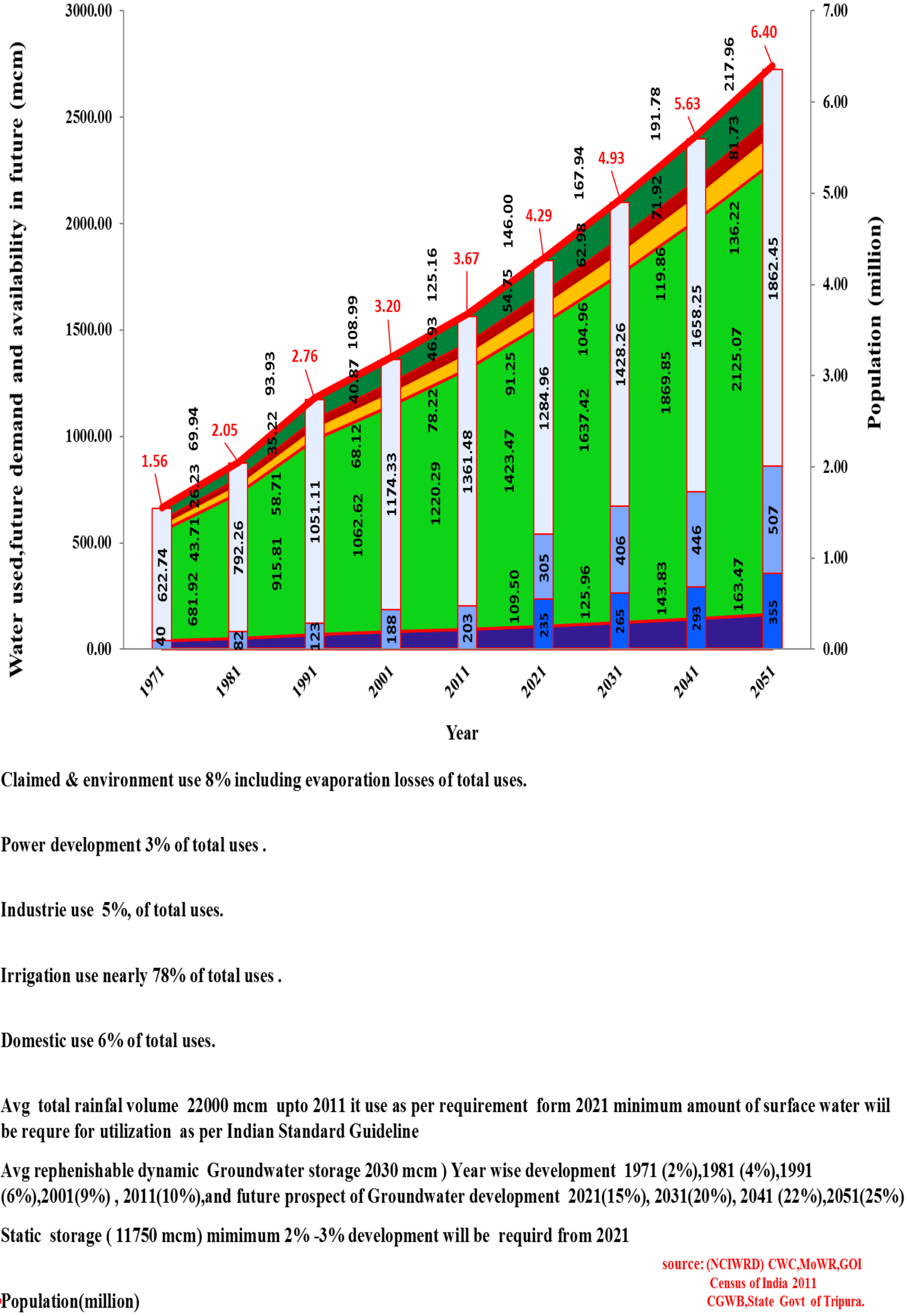


Fig.5.59. Sectorial demands with respect to population growth of Tripura

5.8. Identification of Recharge Zone, Overflow Zone and Development Zone of Tripura State

Hydrometer logical data is have been collected from different Govt. organization such as, CGWB Agartala, GSI Agartala, IMD Kolkata, Agartala, CWC Guwhati, Brahmaputra Board State river basin master plan, Govt. of India organization and State Govt. TSEC, Directorate of Panchyat, Land Record and Settlements, Directorate of Statics deptt, Directorate of Agriculture, Directorate of Fisharies, Directorate of Horticulture, Directorate of Rubber Board, Directorate of Tea Board, Directorate of fo Forest ,PWD (DWS) PW(Road),PWD (WR),and Urban Development and Municipality during the period of 1901to 2015.

Valley wise groundwater recharge zone of Tripura state is made of using auto-cad software as depicted Fig.5.59.(a). All attributes are considered to delineate the map it is validated with physical survey. considering some hot spot area different calculation are make as given in index to identify different zone the estimated value of the hydraulic conductivity, storativity, specific capacity, and transmissibility against valley wise of the study area ranging between in table.

At dry season in hilly areas no water is available. All mini waterfalls are situated at the top of the hills that could be stopped for flowing of water. At plain land of the valley referred in Fig. 5.59 (b), overflow water are available throughout the year which comes usually from static groundwater level (< 50 m). The dynamic ground water level has got decreased about 2 to 3 m in plain land during rainy season whereas about 20 to 100 m has got reduced in case of hilly areas and thus resulting there is a relationship developed between static water layer and dynamic water layer due to downward movement (hilly zone to flat zone).

A similar kind of map with additional attribute are incorporated to prepare the map for identification of zone for present and future groundwater development in Tripura state development in Fig.5.59.(c).identical colour are marked in the map to identify the water available zone with sustainable yield for shallow and deep tubewell. The colour wise drawdown are highlighted to operated optimum pumping arrangement to receive optimum and sustainable water resources at present and future scenario of Tripura state and also area measure that water body area 33887 ha,(3.23%) (deep blue) high yield 225840 ha (22.24%) (blue), normal yield 358051 ha (35.26) (green) and low yield 431390 ha (42.49%)(red) calculated

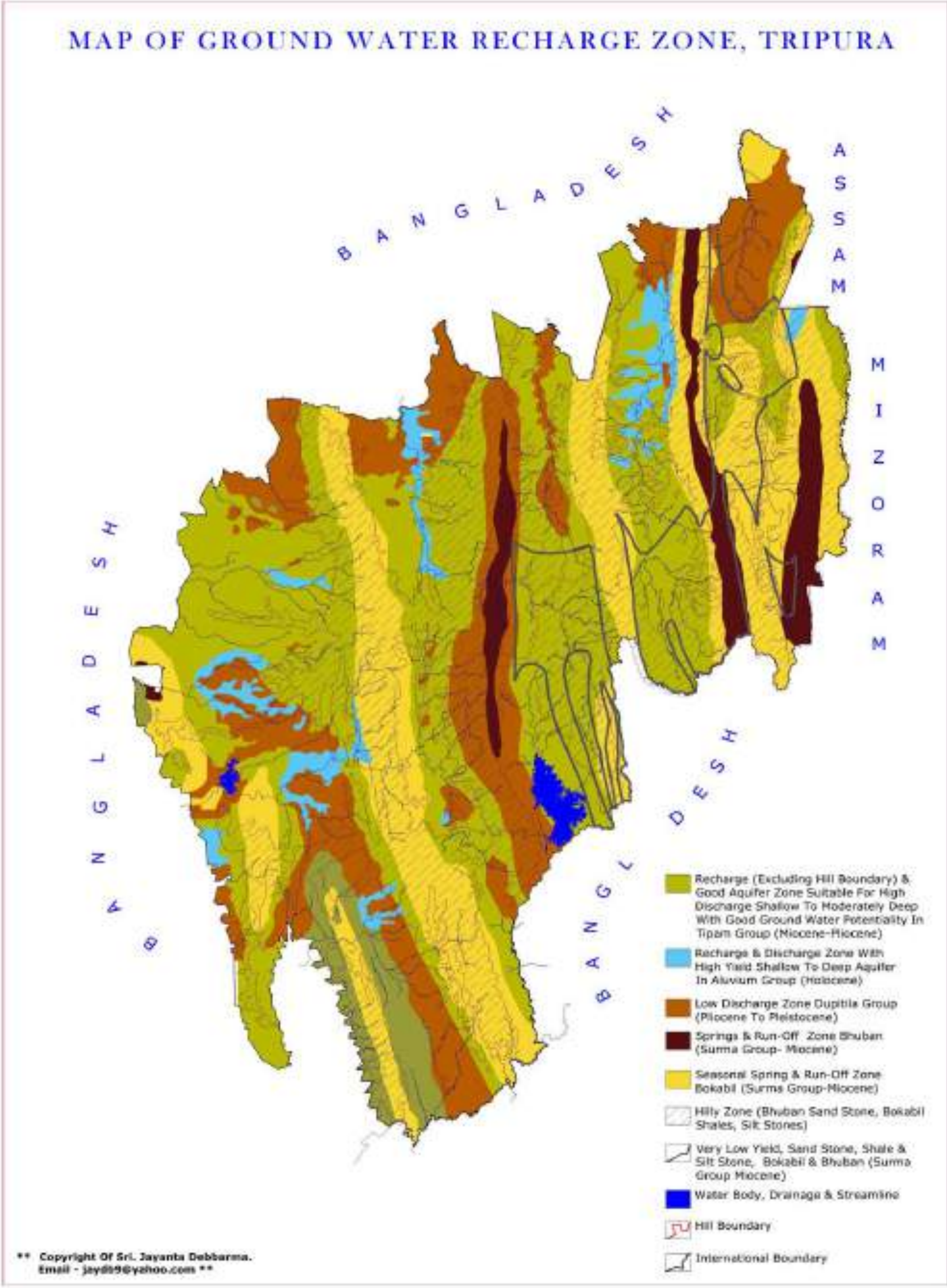


Fig. 5.59.(a). Groundwater Recharge zone of Tripura State

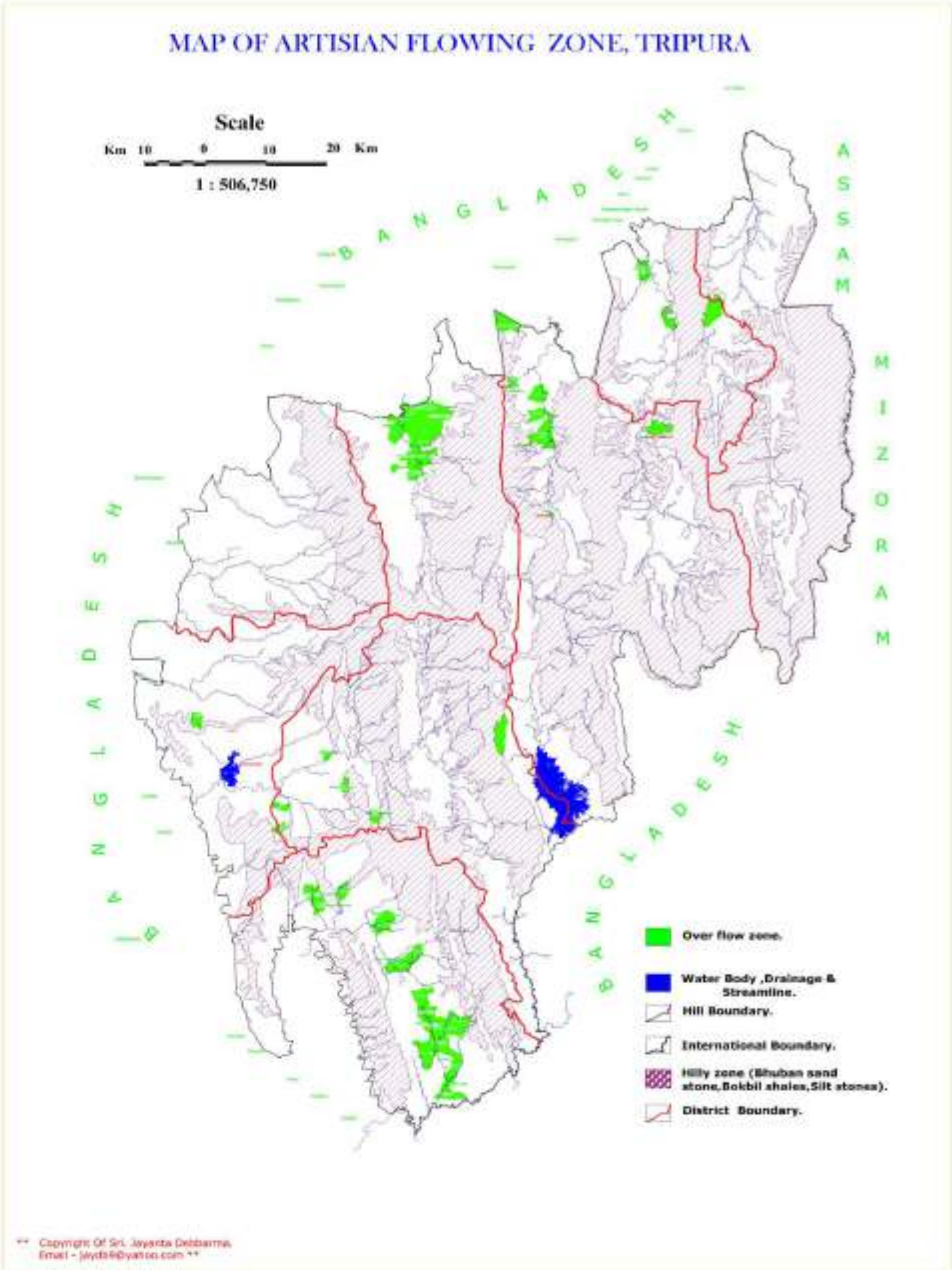


Fig. 5.59 (b).Overflow zone of Tripura State

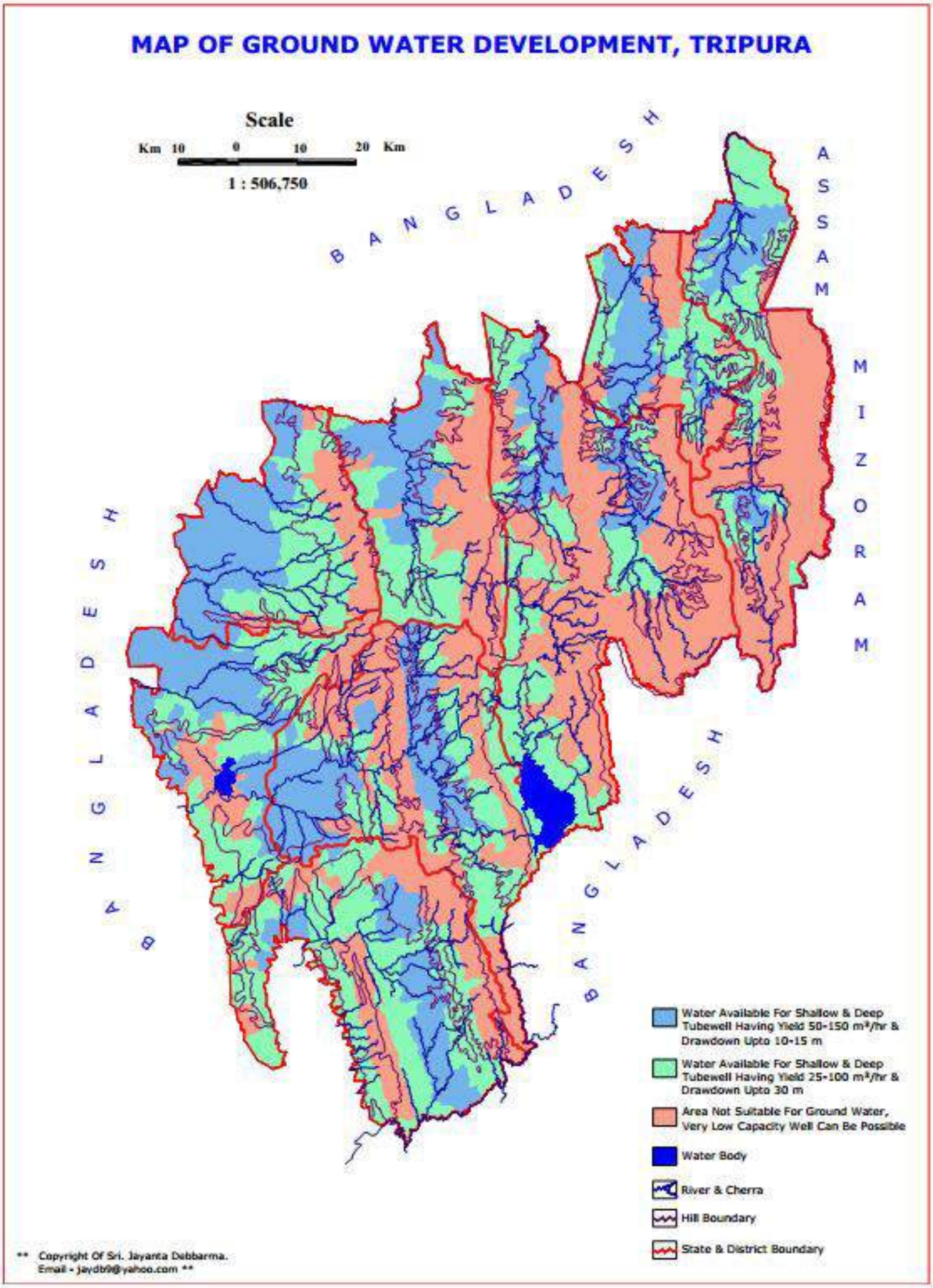


Fig. 5.59.(c). Groundwater Development Zone of Tripura State

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1. Overall Conclusion

- ✓ The general geology of the study area is represented by a respective succession of argillaceous and arenaceous sedimentary rocks like sandstone, shale, siltstone and clay belonging to Surma, Tipam and Dupitila Groups. The study area is also found by mottled clay, clayey sandstone, coarse to gritty ferruginous sandstone and pockets of bluish to gray plastic clays with form silica and laterites. The recent alluvium formation is represented by unconsolidated silt, sand, clay, silty clay, etc. and is developed along the rivers streams etc.

- ✓ The total river of Tripura state has considered as seventeen having a catchment area of 1.049 Mha. Out of seventeen, eight rivers are covered by 83% of the total catchment area and the rest 17% of the total catchment area is belonged to the other rivers. These major perennial rivers are all joined by ninety four nallah and Chharas where the total length is covered by approximately 2428 km which in turnforms a part of Meghna sub-basin. The common drainage patterns are sub-parallel to parallel and dendritic up to 4^{th} order streams are found in the study area. The total average river flow of Tripura state is found to be in the tune of 10.89 BCM contributed the base flow of 4.255 BCM. Out of which, a magnitude of 8.92 BCM of river flow is flowing through eight major rivers.

- ✓ The highest 39-years average rainfall of Tripura state is found to be 2116 mm. The highest rainfall is observed as 3015 mm in the year of 1997-98 whereas the lowest rainfall is received as 1285 mm in the year of 1994-95. The daily highest rainfall occurred in the month of July in 1993 is recorded as 257 mm. The results also depicted that about 60% of total rainfall is observed during the monsoon period.

- ✓ The daily highest temperature is found to be 42.2^0C in the year of May, 1960 whereas the lowest is observed as 2^0C in the month of December, 1972. The decade wise a value of 0.2 ^{0}C is increased for the last 30-years temperature data.

- ✓ Physiographically, the study area is divided by Anticlinal Hill Ranges and Synclinal flat-bottomed valleys. The major hill ranges are Baramura, Atharamura, Longtarai and Shakan. The trend of the hill ranges is almost north-south and the highest peak is recorded as 3066 m in Shakan connected with Manu river. The height of the hill ranges increases from west to east. The broad synclinal valleys are Udaipur- subroom, Amarpur, Agartala, Khowai Dharmanagar, Kamalpur and Kailashahar valley. The valleys are gently undulating with intermittent flood plains of rivers and streams. All the valleys become narrow and constricted towards south and widens towards north. The master slope of the valleys is towards north. The terrain is mostly undulating and hilly with small water streams (Chharas), rivers and fertile valleys intervening. All ephemeral major rivers are originated from top of the hill and flow towards along with valley and ultimately it reaches to Bangladesh. It is true that all rivers are originated in Tripura state which is unique geographical feature.

- ✓ Presently in Tripura state eight districts, fifty eight blocks and twenty municipalities/nagar panchayats are recorded. Initially there were four districts, thirty eight blocks and twelve municipalities. However, without further increased the geographical area, all added boundary are redistributed and formed new revenue land structures in the study area.

- ✓ There are three hydrogeological units / water bearing formations identified in the state are Alluvial formation, Dupitila formation and Tipam formation. In case of alluvial formation, it occurs along the banks of main rivers and its thickness varies from 0 to 10 m bgl against recent formation and above 10 m bgl found as older formation. In this section, recharge as well as discharge value found are sufficient. Ground water occurs under unconfined condition. Ground water is developed through dug wells and ordinary hand pumps.

- ✓ Dupitila formation is nearly horizontal in disposition and its thickness varies from 10 to 30 m. The formation consists of mainly clay and silts with some intercalations of gritty and ferruginous and stones. It is exposed in the central portion of Udaipur valley. In general, it has low permeability and low storage capacity due to high clay content. It has been developed through dugwells and hand pumps. Tipam formation consists of sub-rounded, fine to medium grained, friable sandstone with intercalated clay. Tipam formation is found in the majority of the valley portion. Sandstone of Tipam formation constitutes the principal aquifer in the study area. The permeability of this sandstone is much higher than that of Dupitila sandstone or Surma sandstone. The recharge area of the sandstone is in the anticline hills. Groundwater occurs under semi-confined to confined conditions. This sandstone is developed by deep tubewell sand shallow tubewells.

- ✓ The static and dynamic groundwater is calculated using GEC, 09 (Water level fluctuation method) considered overflow zone area for static but not for dynamic condition. The depth ranges from 30-35 m is considered for replenishable dynamic groundwater recharge and storage as well. The specific yield is considered as 0.08 referred by Central Ground Water Board, Govt. of India for estimation of dynamic groundwater recharge. But for static it is considered starting 30 m onwards up to 300 m bgl. So, the total static groundwater storage is estimated as 11.75 BCM with the help of total available boring depth. Again, the dynamic groundwater replenishable as well as storage would be received as 2.03 BCM.

- ✓ Nine empirical formulae are used to estimate the replenishable dynamic groundwater and it is validated with the estimated value. The result is also very close to the value found by the Central Ground Water Board (CGWB), Govt. of India considered the period of 1996-2014. The deviated average value of 10.6% is observed compared to CGWB which is a good agreement as close to 20% error prescribed by any past literature.

- ✓ The results also showed that the storativity, transmissivity, permeability, hydraulic gradient and yield for confined aquifer of Tripura State are highlighted as given below:

Sl. No.	Storativity	Transmissivity (m^2/day)	Permeability. (m/day)	Hydraulic gradient	Slot
North Tripura valley	$4.2x10^{-4}$ - $2.7x10^{-4}$	4.5-507	0.1-12	$3.13x10^{-3}$ - $1.39x10^{-3}$	3-5
Kailashar valley	$2.2x10^{-3}$ - $5.9x10^{-4}$	26.4-1212	0.4-23.7	$8.42x10^{-4}$ - $4.13x10^{-3}$	4-7
Kamalpur valley	$1.85x10^{-3}$ - $2.85x10^{-4}$	709-1186	26-43	$2.74x10^{-3}$ - $7.4x10^{-4}$	2-7
Khowai valley	$1.0x10^{-2}$ - $5.16x10^{-3}$	1073-1698	15-28		3-6
Agartala valley	$2.06x10^{-3}$ - $4.42x10^{-4}$	86.67-1449	3.62-40.85	$1.01x10^{-2}$ - $8.42x10^{-3}$	2-7
Udipur – Sabroom Valley	$1.36x10^{-3}$ - $4.2x10^{-4}$	246-897	4.6-22.4	$2.4x10^{-2}$ - $7.17x10^{-3}$	2-9
Amarpur valley	-	326-794	7.1 -10.7	$6.28x10^{-4}$ - $2.73x10^{-3}$	3-6

The above all aquifer parameters are within the limit. Yield test of all individual valleys is conducted for 8 hrs duration with a depth of 300 m and accordingly drawdown data with respect to time are measured and prepared different graphs for all seven valleys. Permeability test is also conducted to estimate the permeability. The groundwater parameters are calculated to assess the static and dynamic groundwater potential and it is reflected in the above table.

- ✓ Stations are recorded water levels of eight district during pre and post-monsoon. The minimum and the maximum water level ranges from 1.3 m-5.36 m and 0.68 m-5.34 m during pre-monsoon post-monsoon respectively in North Tripura. The minimum and the maximum water level ranges from 0.93 m-9.32 m and 0.57 m-7.98 m during pre-monsoon post-monsoon respectively in Unokoti. The minimum and the maximum water level ranges from 0.32 m-0.62 and 0.35-5.05 m during pre-monsoon post-monsoon respectively in Dhalai.

- ✓ The static water table ranges from 0.3 m to 67.1 m of the study area. There is one place located at Jampui Hill near Mizoram Border under Kanchanpur Block, North Tripura district, the static water level is found to be in the tune of 154.4 m. The pipe is lowered with a depth of 223 m having a remarkable discharge value of 5.44 m^3/hr. The total filter thickness is given as approximately 48 m.

- ✓ Springs / seepage zones are available in the study area. Traditionally tribal people living in thehilly areas are using spring water for drinking and domestic purposes. In the foothill areas people used to arrest the spring water by constructing seasonal / permanent bund on small streamlets / cherras and used this water for irrigation purpose and sometimes used for drinking and domestic purposes also. Artesian zones occur in Tripura State. These wells are mainly used for irrigation purposes but some of the wells are even used for drinking and domestic purposes. The artesian zones found are discontinuous and are localized phenomenon. It is reported that the wells are constructed within a depth range of 5 to 300mbgl. Discharge of the wells varies from 0.05 to 15lps during pre-monsoon period and from 0.15 to 7.0lps during post-monsoon period.It is to be opined that there is one perched aquifer coming hot water which is connected with deep aquifer ranges from 2000 m to 2500 mbgl at Dackmura under Maharani ,Amarpur Vally.

- ✓ The stage of development is divided into three distinct classes such as high yield, medium yield and low yield based on discharge and drawdown. The values for high, medium and low yield are observed 50-150 m^3/hr, 25-100 m^3/hr and not specified respectively. The drawdown ranges from 0-12 m, 10-45 m and not known for three conditions. As per calculation, 0.2597 BCM (1.16%) is calculated as unaccounted water in water budget which may consider as deep percolation.

6.2. Remarks on Identification of Effective Sand Bed in Aquifer Zones using Resistivity Survey in Tripura

After studying the geological & geophysical properties of the area and interpreting the field data it is suggested / recommended that, since the area falls on sedimentary tract, the water prospect here is by the saturated water present in the sand aquifers below. The tract is alluvial and water availability here is good, the aquifers zones are unconfined and are very useful zones for groundwater development by deep tubewells.

From the interpreted true resistivities at Khowai district, Tripura, we can see that subsurface formations are highly variable. Very coarse sand particles with gravel, clay mixed with fine sand particles, clayey soil, clay with conserved moisture contents, very coarse sand particles, silty clay are the main subsurface formations of this area. The survey yields that for getting a water quantity of (8000 - 10000) gallon per hour at Teliamura location drilling up to 190 m, at Kalyanpur location drilling up to 180 m, at Padmabil location drilling up to 180 m and at Khowai location drilling up to 170 m is recommended.

From the interpreted true resistivities at West Tripura district, Tripura, we can see that subsurface formations are highly variable. Impervious type clay, clay mixed with fine sand particles, clay with conserved moisture contents, very coarse sand with gravel, very coarse sand particles, silty clay are the main subsurface formations of this area. The survey yields that for getting a water quantity of (10000 - 12000) gallon per hour at Jirania location drilling up to 180 m is recommended and for getting a water quantity of (8000 - 10000) gallon per hour at Hezamara location drilling up to 200 m is recommended.

From the interpreted true resistivities at Sepahijala district, Tripura, we can see that subsurface formations are highly variable. Hard impervious type clay, clay with conserved moisture contents, clay mixed with fine sand particles, very coarse sand particles, silty clay, clayey soil are the main subsurface formations of this area. The survey yields that for getting a water quantity of (8000 - 10000) gallon per hour at Maheshpur location drilling up to 185 m is recommended, for getting a water quantity of (10000 - 11000) gallon per hour at Kathalia location drilling up to 180 m, at Sonamura location drilling up to 180 m, at Boxanagar location drilling up to 175 m is recommended and for getting a water quantity of (10000 - 12000) gallon per hour at Maheshpur location drilling up to 185 m is recommended.

From the interpreted true resistivities at Gomati district, Tripura, we can see that subsurface formations are highly variable. Dry layer of coarse sand, clay mixed with very fine sand particles, very coarse sand particles with gravel, coarse sand particles, clay with conserved moisture contents, clayey soil, silty clay are the main subsurface formations of this area. The survey yields that for getting a water quantity of (8000 - 10000) gallon per hour at Tepania location drilling up to 190 m, at Matabari location drilling up to 180 m, at South Karbook location drilling up to 170 m, at East Karbook location drilling up to 170 m is recommended and for getting a water quantity of (10000 - 11000) gallon per hour at Amarpur location drilling up to 170 m is recommended.

6.2.1. Recommendation for Identification of Effective Sand Bed

Based on the results of VES resistivity survey, this study leads to the following recommendations:

- ✓ The VES survey has the potential to provide reasonable accurate results that can be used to understand the subsurface layers in groundwater exploration. The results of the VES must be verified with secondary hydro-geological data available in the study area.
- ✓ Other geophysical methods like the Seismic Refraction, Electromagnetic Method and Dipole-dipole electrical resistivity survey can be used to complement the methods used for this study.
- ✓ The VES survey should be avoided in monsoon season as the mobilization of the field personals during the survey becomes difficult due to precipitation as well as the water saturation of the top soil might yield inaccurate results.
- ✓ For getting accuracy horizontal profiling should also be done. Profiling also detects the geological faults and fissures.
- ✓ For development of correlation coefficient and regression analysis equation between results of VES survey and borehole litholog data large number of survey points should be taken so that accuracy could be achieved.
- ✓ For correlation of results obtained from interpreting data of VES data with litholog obtained from borehole drilling, the drilling should be done as nearer possible to the centre of the survey.

6.3. Remarks on Estimation of Aquifer Thickness in Tripura District

- ✓ Subsurface formations are highly variable in the subsurface. Sand of various grades like fine, medium and coarse, sandy clay, clay, weathered rocks of sand stone, shale, siltstone and laterites as well as traces of carbonate rocks/minerals are interpreted in the subsurface. These formations mostly belong to upper tertiary to recent age and belong to Surma, Tipam and Dupitilla groups. Groundwater is mostly available in moderate to good quantity at shallow depth in Tipam formations under water table conditions and at deeper level under confined conditions. Groundwater yield is more in bore wells where sand is not consolidated and yield is less where formations are semi consolidated or consolidated. Groundwater yield is negligible in sand stones. Shale and silt stones are devoid of groundwater.

- ✓ Resistivity sounding data (VES) of 18 locations, where data collections were good, spreads over 4-valleys indicate that the subsurface formations in the areas of investigation are having distinct resistivity values with some overlapping. Resistivity in the range of 30-120 m is considered to be reflective of a good aquifer zone comprising medium/coarse grain sands/loosely cemented sand stone. Broad topographic lows are also considered good target areas for ground water. Based on resistivity data, hydrogeological considerations and field experience, yield potential has been predicted which, by and large, tallies with the groundwater yield of subsequent bore wells in the area. Also, all bore wells drilled on the basis of resistivity survey encountered sufficient ground water.
- ✓ Above analysis and discussions indicate the utility of geophysical resistivity survey in ground water exploration especially for locating bore well sites, delineation of aquifer zones and depth of boring for bore wells. Average thickness of aquifer zones in the depth range 60 m-200 m (from where groundwater is abstracted through bore wells) in the Agartala valley, Udaipur valley, Dharmanagar valley and Kailasahar valley are found to be 71.25 m, 118 m, 85.18 m, 111.13 m respectively.

6.4. Remarks on Study of Sub-surface Aquifer of Dhalai Tripura

- ✓ Resistivity sounding data (VES) of 38 points with 19 locations, where data collections were good, spreads over Kamalpur valley in both sides of Dhalai river under Dhalai district indicate that the subsurface formations in the areas of investigation are found to be distinct in terms of resistivity values.
- ✓ Resistivity values ranged between 30 ohm and 150 ohm are depicted with good aquifer zone varied between 110 m and 146 m and it has also been validated by Debbarma et al (2016c) in case of same terrain condition.
- ✓ However the discharge of well is observed to be limited even available of water is obtained at a greater extent.
- ✓ Thus it can be concluded that resistivity survey could be a good exercise not only to select the exact location of borewell but also in terms of cost and also to reduce the chances of failure of making a new bore well with a higher cost involvement.
- ✓ It also helps to prepare a contingency plan for estimation of availability of water for both irrigation as well as domestic purposes in the short as well as in the long run.

6.5. Remarks on Groundwater Overflow Zone of Tripura

- ✓ Overflow zone called as ‘flowing artesian well’ has been confined by impermeable materials and also the static water level is found to be top of the aquifer and the ground level surface. The results showed that overflow zones are found as maximum in flat portion compared to hilly area as because the movement of water is upward to downward.

- ✓ The higher amount of uncontrolled discharge with good water pressure and limited aquifer thickness in some valleys from flowing wells may cause flooding of the area and also aquifer materials may come along with the groundwater to the ground surface and eventually may reach surface water bodies and thus the quality of surface water may get deteriorate. This paper also concludes the uncontrolled overflow zones from wells may cause water scarcity if not properly utilized in a sustainable manner.

6.5.1. Recommendation for Groundwater Overflow Zone of Tripura

- ✓ Micro-water storage in the hilly area could be made by combining two valleys so that it will enhance not only storage capacity but also to be increased recharge volume.
- ✓ Since the movement of water comes from upstream to downstream so water withdrawal would be limited particularly in hilly terrain to avoid landslide and also to increase the overburden pressure in the overflow zones.
- ✓ If the withdrawal rate is found to be higher the soil materials will be dislodged faster with more granular space between the soil particles with following elastic and geometric property resulting secondary settlement may occur due to heavy loads.
- ✓ It is also observed that almost all flat areas are found to be overflow zone so more water could be extracted using extra pumping arrangement and to be stored in a separate reservoir for future use in water scarcity areas and also to reduce any kind of material damage.
- ✓ Since all stream present in Tripura are almost perennial to some extent, however still Tripura is a water scarcity in some patches which might be the fluctuation level of water table varying in a wider range seasonally. So to minimize these problems if more water to be stored, surface water retaining structures could be an alternative measures in or nearby artesian aquifer zone to mitigate the water crisis for a longer period.
- ✓ Gate valve may be installed at all uncontrolled discharge of deep tubewell supposed to be considered as overflow zone to be utilized to mitigate the water crisis for scarcity area and also to be increased the life of all selected overflow zone.

6.5.2. Remarks on Surface and Groundwater Interaction of Tripura State using GMS MODFLOW

- ✓ The aquifer of both study areas are hydraulically connected with the river and the river played a very important role to this conceptual model. The groundwater recharge to the aquifer is done through rainfall as well as through the river bed. Volumetric groundwater flow model has been designed for both Agartala and Khowai study areas. In the Agartala study area three seasonal variations summer, rainy and winter of river head-stage and precipitation were considered to find out the volumetric flow budgets and hydraulic heads for groundwater. Whereas in Khowai study area, the average river head-stages and rainfall were used to estimate volumetric flow budget and hydraulic heads for groundwater.
- ✓ Here this study tries to build up a conceptual model with the help of GMS MODFLOW to represent hydraulic head variations with respect to discharge as well as recharge well and also how the surface water could affect on the groundwater system due to changes in the

river head so that it will help not only to estimate the groundwater volume for water budgeting but also to make water security plan for sustainable withdrawal and also whether there could be any further development without disturbing confined or neither confined nor unconfined zone in the peripheral region.

- ✓ This conceptual model has been run using GMS MODFLOW package in steady state analysis method for 24 hours by taking average rainfall and with some assumptions. The hydraulic heads considerably changed near the wells and it also effected at the river heads which were very close to the wells. Thus the results conclude the heads decrease for the discharge wells whereas it increases towards recharge wells.

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"Tathapanji" 2009: Tripura Darpan

ANNEXURE-A (SOIL PROFILE)

SOIL PROFILE

Krishna Sadhu para		Aniram Para under dashamani para	
Dasda		**Dasda**	
Drilling completion	**26-7-12**	**Drilling completion**	**5-9-15**
Static water level (m)	**18.3**	**Static water level (m)**	**27.4**
Discharge(m^3/h)	**56.83**	**Discharge(m^3/h)**	**11.37**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Surface soil yellow in colour	3.05	Surface soil yellow in colour	6.10
Sticky Clay formation	109.73	Sand slate grey in colour	12.19
Fine sandy clay mixed grey in colour	21.34	Slate grey in colour	12.19
Fine sand grey in colour	24.38	Fine to medium sand grey in colour	73.15
Fine sandy clay grey in colour	3.05	Slate grey in colour	36.58
Fine to medium sand grey in colour	3.05	Fine sand grey in colour	3.05
Hard sand stone formation	9.14	Slate soil grey in colour	27.43
Fine sand grey in colour	6.10	Fine sand grey in colour	18.29
Sandy clay	3.05	Slate soil grey in colour	24.38
Fine sand grey in colour	6.10	Fine to medium sand grey in colour	21.34
Fine to medium sand grey in colour	18.29	Slate soil grey in colour	9.14
Clay	6.10	Fine to medium sand grey in colour	15.24
Sand mixed with clay	36.58	Slate soil grey in colour	106.68
Clay	24.38	**Total bore hole**	**365.76**
Total bore hole	**274.32**		
Jayashree		**Upath khali**	
Dasda		**Dharmanagar**	
Drilling completion	**07-02-13**	**Drilling completion**	**20-06-08**
Static water level (m)	**12.19**	**Static water level (m)**	**3**
Discharge(m^3/h)	**45.46**	**Discharge(m^3/h)**	**45.46**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Surface clay	6.10	Surface soil	6.09
Sandy clay colour high yellow	103.63	Sandy clay yellow	12.19
Hard clay colour light white	27.43	Clay mix with fine sand	30.48
Hard shale colour light grey	24.38	Sandy clay light yellow	33.53
Fine to medium sand in grey colour	30.48	Fine sand yellow in colour	10.67
Sandy clay grey in colour	27.43	Fine to medium sand grey in colour	9.14
Total bore hole	**219.46**	Medium sand yellow in colour	16.76
		Fine sand yellow in colour	24.38

		Fine to medium sand grey in colour	17.91
		Fine sand yellow in colour	12.54
		Total bore hole	**173.70**
Panisagar		**Roa 32 drone**	
Panisagar		**Dharmanagar**	
Drilling completion	**20-06-08**	**Drilling completion**	**30-05-08**
Static water level (m)	**3**	**Static water level (m)**	**3.5**
Discharge(m^3/h)	**45.46**	**Discharge(m^3/h)**	**45.46**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Surface soil	6.09	Top soil	3.05
Sandy clay yellow	12.19	Sandy clay yellow in colour	21.34
Clay mix with fine sand	30.48	Fine to medium sand yellow in colour	18.29
Sandy clay light yellow	33.53	Medium sand yellow in colour	12.19
Hard shale colour light grey	18.10	Fine to medium sand yellow in colour	6.10
Fine sand yellow in colour	10.67	Medium sand grey in colour	6.10
Fine to medium sand grey in colour	9.14	Sandy clay yellow in colour	24.38
Medium sand yellow in colour	16.76	Medium sand grey in colour	24.38
Fine sand yellow in colour	24.38	Sandy clay grey in colour	6.10
Fine sand yellow in colour	12.54	Fine to medium sand grey in colour	27.43
Fine to medium sand grey in colour	18.00	Sandy clay grey in colour	18.29
Fine sand yellow in colour	6.11	Clay yellow in colour	12.19
Total bore hole	**198**	**Total bore hole**	**179.83**
R1			
Chhechuya ADC Village		**West Sharbang ADC Village**	
Ompi		**Amarpur**	
Drilling completion	**10-06-12**	**Drilling completion**	**15-10-12**
Static water level (m)	**3.0**	**Static water level (m)**	**5.5**
Discharge(m^3/h)	**68.19**	**Discharge(m^3/h)**	**37.73**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Ordinary sandy soil yellowish in colour	36.58	Sandy soil light yellowish in colour	60.96
Clay grey in colour	3.05	Sandy soil yellowish in colour	6.10
Fine sand with mud yellowish in colour	33.53	Fine sand light yellow in colour	12.19
Sand with mud light reddish in colour	39.62	Clay with sand light yellowish in colour	36.58
Fine to medium sand grey in colour	33.53	Fine sand light yellowish in colour	6.10
Clay grey in colour	12.19	Fine to medium sand grey in colour	15.24
Fine to medium sand grey in colour	6.10	Fine sand light yellowish in colour	6.10

Clay grey in colour	18.29	Clay grey in colour	39.62
Total bore hole	**182.88**	**Total bore hole**	**182.88**
Thalbhanga para		**Dalak ADC Village**	
Amarpur		**Amarpur**	
Drilling completion	**01-05-12**	**Drilling completion**	**21-2-12**
Static water level (m)	**3.7**	**Static water level (m)**	**7.6**
Discharge(m^3/h)	**45.46**	**Discharge(m^3/h)**	**45.46**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Top soil light yellow in colour	9.14	Soil reddish in colour	9.14
Sandy soil light yellowish in colour	39.62	Sandy Soil reddish in colour	45.72
Fine sandy clay grey in colour	18.29	Clay grey in colour	3.05
Fine to medium sand grey in colour	24.38	Fine sand reddish in colour	48.77
Clay with sand light yellow in colour	3.05	Fine sand light grey in colour	39.62
Fine sand light grey in colour	12.19	Fine sandy clay grey in colour	24.38
Sandy clay grey in colour	15.24	Clay grey in colour	9.14
Clay grey in colour	39.62	**Total bore hole**	**179.83**
Total bore hole	**161.54**		
R2			
Salghara		**Paratia**	
Matabari		**Matabari**	
Drilling completion	**18-01-12**	**Drilling completion**	**16-05-13**
Static water level (m)	**3.66**	**Static water level (m)**	**3.35**
Discharge(m^3/h)	**177.30**	**Discharge(m^3/h)**	**45.46**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Top soil reddish in colour	3.05	Top soil yellowish in colour	60.96
Sandy soil yellowish in colour	51.82	Clay grey in colour	12.19
Clay grey in colour	3.05	Fine sand yellowish in colour	48.77
Fine sand light grey in colour	12.19	Clay grey in colour	18.29
Fine to medium sand	36.58	Fine to medium sand grey in colour	30.48
Sand with clay grey in colour	12.19	Fine sandy clay grey in colour	15.24
Fine sand light grey in colour	15.24	Fine to medium sand grey in colour	18.29
Fine sand light grey in colour	24.38	Clay grey in colour	9.14
Clay grey in colour	9.14	**Total bore hole**	**213.36**
Total bore hole	**167.64**		
Bagafa		**Nabaidya para (Garifa)**	
Bagafa		**Rupaichari**	

Drilling completion	**20-11-15**	**Drilling completion**	**22-11-11**
Static water level (m)	**Over flow**	**Static water level (m)**	**12.19**
Discharge(m^3/h)	**68.19**	**Discharge(m^3/h)**	**68.19**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Ordinary soil yellow in colour	6.10	Surface soil	3.05
Fine to medium sand yellow in colour	149.35	Yellow clay	3.05
Fine sand light grey in colour	42.67	Light Yellow fine sand	6.10
Fine sand grey in colour	6.10	Light Yellow clay	21.34
Sandy clay grey in colour	9.14	Light Yellow fine sand	6.10
Total bore hole	**213.36**	Yellow clay	3.05
		Light Yellow fine sand	3.05
Jalefa Market		Light Yellow clay	24.38
Satchand		Light grey fine sand	10.67
Drilling completion	**12-09-11**	Grey clay	7.62
Static water level (m)	**5.49**	Grey medium to fine sand	12.19
Discharge(m^3/h)	**68.65**	Light Yellow clay	4.57
Soil layer thickness	**bgl(m)**	Grey medium to fine sand	7.62
Surface soil	3.05	Yellow medium to fine sand	3.05
Reddish clay	6.10	Grey medium to fine sand	39.62
Light grey clay	9.14	Grey fine sand	4.57
Light grey sand	3.05	Grey clay	16.15
Grey clay	6.10	**Total bore hole**	**176.17**
Light grey sand	6.10		
Light Yellow clay	3.05		
Grey fine sand	9.14		
Grey clay	3.05		
Grey medium to fine sand	36.57		
Grey clay	6.10		
Grey medium to fine sand	48.77		
Grey clay	6.10		
Fine reddish clay	9.14		
Total bore hole	**155.44**		
R3			
Thalbhanga para		**Maidabari (Purba mock puskarini)**	
Amarpur		**Matabari**	
Drilling completion	**01-05-12**	**Drilling completion**	**16-09-11**

Static water level (m)	**3.7**	**Static water level (m)**	**Over flow**
Discharge(m^3/h)	**45.46**	**Discharge(m^3/h)**	**45.46**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Top soil light yellow in colour	9.14	Mud with clay grey in colour	3.05
Sandy soil light yellowish in colour	39.62	Sandy soil yellowish in colour	36.58
Fine sandy clay grey in colour	18.29	Fine sandy hard rock reddish in colour	12.19
Fine to medium sand grey in colour	24.38	Fine sand with mud yellowish in colour	33.53
Clay with sand light yellowish in colour	3.05	Fine sandy clay grey in colour	15.24
Fine sand light grey in colour	12.19	Fine to medium sand grey in colour	36.58
Sandy clay grey in colour	15.24	Fine sand with clay grey in colour	39.62
Clay grey in colour	39.62	Cite clay grey in colour	6.10
Total bore hole	**161.54**	**Total bore hole**	**182.88**

East Sarashima	
Hrishyamukh	
Drilling completion	**05-07-16**
Static water level (m)	**4.4**
Discharge(m^3/h)	**50.01**
Soil layer thickness	**bgl(m)**
Surface Soil	6.10
Yellow Clay	30.48
Sandy Clay yellow in colour	36.58
Whitish medium coarse sand	12.19
Clay grey and yellow in colour	45.72
Yellow fine to medium sand	30.48
Yellow clay	21.34
Total bore hole	**182.88**

R4

Rahimpur(RWS)		**Kalam Chowra**	
Baxanagar Block		**Baxanagar Block**	
Drilling completion	**05.04.01**	**Drilling completion**	**22.05.05**
Static water level (m)	**9.14**	**Static water level (m)**	**4.57**
Discharge(m^3/h)	**57.16**	**Discharge(m^3/h)**	**57.16**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Top soil.	6.10	Top Soil, Radish in colour.	3.05
Clay brown in colour.	6.10	Fine sand yellow in colour.	27.43

Clay grey in colour.	18.29	Fine sand light yellow in colour.	12.19
Sticky clay grey in colour.	30.48	State clay with stone.	147.83
Sticky clay deep grey in colour.	18.29	Grey medium to fine sand.	16.76
Fine to medium sand grey in colour.	54.86	Fine sand grey in colour.	15.24
Clay deep grey in colour.	48.77	Very fine sand.	3.04
Clay grey in colour.	24.38	Hard clay dark grey in colour.	6.10
Total bore hole	**207.26**	**Total bore hole**	**231.64**
Kamalanagar		**Tamshabari W/S(Rept.)**	
Baxanagar Block		**Sonamura Block**	
Drilling completion	**30.09.03**	**Drilling completion**	**29.11.95**
Static water level (m)	**4.57**	**Static water level (m)**	**5.79**
Discharge(m^3/h)	**56.78**	**Discharge(m^3/h)**	**51.23**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Fine sand yellow in colour.	3.05	Sandy clay with yellow in colour.	3.05
Sticky clay grey in colour.	82.30	Clay grey in colour.	3.05
Fine to medium sand grey in colour.	39.62	Fine sand light grey in colour.	3.05
Sticky clay grey in colour.	57.91	Fine sandy clay grey in colour.	3.05
Total bore hole	**182.88**	Fine sandy clay yellow in colour.	6.10
		Fine sand grey in colour.	6.10
Sobhapur		Medium sand white in colour.	12.19
Sonamura Block		Clay in dark grey in colour.	109.73
Drilling completion	**15.06.04**	Fine to medium sand grey in colour.	3.05
Static water level (m)	**8.0772**	Clay dark grey in colour.	15.24
Discharge(m^3/h)	**68.64**	Fine to medium sand grey in colour.	3.05
Soil layer thickness	**bgl(m)**	Medium sand grey in colour.	15.24
Top soil.	3.05	Sandy clay grey in colour.	3.04
Light yellow fine sand.	1.52	Clay dark grey in colour.	15.24
Yellowish sandy clay.	13.72	**Total bore hole**	**201.16**
Fine sand light yellow in colour.	30.48		
Light yellow fine to medium sand.	7.62	**I C Nagar**	
Medium to fine sand grey in colour.	33.53	**Rajnagar Block**	
Grey very fine sand.	3.05		
Clay greyish in colour.	83.82	**Drilling completion**	**21-09-11**
Total bore hole	**176.78**	**Static water level (m)**	**4.57**
		Discharge(m^3/h)	**45.46**

Nirbhoypur(M.I)		Soil layer thickness	bgl(m)
Khatalia Block		Surface soil	3.05
Drilling completion	**20.03.06**	Yellow fine sand	10.67
Static water level (m)	**7.62**	Yellow Medium to fine sand	25.91
Discharge(m^3/h)	**34.10**	Yellow sand	24.38
Soil layer thickness	**bgl(m)**	Light yellow clay	6.10
Hard soil, brown in colour.	6.10	Light yellow sandy clay	9.14
Sandy soil, yellowish in colour.	33.53	Yellow Medium to fine sand	21.34
Fine sand, light yellow in colour.	39.62	Light yellow clay	3.05
Sandy soil, yellow in colour	12.19	Yellow Medium to fine sand	9.14
Fine sand, light yellow in colour.	24.38	Grey Medium to fine sand	3.05
Clay, grey in colour.	6.10	Grey clay	7.62
Medium sand light yellow in colour.	51.82	Grey Medium to fine sand	7.62
Sand, light yellow in colour.	9.14	Grey clay	9.14
Total bore hole	**182.88**	Grey Medium to fine sand	10.67
		Grey clay	3.05
Manai Pathar		Grey Medium to fine sand	12.19
Sonamura Block		Grey clay	8.53
Drilling completion	**03.04.00**	**Total bore hole**	**174.65**
Static water level (m)	**9.14**		
Discharge(m^3/h)	**29.55**		
Soil layer thickness	**bgl(m)**		
Clay sticky and hard black in colour.	6.10		
Hard sticky sand dark grey in colour.	155.45		
Fine sand deep grey in colour.	39.62		
Fine sand dark grey in colour.	6.10		
Clay hard shale dark grey in colour.	6.10		
Total bore hole	**213.36**		
R5			
East jarulbachai		**Takarjala**	
Jampaijala Block		**Jampaijala Block**	
Drilling completion	**11.01.05**	**Drilling completion**	**29.03.07**
Static water level (m)	**21.34**	**Static water level (m)**	**0ft.**
Discharge(m^3/h)	**54.10**	**Discharge(m^3/h)**	**46.59**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Top soil brick red in colour.	6.10	Sand with soil.	9.14

Fine sand light yellow in colour.	24.38	Fine sand with soil, brown in colour.	9.14
Sandy soil, brown in colour.	6.10	Fine sand with soil, brown in colour.	6.10
Sand mixed with soil yellow in colour	21.26	Fine sand with soil, brown in colour.	3.05
Sandy soil, brown in colour.	12.19	Fine sand with soil, brown in colour.	15.24
Sandy soil, yellow in colour.	12.19	Fine sand, grey in colour.	12.19
Fine sand grey in colour.	36.58	Clay, grey in colour.	3.05
Very Fine sand grey in colour.	30.48	Sand with clay, grey in colour.	6.10
Fine to medium sand grey in colour.	36.58	Clay, dark grey in colour.	60.96
Fine sand grey in colour.	9.14	Fine to medium sand, grey in colour.	36.50
Total bore hole	**195.00**	Clay with sand, grey in colour.	6.10
		Fine to medium sand, grey in colour.	21.34
South Gokul Nagar		Sand with clay, grey in colour.	6.10
Sonamura Block		**Total bore hole**	**195.00**
Drilling completion	**12.04.06**		
Static water level (m)	**1.10**		
Discharge(m^3/h)	**68.19**		
Soil layer thickness	**bgl(m)**		
Top soil yellowish in colour.	3.05		
Light grey fine sand.	6.10		
Yellow medium sand.	3.05		
Yellowish sandy clay.	48.77		
Very hard slate clay.	3.05		
Sandy clay yellowish in colour.	94.00		
Yellow medium sand.	3.05		
Yellow sandy clay.	3.05		
Greyish caly mixed with sand.	6.10		
Light grey fine to medium sand.	27.43		
Grey hard clay.	4.37		
Total bore hole	**202.00**		
R6			
Charipara(BADP)		**Gajaria (Replacement)**	
AMC		**AMC**	
Drilling completion	**02.12.94**	**Drilling completion**	**22.02.05**
Static water level (m)	**5.49**	**Static water level (m)**	**3.2**
Discharge(m^3/h)	**80.92**	**Discharge(m^3/h)**	**68.19**
Soil layer thickness	**bgl(m)**	Soil layer thickness	**bgl(m)**

Clay, reddish in colour.	3.05	Top soil yellow in colour.	48.77
Clay, grey in colour.	12.19	Fine sand grey in colour.	24.38
Sand brown in colour.	36.58	Clay dark grey in colour.	3.05
Sand grains are very fine grey in colour.	76.20	Medium sand grey in colour	45.72
Medium sand grey in colour.	36.58	Fine sand grey in colour.	18.29
Total bore hole	**164.59**	**Total bore hole**	**140.21**
West Bhubanban		**Narayanpur Labour Colony(WR)**	
AMC		**Mohanpur Block**	
Drilling completion	**31-08-05**	**Drilling completion**	**28.1.08**
Static water level (m)	**6.71**	**Static water level (m)**	**9.14**
Discharge(m^3/h)	**80.92**	**Discharge(m^3/h)**	**77.74**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Top soil radish in colour	6.10	Top soil, brown in colour.	6.10
Yellow sandy clay	57.91	Sandy clay light yellow in colour	36.58
Grey sandy clay	6.10	Sandy soil, grey in colour.	6.10
Grey find sand	30.48	Clayey soil, light yellow in colour.	18.29
Clay grey in colour	3.05	Sandy clay light brown in colour.	12.19
Grey find sand	21.34	Fine sand whitish in colour.	24.38
Grey medium find sand	9.14	Fine sand grey in colour.	30.48
Grey medium find sand	36.58	clayey soil light grey in colour.	12.19
Sandy clay greyish in colour	12.19	Fine sand grey in colour.	42.67
Total bore hole	**182.88**	Fine sand, grey in colour.	9.14
		Total bore hole	**198.12**
Dakshin Ranguti			
Mohanpur Block		**P.T.C.Narsingarh**	
		Mohanpur Block	
Drilling completion	**28.01.09**	**Drilling completion**	**24.10.05**
Static water level (m)	**7.62**	**Static water level (m)**	**7.32**
Discharge(m^3/h)	**68.19**	**Discharge(m^3/h)**	**90.92**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Top soil, light brown in colour.	6.10	Top soil, brown in colour.	3.05
Sandy soil, light grey in colour.	12.19	Yellow soft clay.	6.10
Sand with soil, light brown colour.	42.00	Soft sandy clay brown in colour.	36.58
Fine to medium sand, grey colour.	83.82	Grey sticky clay.	6.10
Clay soil, grey in colour.	10.67	Light grey sand mixed with clay.	21.34

Total bore hole	**154.78**	Sandy clay yellowish in colour.	21.34
		Grey fine to medium sand.	24.38
		Clay grey in colour.	9.14
		Almost fine sand grey in colour.	9.14
		Fine sand grey in colour.	42.66
		Almost fine sand grey in colour.	6.10
		Total bore hole	**185.92**
R7			
Mohinipur		**Mohanpur Hospital**	
Mohanpur Block		**Mohanpur Block**	
Drilling completion	**08.04.09**	**Drilling completion**	**03.05.09**
Static water level (m)	**9.14**	**Static water level (m)**	**12.19**
Discharge(m^3/h)	**59.55**	**Discharge(m^3/h)**	**59.55**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Top soil, light grey in colour.	6.10	Top soil, brown in colour.	6.10
Sandy soil, brown in colour.	12.19	Sandy soil, light brown in colour.	15.24
Clay soil, grey in colour.	6.10	Sandy clay light grey in colour.	39.62
Fine sand, light yellow colour.	12.19	Fine to medium sand, grey in colour.	100.58
Medium sand light whitish colour.	6.10	**Total bore hole**	**161.54**
Fine to medium sand, grey in colour.	30.48		
Fine sand, light grey in colour.	6.10	**Rajchantai**	
Fine sand light brown in colour.	45.72	**Mandai**	
Fine to medium sand, grey in colour.	27.43	**Drilling completion**	**25.10.08**
Fine to medium sand, light whitish.	6.10	**Static water level (m)**	**4.57**
Fine to medium sand yellow colour.	12.19	**Discharge(m^3/h)**	**68.65**
Total bore hole	**170.68**	**Soil layer thickness**	**bgl(m)**
		Surface soil	3.05
Biman Kobra Para		Clay yellow in colour.	3.05
Mandai		Sandy clay yellow in colour.	12.19
Drilling completion	**11.04.03**	Sand with pebbles brown in colour.	6.10
Static water level (m)	**7.92**	Fine sand yellow in colour.	12.19
Discharge(m^3/h)	**68.19**	Clay grey in colour.	3.05
Soil layer thickness	**bgl(m)**	Fine sand yellow in colour.	9.14
Fine Sand light brown in colour.	33.53	Clay grey in colour.	3.05
Medium Sand light brown in colour.	33.53	Fine sand deep yellow in colour.	3.05
Fine Sand dark brown in colour.	6.10	Fine to medium sand yellow in colour.	42.67

Fine Sand light brown in colour	24.38	Sandy clay dark yellow in colour.	6.10
Clay grey in colour.	9.14	Medium to fine sand grey in colour.	12.19
Medium Sand grey in colour.	51.82	Medium sand grey in colour.	42.67
Fine clay sand grey in colour.	9.14	Fine sand grey in colour.	6.10
Sandy soil grey in colour.	15.24	Sandy clay grey in colour.	3.05
Total bore hole	**182.88**	Clay grey in colour.	6.10
		Total bore hole	**173.74**
R8			
Isha Ch. Nagar		**Chandranagar - I**	
Madhupur Block		**Bishalgarh Block**	
Drilling completion	**25.04.99**	**Drilling completion**	**26.12.99**
Static water level (m)	**2.44**	**Static water level (m)**	**4.5**
Discharge(m^3/h)	**80.92**	**Discharge(m^3/h)**	**80.92**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Top soil grey in colour.	39.62	Sandy soil light yellow in colour.	15.24
Fine sandy clay yellow in colour	42.67	Sandy clay grey in colour.	15.24
Fine sandy clay grey in colour.	15.24	Sandy clay light yellow in colour.	6.10
Fine sand yellow grey in colour	42.67	Sandy clay light grey in colour.	45.72
Fine sandy clay grey in colour.	30.48	Sand fine sand dark grey in colour.	33.53
Fine sand yellow in colour.	36.58	Sandy clay blackish in colour.	21.34
Total bore hole	**207.26**	Fine sandy clay blackish in colour.	15.24
		Clayey sand blackish in colour.	30.48
Bikram Nagar – II		**Total bore hole**	**182.88**
Bishalgarh Block			
Drilling completion	**06.01.98**	**Vivekananda Palli (Ramkrishna)**	
Static water level (m)	**7.8**	**Bishalgarh Block**	
Discharge(m^3/h)	**45.32**	**Drilling completion**	**21.02.99**
Soil layer thickness	**bgl(m)**	**Static water level (m)**	**6.10**
Surface soil.	6.10	**Discharge(m^3/h)**	**80.92**
Yellow medium sand.	39.63	**Soil layer thickness**	**bgl(m)**
Yellowish-white fine to medium sand.	21.34	Fine sand yellowish in colour.	15.24
Greyish fine sand.	12.19	Fine sandy clay yellowish in colour.	30.48
Sandy clay.	6.10	Sandy clay yellowish in colour.	30.48
Grey fine sand.	51.82	Fine sand yellowish in colour.	30.48
Grey sandy clay	6.10	Sandy clay yellowish in colour.	21.34
Grey medium sand.	39.53	Coarse sand grey in colour.	36.58

Grey medium to fine sand.	6.10	Fine sand grey in colour.	3.05
Blackish sticky clay.	9.14	Fine sandy clay dark grey in colour.	15.24
Total bore hole	**198.03**	Fine Sand dark grey in colour.	60.96
		Total bore hole	**243.84**
Nalchar(South)			
Melaghar		**Melaghar W/S scheme (Rept.)**	
Drilling completion	**26.12.99**	**Melaghar**	
Static water level (m)	**1.52**	**Drilling completion**	**18.12.95**
Discharge(m^3/h)	**33.5**	**Static water level (m)**	**5.49**
Soil layer thickness	**bgl(m)**	**Discharge(m^3/h)**	**45**
Fine sand yellowish in colour.	85.34	Soil layer thickness	**bgl(m)**
Sand fine to medium grey in colour.	54.86	Fine sand light brown in colour.	6.10
Sandy clay grey in colour.	18.29	Fine sand brown in colour.	6.10
Total bore hole	**158.50**	Fine sand yellow in colour.	18.29
Chandrigarh		Sandy pebble yellow in colour.	6.10
Melaghar		Fine sand yellow in colour.	48.77
Drilling completion	**20.09.00**	Fine sand brown in colour.	6.10
Static water level (m)	**8.53**	Fine sand light brown in colour.	12.19
Discharge(m^3/h)	**38.9**	Medium sand grey in colour.	36.58
Soil layer thickness	**bgl(m)**	Fine sand with light clay in colour.	48.77
Top soil, brown in colour.	6.10	Fine sand with clay.	6.10
Fine to medium sand brown in colour.	9.14	**Total bore hole**	**195.07**
Fine sand light brown in colour.	18.29		
Fine sand dark brown colour.	18.29		
Fine sand yellowish in colour.	76.20		
Sand dark grey in colour.	6.10		
Fine sandy clay grey in colour.	3.05		
Fine sandy clay grey in colour.	9.14		
Fine to medium sand grey in colour.	30.48		
Sandy clay grey in colour.	6.10		
Total bore hole	**182.88**		
R9			
Singi chara near BSF camp		**East Ganki**	
Khowai		**Khowai**	
Drilling completion	**36196**	**Drilling completion**	**36102**
Static water level (m)	**Over flow**	**Static water level (m)**	**5.49**

Discharge(m^3/h)	**136.38**
Soil layer thickness	**bgl(m)**
Sandy clay light brown in colour	12.19
Clay sticky brown in colour	12.19
Sand fine to medium grey in colour	6.10
clayey fine sand light grey in colour	60.96
Fine sand dark grey in colour	27.43
Fine sand light grey in colour	18.29
Fine to medium sand grey in colour	21.34
Sandy clay grey in colour	6.10
clayey fine sand dark grey in colour	33.53
Total bore hole	**198.12**
Ramani mohan palli Sonatala	
Khowai	
Drilling completion	**40730**
Static water level (m)	**3.05**
Discharge(m^3/h)	**126.56**
Soil layer thickness	**bgl(m))**
Surface soil brown in colour	12.20
Clay sticky grey in colour	21.35
Fine sand reddish in colour	18.30
Clay sticky grey in colour	3.05
Medium sand grey in colour	3.00
Clay sticky grey in colour	15.10
Medium sand whitish in colour	27.45
Clay sticky grey in colour	3.05
Fine sand Whitish in colour	3.05
Sticky clay with stone grey in colour	9.15
Fine to medium sand grey in colour	29.60
Clay sticky grey in colour	4.15
Medium sand grey in colour	3.05
Clay sticky grey in colour	12.20
Total bore hole	**164.7**

Discharge(m^3/h)	**110.02**
Soil layer thickness	**bgl(m)**
Clay reddish brown in colour	27.43
Clay grey in colour	15.24
Fine sand grey in colour	42.67
Fine sand grey in colour	60.96
Clay dark grey in colour	12.19
Total bore hole	**158.50**
Malay Najak	
Mungia Kami Block	
Drilling completion	**16.07.04**
Static water level (m)	**4.57**
Discharge(m3/h)	**45**
Soil layer thickness	**bgl(m)**
Top soil light yellow in colour.	6.10
Sand with soil, brown in colour.	6.10
Sandy soil, light yellow in colour.	24.38
Sand light yellow in colour.	67.06
Sandy clay light yellow in colour.	48.77
Fine sand grey in colour.	48.77
Clay, light grey in colour.	12.19
Total bore hole	**213.36**
Taksha Para	
Mungia Kami Block	
Drilling completion	**01.10.05**
Static water level (m)	**1.52**
Discharge(m^3/h)	**46.60**
Soil layer thickness	**bgl(m)**
Top soil, deep yellow in colour.	6.10
Fine sand, yellow in colour.	24.38
Fine sandy clay yellow in colour.	9.14
Fine sand light, yellow in colour.	21.34
Fine to medium Sand mixed with Clay dark yellow in colour.	54.86
Clay dark grey in colour.	9.14

		Fine to medium, light grey in colour.	6.10
		Clay dark grey in colour.	67.06
		Total bore hole	**198.12**
R10			
Mohanpur Hospital		**Lembucharra Agriculture.**	
Mohanpur Block		**Mohanpur Block**	
Drilling completion	**03.05.09**	**Drilling completion**	**04.10.07**
Static water level (m)	**12.19**	**Static water level (m)**	**9.32**
Discharge(m^3/h)	**59.55**	**Discharge(m^3/h)**	**55.69**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Top soil, brown in colour.	6.10	Reddish top soil	3.05
Sand with soil, light brown in colour.	15.24	Clay yellow in colour.	6.10
Sandy clay light grey in colour.	39.08	Clay grey in colour.	3.05
Fine to medium sand, grey in colour.	100.58	Yellow fine sand	6.10
Total bore hole	**161.00**	Clay grey in colour.	21.34
		Grey sand mixed with clay.	33.53
Mekliband (MI)		Fine sand, grey in colour.	24.38
		Clay grey in colour.	3.05
Drilling completion	**10.6.14**	Grey fine to medium sand.	51.82
Static water level (m)	**3.05**	Almost medium grey sand.	15.30
Discharge(m^3/h)	**61.37**	Fine to medium sand.	18.30
Soil layer thickness	**bgl(m)**	**Total bore hole**	**186.00**
Top soil brown in colour.	18.29		
Sand with soil light grey in colour.	42.79	**Rubber Board Bhalukia Tilla**	
Medium sand Smokey grey in colour	115.82	**AMC**	
Sandy clay grey in colour.	6.10	**Drilling completion**	**10.05.08**
Total bore hole	**183.00**	**Static water level (m)**	**9.14**
		Discharge(m^3/h)	**34.10**
City Centre Paradise Chowmohoni Agartala		**Soil layer thickness**	**bgl(m))**
AMC		Top Soil Brown in colour	3.05
Drilling completion	**25.01.09**	Sandy soil radish in colour	27.43
Static water level (m)	**1.52**	Fine sandy clay yellow in colour	15.24
Discharge(m^3/h)	**120.47**	Sand with stiffly clay brown in colour	9.14
Soil layer thickness	**bgl(m)**	Sticky clay yellow in colour	3.05
Surface Soil	3.05	Fine to medium sand yellow in colour	54.86
Clay grey in colour	15.24	Fine to medium sand grey in colour	45.74

Medium sand Yellow in Colour	6.10	Sticky clay grey in colour	3.05
Clay grey in colour	3.05	Fine to medium sand grey in colour	6.44
Fine Yellow in Colour	33.53	**Total bore hole**	**168.00**
Medium sand Grey in colour	86.00		
Fine sand grey in colour	3.04	**Dukali II(w/s)**	
Total bore hole	**150.00**	**Dukli Block**	
		Drilling completion	**29.01.98**
Matinagar		**Static water level (m)**	**7.92**
Dukli Block		**Discharge(m^3/h)**	**68.19**
Drilling completion	**22.11.10**	**Soil layer thickness**	**bgl(m)**
Static water level (m)	**6.94**	Sandy clay light red in colour	18.29
Discharge(m^3/h)	**54.12**	Fine sand light yellow in colour	6.10
Soil layer thickness	**bgl(m)**	Sandy clay light brown in colour	12.21
Fine sandy clay brown in colour	9.14	Medium sand light yellow in colour	42.67
Fine sand light brown in colour	9.14	Sand fine Sand light grey in colour.	12.19
Fine sandy Clay Deep Brown Colour	42.67	Fine sand light grey in colour.	18.68
Fine sand with mica grey brown colour	88.39	Sand fine to medium grey in colour	48.77
Fine to medium sand grey in colour	9.14	Fine sandy clay grey in colour	6.10
Clay deep grey in colour	24.50	**Total bore hole**	**165.00**
Total bore hole	**183.00**		
		Hapania Hospital Medical college	
A.D.Nagar police Line		**Dukli**	
Agartala		**Drilling completion**	**29.03.06**
Drilling completion	**14.02.09**	**Static water level (m)**	**6.10**
Static water level (m)	**9.30**	**Discharge(m^3/h)**	**90.92**
Discharge(m^3/h)	**68.65**	**Soil layer thickness**	**bgl(m)**
Soil layer thickness	**bgl(m))**		
Surface soil.	3.05	Top soil brown in colour.	3.05
Sandy clay yellow in colour.	21.34	Sandy soil, light yellow in colour.	39.62
Fine sand yellow in colour.	9.14	Fine soil, light grey in colour.	48.41
Fine sand brown in colour.	6.10	Fine sand, smoke grey in colour.	73.15
Medium sand yellow in colour.	3.05	Smoke grey in colour.	48.77
Sandy clay yellow in colour.	9.14	**Total bore hole**	**213.00**
Medium sand yellow in colour.	9.14		
Sandy clay yellow in colour.	3.05	**Khash Madhupur**	
Medium sand yellow in colour.	3.05	**Madhupur**	

Clay grey in colour.	9.14
Medium sand yellow in colour.	3.05
Medium sand grey in colour.	12.19
Clay grey in colour.	3.05
Medium sand grey in colour.	51.37
Sand stone	3.05
Medium to fine sand grey in colour.	6.10
Total bore hole	**155.00**
Madhuban	
Drilling completion	**22.10.03**
Static water level (m)	**18.29**
Discharge(m^3/h)	**34.10**
Soil layer thickness	**bgl(m)**
Hard sandy soil deep brown in colour.	6.10
Fine Sand light yellow in colour.	24.38
Fine Sand brown in colour.	24.38
Fine sand yellow in colour.	24.73
Medium sand brown in colour.	18.29
Sand light brown to brown in colour.	27.44
Medium course sand grey in colour.	42.38
Clay deep grey in colour.	18.30
Total bore hole	**186.00**
University complex (surjamaninagar)	
Drilling completion	**10.09.99**
Static water level (m)	**16.76**
Discharge(m^3/h)	**94.79**
Soil layer thickness	**bgl(m)**
Top soil brown in colour.	54.86
Fine sandy clay brownish.in colour	36.58
Fine to medium sand grey in colour.	42.67
Fine sandy clay yellowish in colour	27.43
Clay blackish in colour	21.46

Drilling completion	**28.12.03**
Static water level (m)	**4.57**
Discharge(m^3/h)	**68.19**
Soil layer thickness	**bgl(m)**
Sand fine yellow in colour.	70.10
Fine sandy clay grey in colour.	21.34
fine to medium sand grey in colour.	42.67
fine to medium sand some with clay grey in colour.	18.29
Fine sandy clay dark grey in colour.	30.48
Sandy clay light grey in colour.	15.12
Total bore hole	**198.00**
Harishnagar Tea estate.	
Bishalgarh Block	
Drilling completion	**19.11.03**
Static water level (m)	**6.10**
Discharge(m^3/h)	**81.72**
Soil layer thickness	**bgl(m)**
Fine sand brown in colour.	12.19
Fine sandy clay brown in colour.	18.29
Fine sand light brown in colour.	12.19
Fine sand brown in colour.	6.10
Fine sand light brown in colour.	18.29
Fine sand light grey in colour.	6.10
Fine to medium sand grey in colour.	67.06
Fine sand grey in colour.	6.10
Fine to medium sand grey in colour.	15.70
Sandy clay grey in colour.	12.19
Total bore hole	**174.20**

Total bore hole	**183.00**		
R11			
Lalchara		**Chailengta - II (ST)**	
Chowmanu Block		**Chowmanu Block**	
Drilling completion	**20.07.04**	**Drilling completion**	**3.9.06**
Static water level (m)	**21.336**	**Static water level (m)**	**4.39**
Discharge(m^3/h)	**13.62**	**Discharge(m^3/h)**	**37.682**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Fine sand brown in colour	9.144	To Soil brown in colour	6.096
Fine sand whitish in colour	9.144	Sandy clay, light grey in colour	12.192
Fine sand brown in colour	12.192	Fine sandy clay grey in colour	42.672
Fine sand light brown in colour	18.288	Fine sand grey in colour	36.576
Fine sand grey in colour	27.432	Fine sand grey in colour	33.528
Sandy clay	33.53	Sticky clay blackish in colour	33.528
Sticky clay dark grey in colour	109.73	**Total bore hole**	**164.592**
Total bore hole	**219.46**		
Khetuicherra		**Karathicherra**	
Chowmanu Block		**Chowmanu Block**	
Drilling completion	**8.12.07**	**Drilling completion**	**08.05.06**
Static water level (m)	**Over flow**	**Static water level (m)**	**2.7432**
Discharge(m^3/h)	**22.821372**	**Discharge(m^3/h)**	**45.4609**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Hard soil light brown in colour	6.096	Top soil	3.048
Slate grey in colour	118.872	Clay grey in colour	12.192
Fine sand smoke grey in colour	3.048	Clay with sand grey in colour	33.528
Sandy clay, dark grey in colour	6.096	Fine sandy clay grey in colour	18.288
Fine sand smoke grey in colour	6.096	Fine sand grey in colour	54.864
Shale sticky clay dark grey in colour	57.912	Sticky clay dark grey in colour	97.536
Fine sand light grey in colour	36.576	**Total bore hole**	**219.456**
Fine sand light grey in colour	3.048		
Total bore hole	**237.744**		
Jamir cherra		**Marakpara(W/S)**	
Manu Block		**Manu Block**	
Drilling completion	**10.01.04**	**Drilling completion**	**12.06.04**

Static water level (m)	**6.7056**	**Static water level (m)**	**0.3048**
Discharge(m^3/h)	**68.1913**	**Discharge(m^3/h)**	**113.5**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Sand with soil, brownish in colour	24.384	Fine sand brown in colour	3.048
Fine sand with clay, grey in colour	97.536	Fine sand brown in colour	3.048
Fine to medium sand grey in colour	15.24	Fine sand grey in colour	24.384
Fine sand grey in colour	15.24	Fine sandy clay grey in colour	91.44
Fine to medium sand grey in colour	18.288	Fine sand light grey in colour	51.816
Fine sand with clay, grey in colour	15.24	**Total bore hole**	173.736
Fine sand, grey in colour	12.192		
Sandy clay grey in colour	15.24		
Total bore hole	**213.36**		
Nepaltila- II		**82 Mile**	
Chowmanu Block		**Manu Block**	
Drilling completion	**15.10.04**	**Drilling completion**	**04.12.00**
Static water level (m)	**4.572**	**Static water level (m)**	**7.62**
Discharge(m^3/h)	**45.4609**	**Discharge(m^3/h)**	**94.7859**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Top soil	6.096	Top soil	3.048
Fine sand radish in colour	12.192	Sandy clay yellow colour	131.064
Fine sand brown in colour	48.768	Course sand with grey colour	48.768
Fine sand grey in colour	6.096	Very fine sand with yellow colour	54.864
Fine sand light brown in colour	24.384	**Total bore hole**	**237.744**
Fine sand grey in colour	57.912		
Sandy clay grey in colour	30.48		
Total bore hole	**185.928**		
R12			
Tuichakma		**Raima Cherra**	
Dumburnagar		**Dumburnagar**	
Drilling completion	**14.04.02**	**Drilling completion**	**22.07.04**
Static water level (m)	**6.05**	**Static water level (m)**	**6.05**
Discharge(m^3/h)	**27.28**	**Discharge(m^3/h)**	**20.46**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Sandy clay yellow in colour	6.10	Fine sand yellowish colour	42.67
Sticky hard Clay dark grey in colour	70.10	Medium Sand grey in colour	36.58

Fine Sandy clay deep grey in colour	45.72	Fine Sandy clay deep grey in colour	45.72
Clay hard sticky dark in colour	91.44	Clay dark grey colour	88.39
Total bore hole	**213.36**	**Total bore hole**	**213.36**
Boul Khali		**Madanjoy Para, Raima V.C.**	
		Dumburnagar	
Drilling completion	**11.04.05**	**Drilling completion**	**02.06.12**
Static water level (m)	**3.04**	**Static water level (m)**	**6.05**
Discharge(m^3/h)	**27.28**	**Discharge(m^3/h)**	**11.77**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Top soil	9.14	Top soil yellow in colour	6.27
Clay grey in colour	15.24	Slate soil grey in colour	33.53
Fine sand grey in colour	12.19	Fine sticky clay grey in colour	73.58
Clay grey in colour	27.43	Fine to medium sand grey in colour	28.35
Fine to medium grey in colour	3.05	Sandy clay grey in colour	20.42
Fine to medium grey in colour	9.14	Slate soil grey in colour	75.59
Clay grey in colour	6.10	**Total bore hole**	**237.74**
Fine sand grey in colour	18.29		
Fine sandy clay grey in colour	21.34	**Gandacherra**	
Clay dark grey in colour	60.96	**Dumburnagar**	
Total bore hole	**182.88**	**Drilling completion**	**23.12.00**
		Static water level (m)	**3.60**
Ram Nagar		**Discharge(m^3/h)**	
Dumburnagar		**Soil layer thickness**	**bgl(m))**
Drilling completion		Sandy clay yellow in colour	6.10
Static water level (m)	**3.04**	Sandy clay grey in colour	12.19
Discharge(m^3/h)	**22.73**	Fine sand grey in colour	6.10
Soil layer thickness	**bgl(m)**	Fine to medium sand grey in colour	9.14
Hard soil dark grey in colour	98.63	Sandy clay grey in colour	3.05
Fine sand whitish in colour	6.10	Fine to medium sand grey in colour	6.10
Clay deep grey in colour	33.53	Fine sand grey in colour	9.14
Fine sand with soil grey in colour	3.05	Fine to medium sand grey in colour	6.10
Medium sand grey in colour	36.58	Fine sand grey in colour	6.10
Clay deep grey in colour	6.10	Fine to medium sand grey in colour	6.10
Total bore hole	**183.98**	Fine sand grey in colour	9.14
		Fine to medium sand grey in colour	6.10

		Fine sandy clay grey colour	6.10
		Shale	109.72
		Total bore hole	**201.16**
R13			
Champarai Para		**Hadukalak Para (Kulai RF Extn.)**	
Ambassa		**Ambassa**	
Drilling completion	**07.12.12**	**Drilling completion**	**16.10.12**
Static water level (m)	**67.06**	**Static water level (m)**	**36.58**
Discharge(m^3/h)	**29.55**	**Discharge(m^3/h)**	**46.60**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Surface soil, radish in colour	9.14	Surface soil, radish in colour	36.58
Hard stocky clay, grey in colour	94.49	Stocky clay grey in colour	106.68
Medium sandy clay grey in colour	82.06	Sticky clay sand grey in colour.	91.44
Hard clay, grey in colour	9.14	Medium course sand, grey in colour.	30.48
Course sand grey in colour	54.86	Medium sandy clay grey in colour	12.19
Clay, grey in colour	6.10	Medium course sand, grey in colour.	27.76
Sticky clay, grey in colour	36.58	Fine sand, grey in colour	39.62
Course sand ,grey in colour	6.10	Fine sand clay mixed, grey in colour	18.20
Sandy clay, grey in colour	18.29	Hard clay, grey in colour	3.05
Clay, grey in colour	15.24	**Total bore hole**	366.00
Total bore hole	332.00		
Kamalachara- II		**Ramratan Para**	
Ambassa		**Ambassa**	
Drilling completion	**15.07.05**	**Drilling completion**	**31.12.05**
Static water level (m)	**3.8**	**Static water level (m)**	**7.62**
Discharge(m^3/h)	**59.10**	**Discharge(m^3/h)**	**59.55**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Top soil. Light yellow in colour	6.10	Hard soil yellow in colour	6.10
Sand brown in colour	24.38	Sandy clay yellow in colour	6.10
Fine sand, light grey in colour	6.10	Fine to medium sand yellow colour	18.29
Fine sand grey in colour	12.19	Medium sand yellow in colour	30.48
Fine sandy clay grey in colour	9.14	Clay grey in colour	9.14
Fine sand light grey in colour	36.22	Fine sand yellow in colour	67.06
Fine sand grey in colour	9.14	Fine to medium sand grey in colour	45.74
Sticky clay dark grey in colour	109.73	Sandy clay light colour	6.10
Total bore hole	213.00	**Total bore hole**	189.00

Gantachara		**Harinmara**	
Ambassa		**Ambassa**	
Drilling completion	**31.08.07**	**Drilling completion**	**07.10.02**
Static water level (m)	**7.01**	**Static water level (m)**	**2.44**
Discharge(m^3/h)	**23.64**	**Discharge(m^3/h)**	**34.10**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Top soil	4.57	Top soil	3.05
Fine sand light yellowish in colour	28.96	Sand clay grey in colour	9.14
Fine sand all white in colour	27.43	Sandy clay whitish brown in colour	18.29
Fine sand light yellowish in colour	27.43	Clay with fine sand brown in colour	18.29
Fine sand mixed with clay	18.29	Sandy clay brown in colour	0.30
Fine sand light grey in colour	6.10	Sandy clay deep brown in colour	12.72
Sandy clay	42.67	Sand whitish brown in colour	6.10
Fine sand deep grey in colour	12.22	Fine sand whitish brown in colour	30.48
Sandy clay	3.05	Sandy clay brown in colour	12.19
Fine sand light grey in colour	6.10	clayey sand greyish brown in colour	12.19
Sticky clay	6.10	Clay greyish yellow in colour	18.29
Fine sand deep grey in colour	6.10	Sand deeps grey in colour	12.19
Total bore hole	189.00	Sandy clay brown in colour	18.29
		Sandy clay grey in colour	18.29
Maharani		Fine sandy clay grey in colour	6.10
Salema		Sandy clay grey in colour	6.10
Drilling completion	**21.02.06**	**Total bore hole**	202.00
Static water level (m)	**Over flow**		
Discharge(m^3/h)	**81.83**	Mechurai Para	
Soil layer thickness	**bgl(m)**	**Salema**	
Sticky clay brown in colour	18.29	**Drilling completion**	**03.05.05**
Sandy clay grey in colour	24.38	**Static water level (m)**	**1.83**
Clay grey in colour	12.19	**Discharge(m^3/h)**	**15.91**
Sandy clay grey in colour	6.10	**Soil layer thickness**	**bgl(m)**
Clay grey in colour	12.19	Clay grey in colour	24.38
Fine sandy clay grey in colour	48.77	Fine sand mixed with grey in colour	6.10
Fine to medium sand grey in colour	48.79	Clay grey in colour	6.10
Clay with sand grey in colour	18.29	Fine to medium grey in colour	6.10
Total bore hole	189.00	Clay grey in colour	15.24

		Medium sand grey in colour	9.14
Jamthum		Clay	6.10
Durga Chowmuhani		Fine to medium sand grey in colour	45.72
Drilling completion	**17.08.05**	Clay grey in colour	64.13
Static water level (m)	**1.52**	**Total bore hole**	183.00
Discharge(m^3/h)	**68.19**		
Soil layer thickness	**bgl(m)**	**Purba Tilla, Mahabir G.P, Kamalpur, Dhalai,**	
Top soil yellow in colour	6.10	**Durga Chowmuhani**	
Fine sand light yellow in colour	18.29	**Drilling completion**	**22.03.12**
Fine sandy clay light grey in colour	12.19	**Static water level (m)**	**12.19**
Fine sand grey in colour	9.14	**Discharge(m^3/h)**	**11.37**
Fine to medium sand grey in colour	76.20	**Soil layer thickness**	**bgl(m)**
Fine sand grey in colour	6.10	Top soil light yellow in colour	6.10
Fine to medium grey in colour	12.19	Sandy clay in grey colour	86.87
Fine sandy clay deep grey in colour	42.79	Fine sand whitish in colour	9.14
Total bore hole	183.00	Sticky clay grey in colour	25.91
		Fine sand whitish in colour	42.67
Chankap		Sticky clay grey in colour	42.31
Salema		**Total bore hole**	213.00
Drilling completion	**12.07.02**		
Static water level (m)	**3.48**	Kalachari	
Discharge(m^3/h)	**68.19**	N 24.16646 E 091.81682	
Soil layer thickness	**bgl(m)**	**Durga Chowmuhani**	
Hard soil brown in colour	12.19	**Drilling completion**	**09.10.05**
Sandy soil yellow in colour	12.19	**Static water level (m)**	**8.5344**
Medium sand white in colour	6.10	**Discharge(m^3/h)**	**28.39**
Sandy soil light grey colour	3.22	**Soil layer thickness**	**bgl(m)**
Fine sand grey in colour	12.19	Fine sand yellowish in colour	6.096
Sand brown in colour	21.34	Fine sand grey in colour	51.816
Clay light grey in colour	36.58	Sandy clay	24.384
Fine sand whitish in colour	3.66	Fine sand grey in colour	27.432
Fine sand whitish in colour	2.44	Fine to medium sand light grey	36.576
Clay light grey in colour	18.29	Fine sand grey in colour	12.03
Fine sand deep grey in colour	51.82	Fine to medium light grey in colour	6.096
Total bore hole	180.00	Fine sand light grey in colour	12.192
		Fine to medium sand light grey	6.096

Srirampur		Fine sand light grey in colour	12.192
Durga Chowmuhani		Sandy clay	6.096
Drilling completion	**28.05.04**	**Total bore hole**	201.006
Static water level (m)	**Over flow**		
Discharge(m^3/h)	**68.19**	**Kamalpur Town**	
Soil layer thickness	**bgl(m)**	**Durga Chowmuhani**	
Sandy clay dark brown in colour	27.43	**Drilling completion**	**19.07.00**
Fine Sand light brown in colour	45.72	**Static water level (m)**	**4.88**
Fine Sandy clay dark brown in colour	42.67	**Discharge(m^3/h)**	**17.14**
Sand fine to medium grey in colour	48.77	**Soil layer thickness**	**bgl(m)**
Medium sand grey in colour	48.41	Top soil	3.05
Total bore hole	213.00	Fine sand light yellow colour	15.24
		Sandy clay light yellow in colour	9.14
Mayachari		Fine sand yellowish in colour	6.10
Durga Chowmuhani		Sandy clay yellowish in colour	15.24
Drilling completion	**05.07.08**	Clay grey in colour	6.10
Static water level (m)	**12.34**	Fine sand with clay grey colour	6.10
Discharge(m^3/h)	**37.73**	Sandy clay grey in colour	32.61
Soil layer thickness	**bgl(m)**	Fine sand light yellow colour	3.05
Surface clay	3.05	Fine sand light yellow colour	6.10
Clay brown in colour	39.62	Sandy clay grey in colour	3.56
Sandy clay brown in colour	24.38	Fine sand light yellow colour	12.19
Fine sand light grey in colour	18.29	Sandy clay light grey in colour	30.48
Clay grey in colour	3.05	Fine sand whitish in colour	12.19
Fine sand light grey in colour	3.05	Sand mixed with clay yellow colour	18.28
Clay zone grey colour	6.10	Fine sand whitish in colour	3.05
Sandy clay brown in colour	3.05	Clay grey in colour	33.53
Clay brown in colour	12.19	**Total bore hole**	216.00
Sandy clay brown in colour	6.16		
Medium course sand brown in colour	12.19	**Mohanpur**	
Clay zone brown in colour	18.29	**Durga Chowmuhani**	
Fine sand light grey in colour	12.19	**Drilling completion**	**11.02.07**
Hard Clay	12.20	**Static water level (m)**	**12.19**
Clay zone brown in colour	12.19	**Discharge(m^3/h)**	**9.46**
Total bore hole	186.00	**Soil layer thickness**	**bgl(m)**
		Surface soil	6.10

Ganga Nagar		Fine sand light yellowish in colour	24.38
Durga Chowmuhani			
Drilling completion	10.04.03	Clay	6.10
Static water level (m)	1.52	Fine sand	6.10
Discharge(m^3/h)	22.71	Fine sand mixed with clay	48.60
Soil layer thickness	**bgl(m))**	Sticky clay	109.73
Hard soil brown in colour	9.14	**Total bore hole**	201.00
Sand with soil light black in colour	30.48		
Fine sand with clay, black in colour	12.19		
Fine sand grey in colour	27.43		
Sandy clay black in colour	42.31		
Fine sand light grey in colour	18.29		
Sandy clay dark grey in colour	18.29		
Fine sand light grey in colour	6.10		
Sandy clay light grey in colour	18.29		
Sand clay blackish in colour	18.29		
Fine sand light grey in colour	6.10		
Clay dark grey in colour	6.10		
Total bore hole	213.00		
R14			
Chowmanu		**West Karamchara**	
Chowmanu Block		**Chowmanu Block**	
Drilling completion	**01.09.01**	**Drilling completion**	**29.11.06**
Static water level (m)	**0.61**	**Static water level (m)**	**Over flow**
Discharge(m^3/h)	**37.73**	**Discharge(m^3/h)**	**90.92**
Soil layer thickness	**bgl(m)**	**Soil layer thickness**	**bgl(m)**
Top soil light yellow colour	9.144	Top soil	6.096
Fine sandy clay white in colour	6.096	Clay with sand deep grey in colour	6.096
Clay light grey in colour	51.816	Fine sand deep grey in colour	152.4
Fine to medium sand grey in colour	12.192	Clay with sand grey in colour	18.288
Sticky clay light grey in colour	6.096	**Total bore hole**	**182.88**
Fine to medium sand grey in colour	9.144		
Clay light grey in colour	42.672	**Unakoti (kukidhar)**	
Fine to medium sand grey colour	21.336	**Kumarghat**	
Clay dark grey in colour	6.096	**Drilling completion**	**16-06-10**
Fine sand grey in colour	6.096	**Static water level (m)**	**6.10**

Clay dark grey in colour	18.288	**Discharge(m^3/h)**	**45.46**
Total bore hole	**188.976**	**Soil layer thickness**	**bgl(m)**
		Clay grey in colour	6.10
Unakoti (Paschim Ratachara)		Fine sand grey in colour	82.30
Kumarghat		Sandy clay grey in colour	6.10
Drilling completion	**08-02-08**	Medium sand grey in colour	15.24
Static water level (m)	**7.62**	Medium sand grey in colour	36.58
Discharge(m^3/h)	**45.46**	Sandy clay grey in colour	3.05
Soil layer thickness	**bgl(m)**	Very fine sand black in colour	3.05
Fine sand yellowish in colour	45.72	Clay grey in colour	15.24
Medium sand yellow in colour	24.38	**Total bore hole**	**167.64**
Clay yellow in colour	6.10		
Medium sand yellow in colour	3.05	**Khawrabil**	
Sandy Clay yellow in colour	6.10	**Kailashahar**	
Medium sand yellow in colour	15.24	**Drilling completion**	**05-12-09**
Sandy Clay yellow in colour	3.05	**Static water level (m)**	**5.49**
Medium sand yellow in colour	3.05	**Discharge(m^3/h)**	**113.65**
Sandy Clay	3.05	**Soil layer thickness**	**bgl(m)**
Medium sand yellow in colour	6.10	Top soil	3.05
Sandy Clay	3.05	Sticky Clay yellow in colour	6.10
Slate black in colour	3.05	Medium sand Grey in colour	3.05
Sandy Clay yellow in colour	12.19	Sandy Clay yellow in colour	9.14
Medium sand yellow in colour	12.19	Sticky Clay yellow in colour	12.19
Sandy Clay	32.00	Fine sand yellow in colour	6.10
Total bore hole	**178.31**	Sticky Clay yellow in colour	18.29
		Medium sand Grey in colour	3.05
		Sticky Clay yellow in colour	15.24
		Medium sand Grey in colour	6.10
		Sticky Clay yellow in colour	9.14
		Medium sand Grey in colour	6.10
		Sticky Clay yellow in colour	9.14
		Medium sand Grey in colour	6.10
		Hard Sticky Clay yellow in colour	48.76
		Total bore hole	**161.53**
R15			

ANNEXURE-B

(All standard empirical formulae)

All standard empirical formulae

Average annual Rainfall precipitation=2115.74 mm=83.29685 inches.

Average annual monsoon Rainfall =1253.38 mm =49.34567 inches.

1 Chaturvedi formula:(1936):

= 2.0 (P - 15)^0.4 = 10.83423564 inches =275.1895853 mm

= 0.275189585 m

Recharge volume = area X recharge

= 558997 ha x 0.275189585 m

= 153830.1526 ha-m = 1.538301526 BCM.

where, Ref = net recharge due to precipitation during the year, in inches;

and P = annual precipitation, in inches.

2 Roorkee and the modified form of the formula

= 1.35 (P - 14)^0.5 = 11.23829391 inches =285.4526653 mm

= 0.285452665 m

Recharge volume = area X recharge

= 558997 ha x 0.285452665 m

= 159567.1835ha-m = 1.595671835 BCM.

3 Kumar and Seethapathi (2002):

= 0.63 (P - 15.28)^0.76 = 9.202269 inches = 233.737 mm
= 0.233737635 m

Recharge volume : area X recharge

= 558997 ha x 0.233737635 m

= 130658.6366ha-m = 1.306586366 BCM.

4 Amritsar formula :

= 2.5 (P - 16)0.5 = 20.5091443 inches = 520.9322653 mm

= 0.520932265 m .

Recharge volume : area X recharge

= 558997 ha x 0.520932265 m

= 291199.5735 ha-m = 2.911995735 BCM.

5 Krishna Rao(1970): = 0.35 (P - 600) for areas with P above 2000 mm

= 530.509 mm = 0.530509 m

Recharge volume : area X recharge

. = 558997 ha x 0.530509 m

= 296552.9395 ha-m = 2.96552939 BCM.

6 Chandra and Saxena (1975):

= 3.984 (P – 40.64)^0.5 = 52.087505 cm = 0.52087505 m

Where,

Rr = Recharge to the groundwater (cms)

P = Monthly precipitation (cms).

Recharge volume : area X recharge

= 558997 ha x 0.520875053 m

= 291167.5919 ha-m = 2.911675919 BCM.

7 Bredenkamp (1990):

= 0.2 (p – 395) = 344.148 mm = 0.344148 m

where ,

p is rainfall (in mm/year).

Recharge volume : area X recharge

= 558997 ha x 0.344148 m = 192377.6 ha-m

= 1.923776996 BCM.

8 Sinha and Sharma -1988:

= 50.8 ((p/25.4)-15)^ 0.4 = 275.1845092 mm

= 0.275184509 m

Where,

P= precipitation is greater than 380 mm/year

Recharge volume : area X recharge

= 558997 ha x 0.275184509 m = 153827.3151 ha-m

= 1.53827 BCM

9 The Water 2010 Modelling Approach:

= P = E + R + D , D=P -(E + R) = 2.03 BCM

= A steady-state catchment water balance modelling approach used. Under this approach, precipitation is equal to total evaporation (soil evaporation and transpiration) plus runoff (as surface and subsurface runoff) and drainage to below the root zone.

Where,

P = precipitation, = 2.115m ,vol =22.2 BCM

E = actual evapotranspiration = 13.45BCM

R = surface/ sub-surface runoff = 6.9 BCM

D = deep drainage. =2.03BCM

10 Groundwater storage change (Ws):

$\Delta S = \Delta H. A. Y$

Where,

ΔS = Change in groundwater storage.

ΔH = Water table fluctuation. =1.71 m

A = area under consideration.= 558997 ha

Y = specific yield of the formation = .08 (CGWB)

ΔS = 76470.78 ha-m = 0.7647 BCM

ANNEXURE-C

(Groundwater Resource Estimation Procedure)

Groundwater Resource Estimation Procedure

Step 1

Area considered for assessment (ha) = (total geological area of a block) - (hilly area of the unit)

Total area = 10491.69 sq.km. = 1049169 ha – 490172 ha .(hilly area is zero) [in calculation area considered block wise]

Ground water recharge area = 558997 ha.

Step 2

Groundwater draft= Total nos. of a particular type of Groundwater structure X Unit draft (ha-m/yr) for respective structure.

OR

Dependency on Groundwater As per population,

Year 2015= 985057(Urban), 2878744 (Rural) = 3863801 person

Year 2051= 6.397914711 million (projected)

$$\text{As per population} = \frac{(\text{Persons X 100 l X 365 days}) \text{ (for urban)}}{(1000 \text{ lit X } 10000\text{m}^2.)}$$

= ha-m= 7797ha-m= 0.078BCM.

Note,

In town as per I.S. 1.35 l/head/day, (Tripura DWS 100 lit/capita/day)

In village as per I.S. 60 l/head/day. (Tripura DWS 40 lit/capita/day)

1 hect = 10000m^2.

1 gallon = 4.54 l

(Water supply data from Drinking Water & Sanitation Govt of Tripura. planning circle, Kunjaban Agt as on 31.12.2016. and population data from census office Agartala Govt of India, as on 2016 and also Agartala Municipality Council , population)

Step 3

Gross GW draft for all uses = (Gross GW draft for irrigational uses) + (Gross GW draft for domestic & industrial uses)

Gross GW draft for all uses = (3i) + (3ii)

= ha-m.

Step 3.i

Gross GW draft for irrigational uses = (Gross Monsoon GW draft for irrigation) + (Tripura Gross Non-monsoon GW draft for irrigation) = 0

Step 3.i.a

Gross Monsoon GW draft for irrigation = Draft of over flows during monsoon = 0

Step 3.i.b

Gross non-monsoon GW draft for irrigation

= Draft for overflows during non-monsoon

+ Draft of DTWs + Draft for STWs (shallow pumps)

(Non-monsoon uses of irrigation water from deep tube-well above 500 ft bellow from ground level)

Step 3.ii

Gross GW draft for domestic and industrial uses

= (Gross GW draft for domestic and industrial uses during monsoon) + (Gross draft for domestic and industrial uses during non0monsoon).

= (Draft of total nos. of DTWs, Hand-pumps, MK-II/ MK-III tube-well sanitary wells, ring wells during monsoon) (Draft of total nos. of DTWs, hand-pumps, MK-II/MK-III tube-well sanitary wells, ring wells during non-monsoon)

Step 4

Recharge from irrigation water (RGWI) =

[recharge from irrigation (GW) applied during monsoon for all kinds of crops]

+

[recharge from irrigation n (GW) applied during monsoon for all kinds of crops]

= 4(i) + 4(ii) .= ha-m

Step 4.i

Recharge for irrigation water (GW) applied during monsoon in Tripura is nil

Step 4.ii

Recharge for irrigation water (GW) applied during non-monsoon =

(Irrigation water applied for paddy X REF for paddy) +

(Irrigation water applied for non-paddy X REF for non-paddy)

= (4iii) X REF + (4iv) X REF

= ha-m

Step 4.iii

Irrigation water applied for paddy = (Area irrigated under paddy) X 1.2 m

= ha X 1.2 m = ha-m.

(Data from water resources .Agartala.)

Step 4.iv

Irrigation water applied for non-paddy = (Area irrigated under non-paddy) X 0.1 m

= ha X 0.1 m = ha-m

(Data from water resources Sub-Division .Agartala.)

***Return flow factor (REF) for paddy is 0.45 (GEC'04 book)**

***Return flow fractor (REF) for non-paddy is 0.25 (GEC'04 book)**

(Total irrigation water used from deep tube-well which is below 400 ft from ground)

Step 5.

Recharge from irrigation, surface water (RSWI) applied =

Recharge from irrigation, surface water (SW) applied during monsoon for all kind of crops + Recharge from irrigation, surface water (SW) applied during non-monsoon for all kinds of crops.

= 5(i) + 5(ii) = ha-m

Step 5.i

Recharge from irrigation, surface water (SW) applied during monsoon in Tripura is nil.

Step 5.ii

Recharge from irrigation, surface water (SW) applied during non-monsoon

= (Irrigation water applied for paddy X REF for paddy)

+

(Irrigation water applied for non-paddy X REF for non-paddy)

= 5(iii) X REF + 5(iv) X REF

= ha-m.

Step 5.iii

Irrigation water applied for paddy = (Area irrigated under paddy) x 1.2 m

= ha x 1.2 m= ha-m

(Data from water resources .Agartala.)

Step 5.iv

Irrigation water applied for non-paddy = (Area irrigated under non-paddy) x 0.1 m

= ha x 0.1 m = ha-m

(Data from water resources Sub-Division .Agartala.)

Return flow factor (REF) for paddy is 0.50 (GEC'04 book)

Return flow factor (REF) for non-paddy is 0.30 (GEC'04 book)

Step 6

Recharge from Ponds/Tanks (Rp/t)

= Recharge from ponds/tanks during monsoon (M Rp/t)

+

Recharge from ponds/tanks during non-monsoon (NM Rp/t)

= 6(i) + 6(ii) = ha-m

Step 6.i

Recharge from ponds/tanks during monsoon (M Rp/t) =

$$M\ Rp/t = \frac{(1.44 \times \text{Av. Water spread area} \times \text{No. of days water is available})}{1000} = nil$$

*** Average water spread area of a block is considered as 2% of area considered for assessment of the block (from topo sheets /remote sensing).**

*** No, of days (monsoon) water available is 120 days (for Tripura 122 days) (monsoon days depends on location)**

Step 6.ii

Recharge from ponds/tanks during non-monsoon (MN Rp/t) =

$$MN\ Rp/t = \frac{(1.44 \times \text{Av. Water spread area} \times \text{No. of days water is available})}{1000}$$

MN Rp/t = (1.44 X X 70% X 243) / 1000 = ha-m

Overall water spread area at non-monsoon season is less then monsoon season it depends on location and soil, for Tripura it is 70% (Assumed).

K. Subramanya recommended, 1.4 mm/day for the period of which the tank the average water spread data n/a assume 60% page 359.or Average water spread area of a block is considered as 2% of area considered for assessment of the block (from toposheets/ remote sensing) data. No. of days (non-monsoon) water availability is 245 days (non-monsoon depends on location, for Tripura it is 243 days)

(Water spread area data from water resource planning circle,GoT, Kunjaban, Agartala.)

(Water spread area data from Brahmaputra Board Master Plan of Horah basin)

(Water spread data from Science & Technology,G.o.T. Gurkhabasti, Agartala.)

Step 7

Rainfall Recharge (Rrf) by rainfall infiltration method, RIFM

R_{ef}, RIFM = Monsoon R_{ef} + Non-monsoon R_{ef}

= 7(i) + 7(ii)

= ha-m.

Step 7.i

Monsoon R_{ef} = Area considered for assessment X NMR X RFF

Where,

RFF = Rain Infiltration Factor.

Monsoon R_{ef} = ha x m x 0.16 = ha-m

NMR is the average of 30 years of monsoon rainfall of a rain gauge station

RFF is considered as 0.16 for Tripura (GEC' 97 book)

NMR = 1222.49 mm of Tripura from 1971 2015.

Step 7.ii

Non-monsoon Rrf = Area considered for assessment x NNMR x RFF.

Where,

NNMR = Normal Non-Monsoon Rainfall in m

Non-monsoon Rrf = ha x m x 0.16 = ha-m

NNMR = 865.44 mm for Tripura from 1971 to 2015.

Exam :Percentage = (865.18/2087.93) = 41.449% in Agartala.(hence considered).

NNMR is the average of 30 years of non-monsoon rainfall of a rain gauge station.

Non-monsoon Rrf considered if non-monsoon rainfall as a percentage of normal annual rainfall is greater than 10%

For Tripura percentage of non-monsoon rainfall to normal annual rainfall is greater than 20% and hence non-monsoon Rrf has been computed.

(Rainfall data from Meteorological dept. regional Meteorological Center Kolkata)

(Rainfall data from Meteorological Dept. Meteorological Center Agartala)

(Calculation after discussion with dept of town and country planning Govt. of Tripura)

Step 8

Recharge from other sources (ROS) = Monsoon recharge from other sources

+ Non-monsoon recharge from other sources.

8(i) + 8(ii) = ha-m

Step 8.i

Monsoon recharge from other sources (MR_{others}) =

RSWI (monsoon) + RGWI (monsoon) + Rp/t

Where,

RSWI = Recharge from surface water irrigation

RGWI = Recharge from Groundwater irrigation

Rp/t = Recharge from ponds/tanks

For Tripura RSWI & RGWI during non-monsoon is nil &

Rp/t not considered already considered in (i).

Step 8.ii

Non-monsoon recharge from other sources (NM R_{others}) =

RSWI (non-monsoon) + RGWI (non-monsoon) + Rp/t

Where,

RSWI = Recharge from surface water irrigation = 5(ii)

RGWI = Recharge from Groundwater irrigation = 4(ii)

Rp/t = Recharge from ponds/tanks = 6(ii)

(NM R_{others}) = 4(ii) + 5(ii) + 6(ii)

= ha-m

Step 9

Groundwater Recharge by Water Table Fluctuation Method,

Pre-Monsoon Post Monsoon Water level difference

Step9.i

C_{gws} = Change in Groundwater storage in monsoon

= area x water level fluctuation x specific yield.

year	Cgws (Level in M)	area in ha	Tripura S_y	Recharge water storage in ha-m	Remark
2010			0.08		
2011			0.08		
2012			0.08		
2013			0.08		
2014			0.08		

Where,

C_{gws} = Change in Groundwaterstorage in monsoon.

S_y = Specific Yield.

Water level fluctuation found out from the difference of water level during November and April of National Hydrograph Network station of Tripura. Specific yield is considered as 0.08 (GEC'97 book)

Step 9.ii

Rainfall recharge during monsoon by Groundwater balances approach.

Where,

R_{ef} = rainfall recharge during monsoon by Groundwater balance approach.

C_{gws} = change in GW storage during monsoon.

M R_{others} = Monsoon recharge from other sources.

R_{ef} = C_{gws} + gross Groundwater draft (item no 3) for all uses during monsoon season – M Ros.

R_{ef}= C_{gws} + gross Groundwater draft (item no 3)for all uses during monsoon season - M R_{others}

year	Recharge water storage in (ha-m)	Groundwater draft(ha-m)	Other uses	Total storage(ha-m)
2010				
2011				
2012				
2013				
2014				

Step9.iii Recharge corresponding to Normal Monsoon rainfall (WTFM)=MR (NMR X Rainfall recharge during monsoon)/Actual

Where, NMR= Normal Monsoon rainfall = 1222.49mm

Actual MR = Actual Monsoon rainfall (monsoon rainfall of 2008)

year	Actual Monsoon Rainfal
2010	mm
2011	mm
2012	mm
2013	mm
2014	mm

Data from(1971-2000 for Agartala meteorological dept)

Year	N.M.R(mm)	Water storage(ha-	Actual rainfall(mm)	Actual storage(ha-m)

m)

2010	1222.5
2011	1222.5
2012	1222.5
2013	1222.5
2014	1222.5

average =

Recharge corresponding to Normal Monsoon rainfall (WTFM)=

(NMR x Recharge monsoon)/Actual MR= ha-m

For linear regration analysis				
Year	NMR=X_i(actu MR)	Re area=Y_i (9ii)	x_i^2	x_i x y_i
	S_1	**S_2**	**S_3**	**S_4**
2010				
2011				
2012				
2013				
2014				

NMR=X_i rainfall during in monsoon in metres

Re area=Y_i corosponding recharge inthousand hect metres

N=5 Years

a=[{(N X S_4) - (S_1 X S_2)}/{(N X S_3)-S_1^2}]=

b=[{(S_2-(a x S_1)}/N]=

rainfall Recharge during Monsoon in hect m (WTFM) method =

(a x NMR+ b) x 1000 = ha-m

Step 10

The result of the two methods (WTFM & RIFM) have been compared Using Percent Deviation (P.D)

P.D= [{Rrf(WTFM)- Rrf(RIFM)}/Rrf(RIFM)]X100

= %

Where, Rrf wtfm = Rainfal Recharge by Water table flucutation method

Rrf rifm = Rainfall Recharge by rainfall infiltration factro method

If P.D is between-20% & + 20% then $MR_{ef} = Ref_{(WTfM)}$

P.D is < - 20% $M\ Rrf = 0.8 \times R_{ef(RIFM)}$

P.D is > - 20% $M\ Rrf = 1.2 \times R_{ef(RIFM)}$

* In Tripura for all the blocks P.D is < - 20%, Expect Dukli Block

Step 11 **Annual Recharge from Rainfall = $M\ R_{ef} + NM\ R_{ef}$**

Where,

$M\ R_{ef}$= rainfall recharge during monsoon for estimation (10.i)= (item 7i)X(0.8)

$NM\ R_{ef}$ = Rainfall recharge during non-monsoon (7.ii)

Annual Recharge from Rainfall = $M\ R_{ef} + NM\ R_{ef}$ =

ha-m

Step 12

Total Groundwater Recharge = Annual Recharge From rain fall (11.) +

Annual Recharge from other sources (8.)

Total GW Recharge = ha-m

Step 13 **Net Groundwater Availability =** Total GW Recharge (item12.) - UND(item 12)

Where, UND= Unaccounted Natural Discharge

Und = 0.1 X (Total GW Recharge) if RIFM Used and

0.05 x (Total GW Recharge) if WTFM used

Net Groundwater Availability = ha-m

Step 14 **Stage of Groundwater Development** = $\frac{\text{Year Groundwater Gross Draft}}{\text{Net Groundwater Availability}} \times 100$

Stage of Groundwater Development = ----------------- x 100 = %

Step 15

Annual allocation of Groundwater for domestic & industrial water supply upto next 25 years,

Z = 22 x N x Lg = 22 X X =

Where

N= Projected Population density in thousands per.sqkm

Lg=

Dependency on Groundwater domestic industrial & industrail water supply as a fraction

(less than or equal to 1)

Z = 22 X N X Lg (Domestic Water supply requirement + Industrial water supply Requirement)

Domestic & Industrial water supply requirement =135 lpcd (GEC'97 book)

Step 16

Net Groundwater available for future uses =

Net Groundwater Availability - {(Current gross Groundwater draft for irrigation) +

(Annual allocation of Groundwater for domestic & industrial water supply upto next 25 years)}

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Developing a Correlation for Estimation of Aquifer Layer Using Resistivity Survey with Lithological Logs in Critical Terrain Condition

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Abstract: Vertical Electrical Sounding (VES) study was conducted for 20 points (four sites having five points each) in Damodar River Basin in West Bengal State in India employing Schlumberger Array electrode configuration along with Borehole Litholog. Depth of interpretation was found to be around 25 m at each VES point for the input survey distance of 50 m. From the interpreted resistivity values it can be commented that the points where the soundings were carried out normally had dry sand having variation in moisture content up to a depth of approximately 5 m. But in the case of Site 2 the sand content of the top layer was found to be drier and had bigger gravel and rock particle mixed with sand. From the interpreted results it can be inferred that all the sounding points except three have the existence of a layer saturated with fresh water. Depth to bedrock from VES study was correlated with depth to bedrock from Borehole Lithologs. Therefore this study is significant for both reading public and future workers as the equation developed using the constants and variables can be used to predict depth to Basement Rock in the Terrain prevailing in that region.

Key words: Vertical electrical sounding (VES), borehole litholog, resistivity values, interpretation, regression analysis, correlation co-efficient.

Introduction

Water is a renewable resource which occurs in three forms: liquid, solid and gaseous. Groundwater is essential for irrigation, industry and domestic purpose. Groundwater is an important source for potable water supply, domestic, industrial and agricultural uses; thus there is a necessity to exploit it sensibly so that this resource does not become scarce in near future. The scarcity of groundwater is increasing day by day due to a rapid growth in population, urbanization, industrial and agricultural related activities, natural calamities, etc. The impact of the above said causes on soil and groundwater is becoming alarming with years and has devastating effects on humans and the ecosystem (Ahilan and Senthil Kumar, 2011; Hossain, 2103). Study of groundwater geology is much useful for all the activities of human life. Groundwater is more advantageous than the surface water due to its low levels of concentration of TDS, TSS, turbidity, etc. To meet the demand of water, people are depending more on groundwater yielded by aquifers (Ehirim and Nwankwo, 2010; Hossain, 2013). Purulia is one of the drought prone districts of West Bengal. It has a sub-tropical

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climate nature and is characterized by high evaporation and low precipitation. The increasing demand of water for irrigation, domestic and industrial use is contributing to the water deficiency in the district. Therefore, there is tremendous pressure on the already critical groundwater regime; even total surface and groundwater resources put together are not sufficient to meet the requirement. The main water sources for the district are the Damodar river basin. Therefore it is very important to know the safe yield and aquifer characteristics to make future Water Security Plan for sustainable withdrawal (Roy et al, 2015; SWRE, 2013).

Keeping in view, the present study focuses on finding groundwater potential zones in Raghunathpur-II, Neturia, Santuri blocks of Purulia district of West Bengal, as well as developing a correlation co-efficient and a regression analysis equation between the borehole litholog and sub-soil stratification data as obtained from VES study in that region so that for the terrain type prevailing in that region the data obtained from the VES study may be used to find the litholog of the terrain without further making boreholes in the region thus reducing cost incurred and labour required and thus finding groundwater potential zones economically. The statistical approach adopted in the paper involves the generation and development of a regression analysis equation and correlation co-efficient between the observed values that could be used for correlating and subsequently predicting lithologs from logs obtained from interpretation of VES results in future.

Study Areas

The Damodar river basin is situated between 23°37′43.02″ N latitude and 86°56′08.36″ E longitudes and 23°038′27.43″ N latitude and 86°28′43.97″ E longitudes as given in Figure 1. The study was carried out in the area on Damodar river bed near the three blocks of Purulia district viz., Santuri, Nituria and Raghunathpur-II. A total of 20 VES soundings delineated in Figure 2 using Schlumberger configuration were carried out in the chosen four sites by conducting five VES soundings at each site (Hossain, 2013).

Materials and Methods

Geophysical prospecting of groundwater comes under both surface and subsurface exploration. The Schlumberger array is used to ensure deep penetration and for cases of limited manpower and finance in the field (Emmanuel, 2010). For each VES sounding, the distance between potential electrodes MN was kept fixed at 2 m and the distance between current electrodes was increased gradually from 5 m to 50 m (AB/2) with a steep increase of 5 m or 10 m to investigate up to a maximum depth of 30 m (0.3 times of AB distance) below the ground level. Schlumberger Array was used in the study. The output apparent resistivity data of the above sites was found by Microprocessor based signal stacking digital resistivity meter of IGIS, Hyderabad make, Model SSR-MP-AT-S. The axes of all the VES soundings were aligned parallel to the geological strike in order to reduce the effects of lateral variations. Both the survey procedures resistivity profiling and resistivity sounding (VES) have been carried out. Resistivity profiling has been conducted in a grid pattern. The resistivity data have been qualitatively and quantitatively interpreted and analyzed by software package IPI 2 WIN ver.3.1.2 (Ogungbel et al., 2010).

Results and Discussions

The interpretation of the raw data as observed was done by IPI2WIN version 3.1.2. The depth of interpretation is found up to more or less 25 m at each VES point for the input survey distance of 50 m and it is found up to four geo-electric layers. As the study area consists of sand with gravel and rock somewhere, so from the interpreted resistivity values it can be inferred that the points where the soundings were carried out normally formed with dry sand having variation in moisture content up to a depth of approximately 5 m as the resistivity value of the first layers of most of the sounding points lie between 110 and 250 Ω-m. But in the case of Site 2 it is found that the sand content of the top layer are very much drier and contains bigger gravel and rock particles mixed with sand as the resistivity value of the top layer in Site 2 varies between 327 and 6414 Ω-m. As the resistivity value of sandy layer fully saturated with fresh water lies between 10 and 100 Ω-m, from the interpreted results it can be told that all the VES points show the existence of fresh water saturated layer except the three points S2/P4, S2/P5 and S4/P5. The cause of high resistivity of those points may be those areas consists of sedimentary rock below the ground level. The pseudo-cross-section and cross section wise resistivities are shown in Figures 3 and 4.

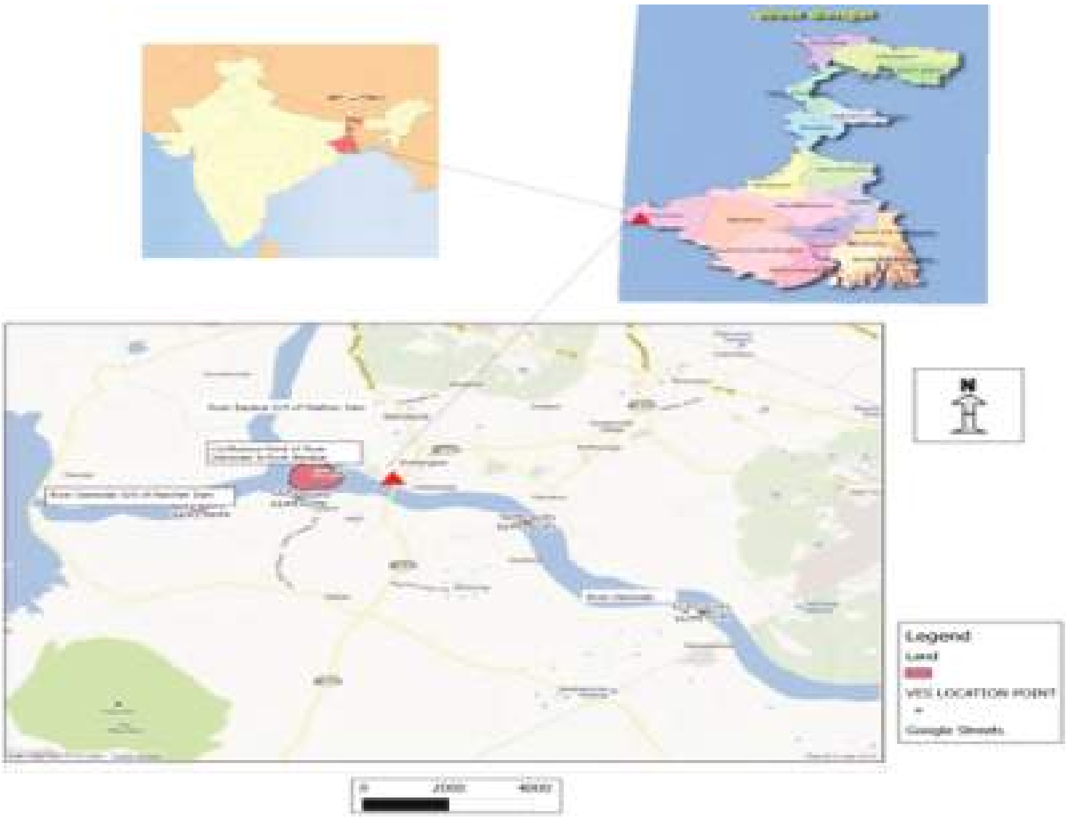

Figure 1: Index map of the study area.

Figure 2: VES location points in the study area.

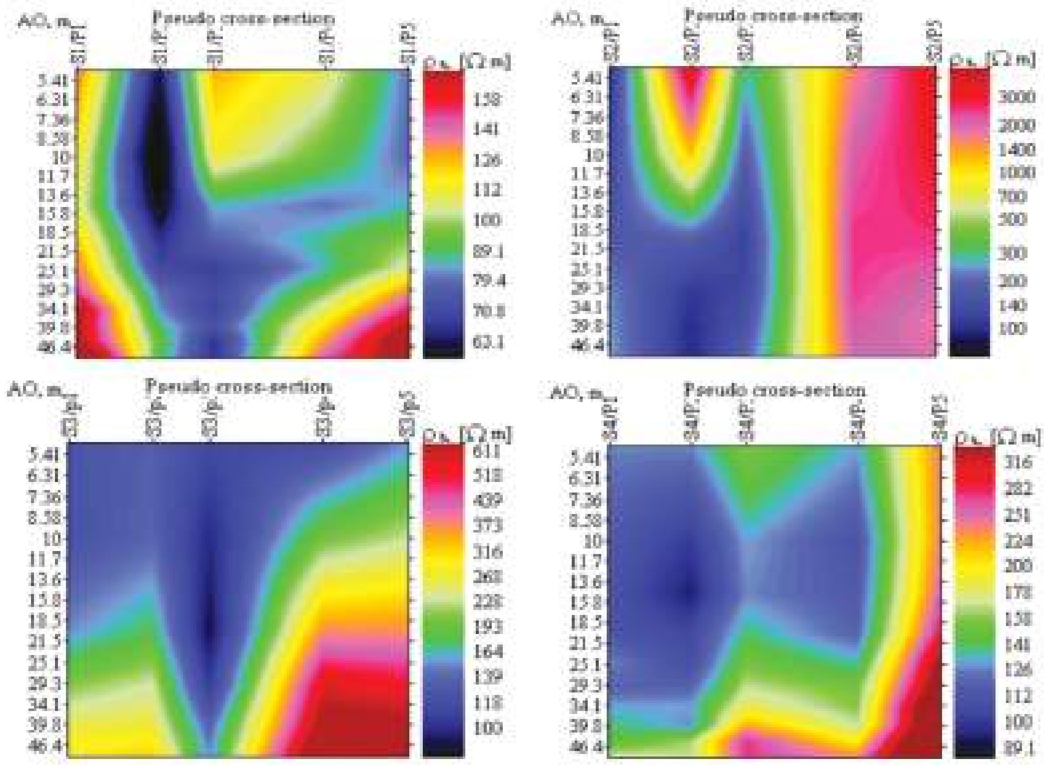

Figure 3: Pseudo cross-sections of the soundings of four sites for study area (Damodar river bed).

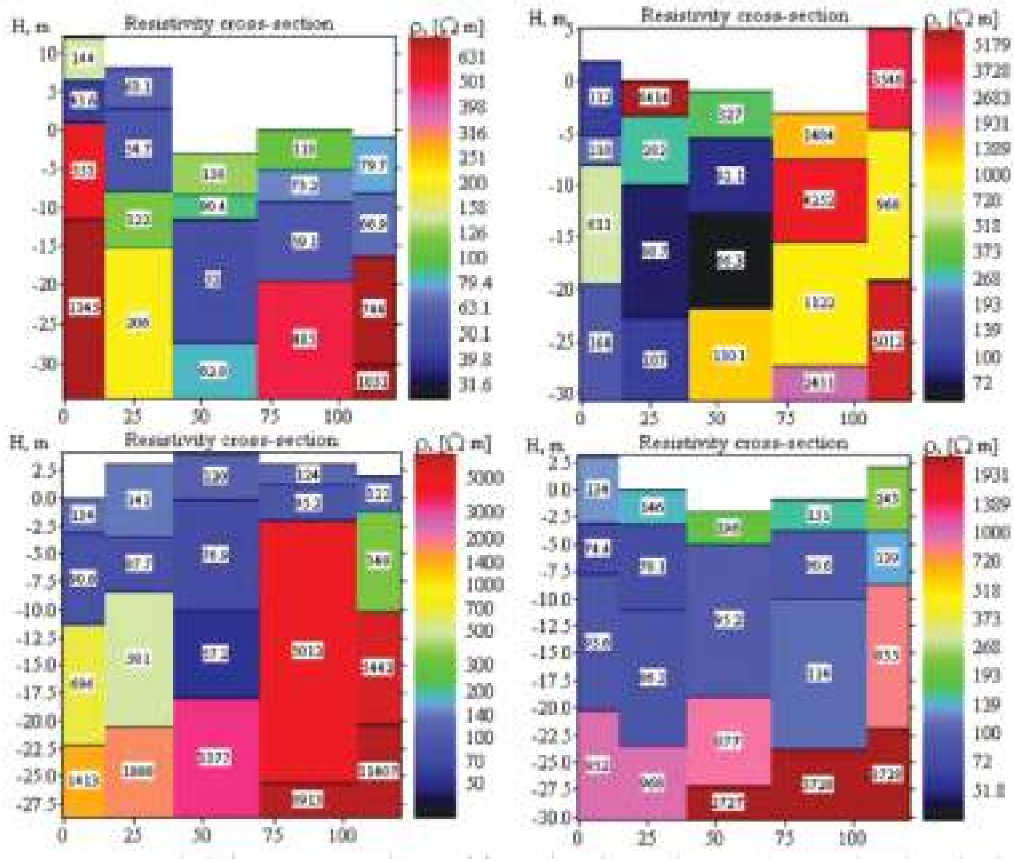

Figure 4: Resistivity cross sections of four sites in study area (Damodar river bed).

From the interpreted results up to four geo-electric layers in case of this study area (Damodar river bed) formed with sand, gravel and rock mixture it is found that the area is dominated by five types of geo-electric curve type viz., QH, HA, AK, KH and AA as shown in Table 1. Out of the five curve types the area is mostly dominated by the curve types HA (ρ1>ρ2<ρ3<ρ4) and QH (ρ1>ρ2<ρ3<ρ4) having percentage of occurrence value 55% and 30% respectively i.e., a total of 85% out of 100% highlighted in Table 2 in the study area.

Table 1: Interpreted curve type at each VES point for the study area (Damodar river bed)

Site location	*VES points*	*Resistivity details*	*Curve type*
Site 1	S1/P1	ρ1>ρ2<ρ3<ρ4	HA type
	S1/P2	ρ1>ρ2>ρ3<ρ4	QH Type
	S1/P3	ρ1>ρ2>ρ3<ρ4	QH Type
	S1/P4	ρ1>ρ2>ρ3<ρ4	QH Type
	S1/P5	ρ1>ρ2<ρ3<ρ4	HA type
Site 2	S2/P1	ρ1<ρ2<ρ3>ρ4	AK Type
	S2/P2	ρ1>ρ2>ρ3<ρ4	QH Type
	S2/P3	ρ1>ρ2>ρ3<ρ4	QH Type
	S2/P4	ρ1<ρ2>ρ3<ρ4	KH Type
	S2/P5	ρ1>ρ2<ρ3<ρ4	HA Type
Site 3	S3/P1	ρ1>ρ2<ρ3<ρ4	HA Type
	S3/P2	ρ1>ρ2<ρ3<ρ4	HA Type
	S3/P3	ρ1>ρ2>ρ3<ρ4	QH Type
	S3/P4	ρ1>ρ2<ρ3<ρ4	HA Type
	S3/P5	ρ1<ρ2<ρ3<ρ4	AA Type
Site 4	S4/P1	ρ1>ρ2<ρ3<ρ4	HA Type
	S4/P2	ρ1>ρ2<ρ3<ρ4	HA Type
	S4/P3	ρ1>ρ2<ρ3<ρ4	HA Type
	S4/P4	ρ1>ρ2<ρ3<ρ4	HA Type
	S4/P5	ρ1>ρ2<ρ3<ρ4	HA Type

Table 2: Occurrence of various curve types for the study area (Damodar river bed)

Curve type	*Frequency*	*Percentage of occurrence (%)*
QH	6	30
HA	11	55
AK	1	5
KH	1	5
AA	1	5

Correlation of VES Results and Borehole Data

The success of any geo-electrical resistivity survey depends on the verification of subsurface truth. VES success relies on the careful interpretation and integration of the results with the other geologic and hydro-geological data for the site. Two basic measurements were carried out in the quantitative assessment of groundwater resources in the study area viz., borehole data and VES survey. Therefore, lithological information obtained from the same VES points was used to calibrate the VES field data interpretation results. For this purpose, lithological samples were obtained vertically at 1 m depth interval at each station after conducting VES survey. To correlate the VES interpretation results with the borehole data, borehole modelling is prepared using Groundwater Modelling System (GMS) version 6.0 software. Two types of model are prepared: one type of model prepared using the borehole data collected from the field and the other type of model is prepared using the interpreted resistivity values and layer thickness by checking the resistivity values from the standard table (Palacky, 1987). All inputs are given to the material observed in the field or found from the interpretation results of the IPI2win software and then given input to GMS version 6.0 in a certain format which needs to be given in that software and borehole models are created using borehole modelling tool of the software (Ogungbel et al., 2010; Palacky, 1987; GMS, 2006). The results obtained from the borehole modelling are tabulated in Table 3.

The observed borehole model depicts that sand of different grade with gravel is found upto maximum 10 m depth (as shown in Figures 5 to 8) and the Interpreted borehole model depicts that sand and gravel mixture of various grade either saturated or partially saturated with water was found upto maximum 35 m depth approximately.

Correlation and Regression Analysis

The predicted depth to the basement from VES study has been compared with the depth borehole logs respectively using correlation and regression analyses.

As per Erricaker, 1971 the expression or correlation co-efficient may be written as,

$$\tau_{xy} = \frac{\mathrm{Cov}(x,y)}{\delta x;\delta y}, -1 \le \tau_{xy} \le 1 \qquad (1)$$

where Cov (x, y) is covariance and δx and δy are standard deviation of x and y respectively.

Table 3: Results as obtained from borehole modelling

Borehole name	*Depth range (m)*	*Material*
Site 1 (S1)	0-3	Fine sand yellowish colour
	3-6	Coarse sand yellowish colour
	6-9	Fine sand yellowish colour
	9-12	Coarse to medium sand yellowish colour
	12-15	Coarse to medium sand greyish colour
	15-18	Medium to fine yellowish colour
	18-20	Coarse sand yellowish colour
Site 2 (S2)	0-3	Medium to coarse sand
	3-6	Medium sand with small size gravels
	6-9	Medium to coarse sand with small size gravels
	9-12	Medium to coarse sand
	12-15	Medium sand
	15-18	Medium sand
	18-21	Sandy clay
	21-25	Coarse sand greyish colour with small size gravels
	25-28	Medium sand greyish colour
	28-31	Sandy clay
	31-35	Sticky clay
Site 3 (S3)	0-3	Coarse to medium yellowish
	3-6	Coarse to medium yellowish
	6-9	Medium to fine sand yellowish
	9-12	Medium to fine sand yellowish
	12-15	Fine sand yellowish
	15-18	Coarse sand yellowish
	18-22	Coarse sand yellowish
Site 4 (S4)	0-3	Coarse sand
	3-6	Coarse to medium sand
	6-9	Coarse sand
	9-12	Coarse to medium sand
	12-15	Coarse sand reddish colour
	15-18	Coarse to medium sand greyish colour
	18-21	Coarse sand reddish colour
	21-27	Sandy clay greyish colour

Table 4: Depth to basement rock as estimated from the two methods of hydrogeological studies

Site	*Average depth to basement rock as estimated from VES interpretation (m)*	*Depth to basement rock as estimated from borehole log (m)*
S1	23.956	20
S2	22.8074	35
S3	23.726	22
S4	23.7	27

Now, the mathematical equation which describes the relationships between the two variables (depth or thickness of the sub-soil stratifications in this case) is defined by regression equation (Erricaker, 1971; Ojo and Ademilue, 2013).

$$y = mx + c \tag{2}$$

$$\Sigma y = Nm + c\Sigma xn \tag{3}$$

$$\Sigma xy = mx + c\Sigma x^2 \tag{4}$$

where m and c are constants, y and x are variables and N, the number of items. The relationship between the predicted depth to the basement from VES study and depth to basement from the borehole logs (Table 3) has been calculated. A correlation coefficient,

$$\tau_{xy} = -0.95248 \tag{5}$$

is obtained and the relationship between the predicted depth and the actual depth to basement is expressed by regression equation,

$y = -12.56\ x + 321.9$, with Regression co-efficient (R^2) = 0.907

Here, y = Depth to basement rock as estimated from borehole litholog and x = Depth to basement rock as estimated from VES interpretations.

Conclusion

It should be noted that the fact that the correlation coefficient is not equal to one signifies that the sub-soil Litholog as interpreted from the VES study is not the same as the Litholog obtained from borehole and should not be treated as same. However, there exists a relation between the sub-soil layer as interpreted from the VES study and the borehole lithologic layer. The regression equation can be used to convert the results obtained from VES study to borehole log with great accuracy. Thus with the use of VES studies in the region in near

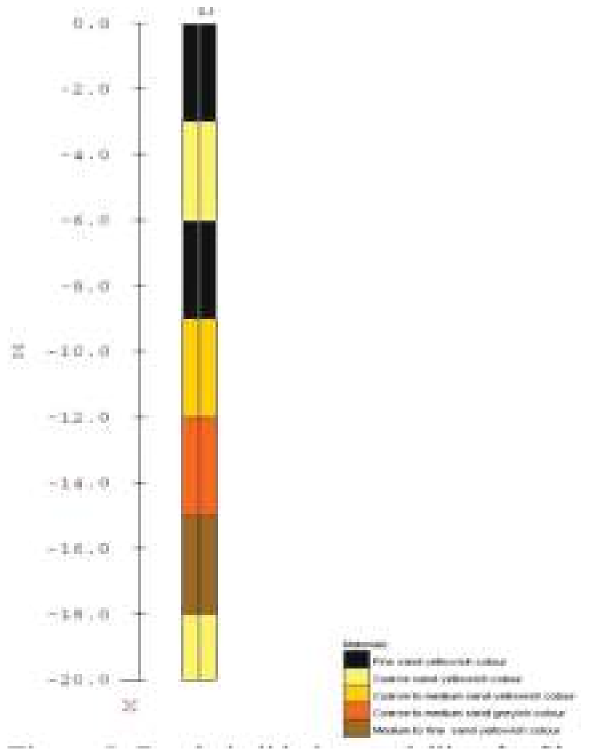

Figure 5: Borehole litholog modelling for Site 1 (S1) as obtained from GMS version 6.0.

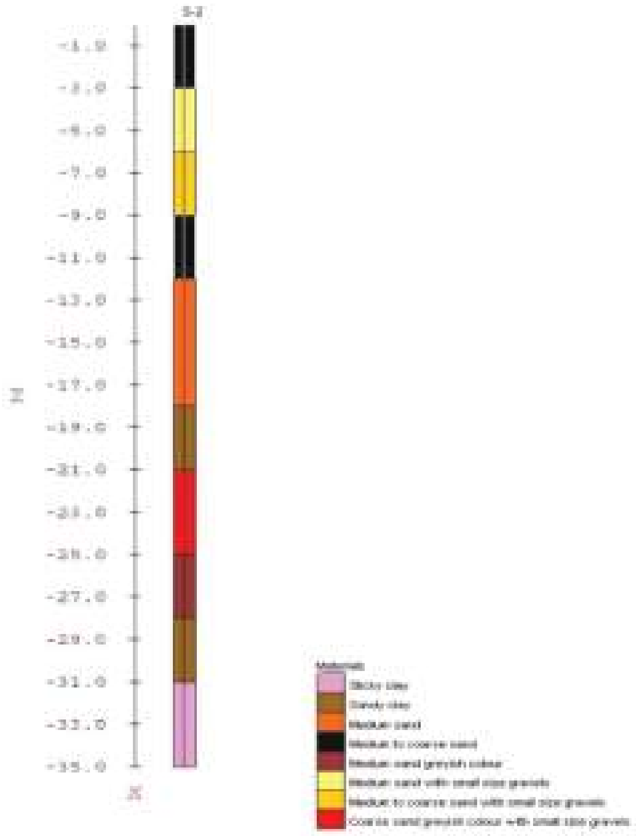

Figure 6: Borehole litholog modelling for Site 2 (S2) as obtained from GMS version 6.0.

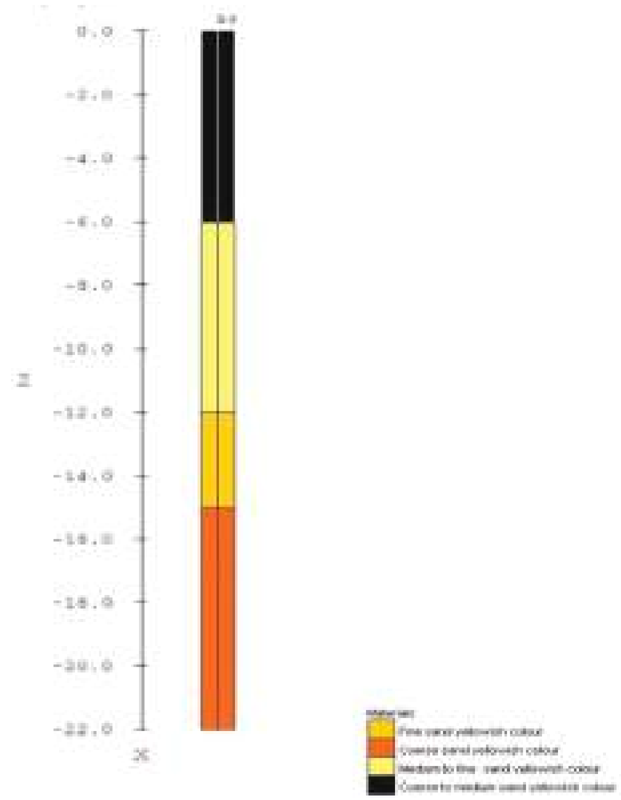

Figure 7: Borehole litholog modelling for Site 3 (S3) as obtained from GMS version 6.0.

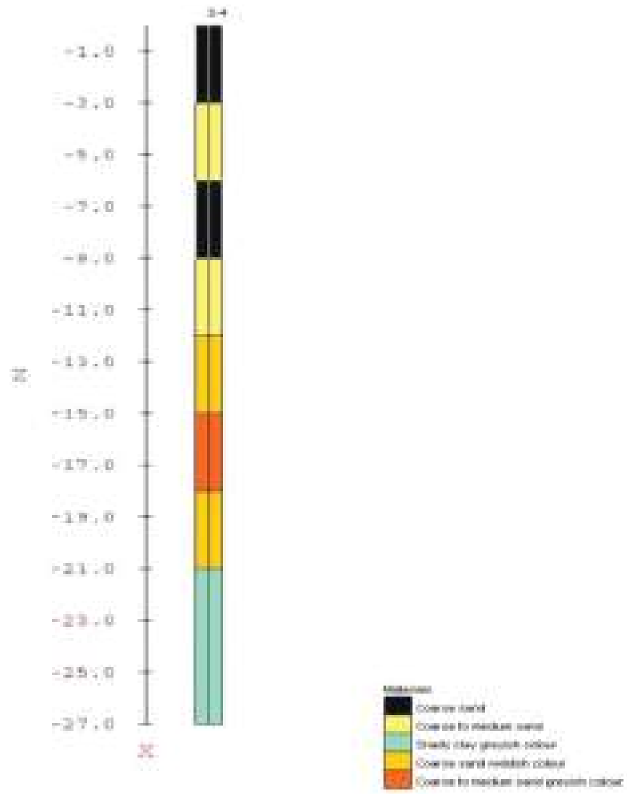

Figure 8: Borehole litholog modelling for Site 4 (S4) as obtained from GMS version 6.0.

future sub-soil Lithologs can be prepared without doing borehole thus saving money and manpower. Moreover quicker results could be obtained referred by Ojo and Ademilue (2013).

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Calendar of Events

International Conference on Innovations in Chemical, Biological and Environmental Sciences (ICBES-2017)
16th and 17th January 2017
Pattaya, Thailand
Website: http://cecabs.org/conference/161
Contact person: Conference Secretary: Carol Phillips
Organized by: International Centre of Excellence in Chemical, Agricultural and Biological Sciences

3rd International Conference on Environment and Bio-Engineering (ICEBE 2017)
21st to 23rd January 2017
Bangkok, Thailand
Website: http://www.icebe.org/
Contact person: Ms. Mickie Gong
Organized by: CBEES

International Conference on Energy and Environmental Science (ICEES 2017)--Ei, Scopus
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Website: http://www.icees.org/
Contact person: Ms. Lauren Ching
Organized by: Thammasat University

4th International Conference on Civil, Environment and Waste Management (CEWM-17)
23rd and 24th January 2017
Manila, The Philippines
Website: http://caeer.org/conference.php?slug=CEWM-17&sid=3&catDid=141
Contact person: Ms. Lipsa Zheng
Organized by: International Association of Civil, Agricultural & Environmental Engineering Researchers

8th International Conference on Environmental Science and Development (ICESD 2017)
8th to 10th February 2017
Frankfurt, Germany
Website: http://www.icesd.org/
Contact person: Ms Eve Lee
Organized by: Frankfurt University of Applied Sciences, Germany

9th edition of the International Conference Air and Water Components of the Environments
17th to 19th March 2017
Cluj-Napoca, Romania
Website: http://aerapa.conference.ubbcluj.ro/Engleza/index.htm
Contact person: Gheorghe Serban
Organized by: Babes-Bolyai University, Faculty of Geography

International Conference on Environmental and Energy Engineering (IC3E 2017)
22nd to 24th March 2017
Suzhou, China
Website: http://www.ic3e.net/
Contact person: Beca Feng

4th International Conference on Coastal and Ocean Engineering (ICCOE 2017)
28th to 30th March 2017
Osaka, Japan
Website: http://www.iccoe.org/
Contact person: Ms. Mickie Gong
Organized by: CBEES

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CRITICAL STUDY OF SUB-SURFACE AQUIFER LAYER FOR GROUNDWATER AVAILABILITY BASED ON ELECTRICAL RESISTIVITY SURVEY: A PART OF DHALAI TRIPURA, INDIA

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ABSTRACT

In Tripura, there are many rivers and most of the rivers are almost dry due to high amount of silt carries from higher altitude and deposits as well at river bed. Thus quantitative as well qualitative results of surface water is not the sustainable resource for supplying for the different stakeholder and thus groundwater has the alternative source to meet the demand for the high density population in the state like Tripura. Dhalai Tripura located in the north east state of India has a good amount of coarse sand for groundwater development dependent. A critical study is undertaken to assess the groundwater availability in the sub-surface aquifer using vertical electrical sounding (VES) survey at nineteen locations with a total of thirty eight points spread over the area. The study results depict resistivity values ranging between 30 ohm and 150 ohm are found to be good aquifer zone with the thickness varied between 36 m and 44 m. Thus it concludes VES survey could be an alternative method to assess the groundwater potential at present and future scenario by reducing the overall project cost and also to reduce the chances of failure for making borewell in the same or nearby critical areas for all stakeholders.

Keywords: aquifer, litholog strata, resistivity value, groundwater, Agartala.

INTRODUCTION

Agartala is a developing and growing city which has the capacity to become the gateway of North-East to South East Asia through an international link. However it is already facing some scarcity of water in the area during non-monsoon seasons. Soils of these catchment areas have low retention capacity. These areas have the maximum density of urban population in the whole state (Debbarma*et al*., 2013). Hydrogeological, geophysical and hydrochemical studies were carried out by Mondal*et al*., (2005) in order to assess the extent of groundwater deterioration due to 80 functioning tanneries in the upper Kodaganar river basin region, India. The data of 37 Schlumberger VES were collected and interpreted using computer software RESIST-88. It was observed that the VES results at each station of the study area were entirely different due to in homogeneity of the subsurface layers and the presence of ion concentration. It was revealed that the resistivity values for spacing AB/2 between 10 m and 25 m were less than of 75 Ω-m. Rai *et al*., (2005) stated that the combined study conducted using remote sensing and geoelectrical methods of water-bearing weathered / fractured rocks varied from 120 Ω-m to 150 Ω-m and the better zones, which were most promising for groundwater exploration could be dug well up to depths of (30 ± 5) m and the study were carried out by VES surveys for 26 points conducted using Schlumberger electrode configuration in the Dhanbad district in Jharkhand, India.

Resistivity could be measured to delineate the depth of the basement rocks (bedrock) and the lithology of the overlying sediments for the purpose of bridges construction route.VES data was collected and interpolated using IX1D software (Mohammed, 2014). The final results of the modeled and interpreted resistivity data were depicted that a close agreement with the geological and hydrogeological conditions of the area was found. The geoelectrical resistivity profiling and VES data were acquired by Asare and Menyeh, (2013) from some small communities areas within the Gushiegu and Karaga Districts of Northern Ghana, in order to study the aquifer characteristics and recommend hydro-geologically suitable sites to construct water supply boreholes for the communities. The geoelectric sequence revealed predominantly a three subsurface layer which is largely congruous to the weathering profile above the fresh bedrock with thick top soil, the weathered and the variably weathered and fractured bedrock respectively were recommended on the basis of the perceived aquifer properties, sites for drilling water supply boreholes for the communities.

Vertical Electrical Sounding (VES) was tested by Sikandar and Christen, (2012) to estimate aquifer hydraulic conductivity at Chaj Doab and Rachna Doab, Punjab, Pakistan. The field data were interpreted using the Interpex IX1D computer software and the aquifer resistivity (ρ) vs depth models for each location were estimated. The VES survey has the potential to provide reasonable accurate results that can be used to understand the subsurface layers in groundwater exploration. The results of the VES must be verified with secondary hydro-

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geological data available in the study area referred by Debbarma*et al* (2016b).Atzemoglou and Tsourlos (2012) stated that 2D interpretation of 1D VES measurements can produce improved subsurface geophysical images and presents a potential useful tool for larger scale geological investigations especially in the case of reprocessing existing VES data sets.

It should be noted that the fact that the correlation coefficient is not equal to one signifies that the sub-soil litholog as interpreted from the VES study reported by Debbarma*et al*., (2017) is not the same as the litholog obtained from borehole and should not be treated as same. However, there exists a relation between the sub-soil layer as interpreted from the VES study and the borehole lithologic layer. The regression equation can be used to convert the results obtained from VES study to borehole log with great accuracy. Thus with the use of VES studies in the region in near future sub-soil lithologs can be prepared without doing borehole thus saving money and manpower moreover quicker results could be obtained (Felix *et al*., 2013).

Since as we know presently Agartala Municipality area has a higher water demand than any other parts in the state due to its higher density of population stated by Debbarma*et al*., (2016a) so detail information is needed related to sub-surface aquifers with the help of VES survey. Also the objective of this paper is to give a plan for estimating present as well as future water groundwater availability particularly for sub-surface aquifer only by knowing resistivity results with minim investment and also the study results will become user friendly manual for all kinds of stakeholders and to be reliable and sustainable resource without any lithological strata.

MATERIALS AND METHODS

Methodology

Total 19 nos. of location has been considered for the proposed study. Two nos. of point has been surveyed for each location with a total number of 38 points for the resistivity survey. A map is prepared referred in Figure-1 from google map mentioned all VES locations and accordingly resist survey is carried out with the help of VES instrument. The lithological strata for all locations are prepared for all sampling points with effective sand media even 250 m bgl from ground level. Finally after studying the geological and geophysical properties of the area and all field data are interpolated through hydrogeological software and also it is been inferred here.

Study area

After studying and interpreting the satellite imagery the area seems to fall under mountainous and elevated portion of Dhalai district. The soil of the region is somewhat alluvial in nature, with occasional Hills of alluviums. The soil has a thick cover of clay at top and lateritic formation with slate in abundance. The rivers are here in their mature stage and forms meanders. The main river is Gomati and distributaries of its crisscrossed the region.The region is well fertile and practiced with agricultural land by the local farmers. Natural vegetation is also seemed to be in good proportion.

Geological and physiographical settings

The proposed site falls on the east side of Dhalai district. The geological formation is of tertiary sediment sand of pliestocene-lower age. The lithostratigraphic units of alluvial formation consisting of Residual soil and is composed of sand, silt, clay (soft sediments) with rock fragments and laterite out crops and slate stone (hard formation).

Geomorphologically the area is a mountainous and hillock area. During rainy season the shallow river beds frequently over flow. The soil of the region is somewhat alluvial in nature. The area has been subjected to earthquakes in the past and land has formed hills of alluviums. Their folded structure is a synclinorium consisting of broad synclines and tight-faulted anticlines.

Hydro-geologically the area is a moderate to good zone for groundwater development. The water table lies between 15 m and 20 m below ground level in the unconsolidated sandy sediments of recent alluvium. Here the groundwater yield is good and can be developed with the use of deep tube wells.

Figure-1.VES location points of the study area.

Hydro geological and hydrology

The area and blocks water supply is augmented with dug wells, shallow hand pumps and mini deeptubewells. Drinking water supply division, resource water division has taken initiatives and has installed numberoftubewellsin the area, which are in operation mode.

The tube wells are installed with water jet method and rotary rig method (direct/reverse).Static water level is in the range of 10-15m below ground level (bgl).Numbers of water ponds are also there which augments village water supply. Rainfall is high in the range of 1800-2000 mm annually. The study area is mostly dominated by dense vegetation. Paddy cultivation is practiced based on the rainfall.

RESULTS AND DISCUSSIONS

The area under study is a part of the eastern margin of Dhalai district. The water prospects hereareby the saturated water present in the sand aquifers below. The

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tract is alluvial and composition of layers of the different sites (locations) investigated are almost identical, as such the tube wells may be installed at any of the points surveyed as per suitability. VES survey is carried out for two sampling location for each site with a total number of 38 VES points mentioned even block also. The resistivity results depicted that the aquifer depth are varied between 90 m and 180 m whereas the expected yields are calculated ranged between 27.27 and 45.46 m^3/h as highlighted in Table-1. The interpreted results depicted that the expected yield is found to be higher where resistivity values are varied between lower and higher reflected in Tables 2 (a), (b), (c), (d) and (e). Due to paucity of space and reducing the paper length, Figure-2 and Figure-3 represents the typical resistivity and thickness of different sub-surface layer considered as sample figure for one location. It is observed that the resistance values are found at different distance shown in Figure-2 whereas the aquifer formation at the same points is highlighted in Figure-3.

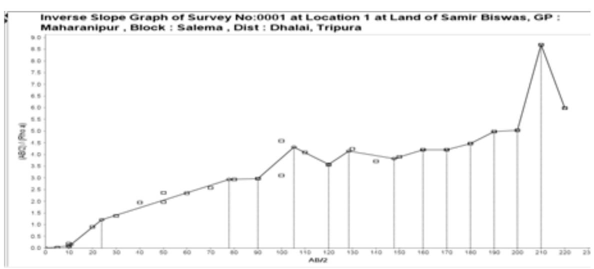

Figure-2. Distance vs. resistivity for L1(I).

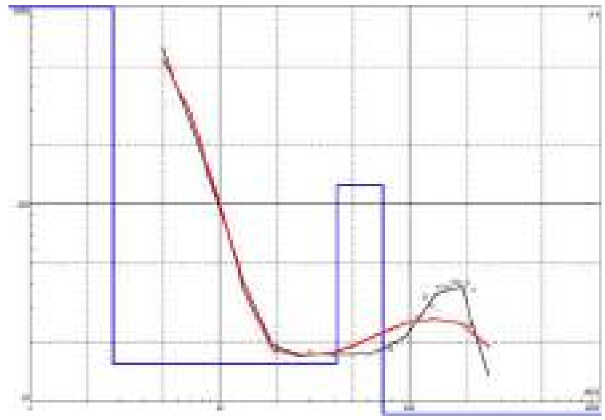

Figure-3. Depth vs. resistivity for L1(I).

CONCLUSIONS

Resistivity sounding data (VES) of 38 points with 19 locations, where data collections were good, spreads over Kamalpur valley in both sides of Dhalairiver under Dhalai district indicate that the subsurface formations in the areas of investigation are found to be distinct in terms of resistivity values. Resistivity values ranged between 30 ohm and 150 ohm are depicted with good aquifer zone varied between 110 m and 146 m and it has also been validated by Debbarma*et al* (2016c) in case of same terrain condition. However the discharge of well is observed to be limited even available of water is obtained at a greater extent. Thus it can be concluded that resistivity survey could be a good exercise not only to select the exact location of borewell but also in terms of cost and also to reduce the chances of failure of making a new bore well with a higher cost involvement. It also helps to prepare a contingency plan for estimation of availability of water for both irrigation as well as domestic purposes in the short as well as in the long run.

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Table-1. Aquifer information with expected yield in different blocks of Dhalai district.

S. No	District	Block	G.P./VC*	Location-1			Location-2			Aquifer zones depth (m)	Expected yield (m^3/h)
				Latitude	Longitude	Map Location	Latitude	Longitude	Map location		
1	Dhalai	Salema	Maharanipur VC	24.05374° N	91.82157° E	L-1(1)	24.05374° N	91.82138° E	L-1(2)	110-140	36.38-45.46
2	Dhalai	Salema	MaharanipurVC	24.05987° N	91.82454° E	L-2(1)	24.05982° N	91.82448° E	L-2(2)	120-150	36.38-45.46
3	Dhalai	Durgachowmuhani	Debichara	24.08876° N	91.83137° E	L-3(1)	24.08882° N	91.83136° E	L-3(2)	90-130	36.38-45.46
4	Dhalai	Durgachowmuhani	Chankap	24.07136° N	91.84688° E	L-4(1)	24.07129° N	91.84681° E	L-4(2)	110 -140	36.38-45.46
5	Dhalai	Salema	South Kachuchara	24.02309° N	91.85622° E	L-5(1)	24.02308° N	91.85642° E	L-5(2)	90 -130	31.82-36.38
6	Dhalai	Salema	Singinala	24.01234° N	91.84012° E	L-6(1)	24.01223° N	91.84005° E	L-6(2)	100-130	31.82-36.38
7	Dhalai	Salema	Avanga	24.01652° N	91.83810° E	L-7(1)	24.01662° N	91.83815° E	L-7(2)	150 -180	36.38-45.46
8	Dhalai	Salema	Dabbari	24.06684° N	91.83202° E	L-8(1)	24.06682° N	91.83223° E	L-8(2)	110-140	36.38-45.46
9	Dhalai	Salema	PaschimDaluchara	23.98741° N	91.79570° E	L-9(1)	23.98742° N	91.79552° E	L-9(2)	110-130	31.82-36.38
10	Dhalai	Salema	AshapurnaRoaza Para	23.98878° N	91.79886° E	L-10(1)	23.98877° N	91.79860° E	L-10(2)	105-125	36.38-45.46
11	Dhalai	Salema	Mendhi	24.03603° N	91.78931° E	L-11(1)	24.03558° N	91.78925° E	L-11(2)	105-125	27.27-36.38
12	Dhalai	Durgachowmuhani	WestKuchainala	24.16816° N	91.82442° E	L-12(1)	24.16794° N	91.82425° E	L-12(2)	100-130	36.38-45.46
13	Dhalai	Durgachowmuhani	West Kuchainala	24.15864° N	91.81969° E	L-13(1)	24.15884° N	91.82020° E	L-13(2)	100-130	36.38-45.46
14	Dhalai	Durgachowmuhani	Kuchainala	24.16117° N	91.84283° E	L-14(1)	24.16143° N	91.84279° E	L-14(2)	90-110	27.27-36.38
15	Dhalai	Durgachowmuhani	Marachara	24.15960° N	91.86553° E	L-15(1)	24.15944° N	91.86561° E	L-15(2)	120-140	31.82-36.38
16	Dhalai	Durgachowmuhani	Shibbari	24.13744° N	91.87054° E	L-16(1)	24.13735° N	91.87082° E	L-16(2)	120-150	36.38-45.46
17	Dhalai	Durgachowmuhani	Mohanpur	24.21344° N	91.84650° E	L-17(1)	24.21352° N	91.84650° E	L-17(2)	110-140	36.38-45.46
18	Dhalai	Durgachowmuhani	Noagaon	24.19168° N	91.80380° E	L-18(1)	24.19205° N	91.80382° E	L-18(2)	110-140	27.27-31.82
19	Dhalai	Durgachowmuhani	Srirampur	24.13080° N	91.77812° E	L-19(1)	24.13104° N	91.77832° E	L-19(2)	120-150	27.27-36.38

*VC-Village Council

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Table-2(a). Resistivity survey with interpreted results for four locations (LS-1 to LS-4).

S. No.	Location-1	Location-2	Probable strata section as interpreted from Inverse slope & VES curve			Resistivity nature
	Map location	Map location				
1	L-1(1)	L-1(2)	1stlayer	0-30 m	Shallow Depth Soil and Sand-Dry	Very High to High Resistance
			2ndlayer	30-40 m	Fine Sand	High Resistance
			3rdlayer	40-110 m	Clay Beds	Moderate High to Low Resistance
			4thlayer	110-140m	Finesand (Aquifer Zone for strainer)	Low to High Resistance
			5thlayer	140-250 m	Clay Beds	Low Resistance
2	L-2(1)	L-2(2)	1stlayer	0-30 m	ShallowDepthSoilandSand-Dry	Very High to High Resistance (Topsoil& Dry Sand)
			2ndlayer	30-45 m	Fine Sand	High Resistance (1stAquifer Fine Sand)
			3rdlayer	45-120 m	Clay Beds	Moderate High to Low Resistance
			4thlayer	120-150 m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	140-220 m	Clay Beds	Low Resistance
3	L-3(1)	L-3(2)	1stlayer	0-20m	Shallow Depth Soil and Sand-Dry	Very High to High Resistance (Top soil & Dry Sand)
			2nd layer	20-40 m	FineSand	High Resistance
			3rdlayer	40-90 m	Sandy Clay	Moderate Highto Low Resistance
			4thlayer	90-120m	Fine sand(Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	120-240 m	Clay Beds	Low Resistance
4	L-4(1)	L-4(2)	1stlayer	0-20m	Shallow Depth Soil and Sand-Dry	Very High to High Resistance (Topsoil & Dry Sand)
			2ndlayer	20-30 m	Fine Sand	High Resistance (1stAquifer Fine Sand)
			3rdlayer	30-110 m	Clay Beds	Moderate Highto Low Resistance
			4thlayer	110-150 m	Fine to Medium sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	150- 230 m	Clay Beds	Low Resistance

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Table-2(b). Resistivity survey with interpreted results for four locations (LS-5 to LS-8).

S. No.	Location-1 Map location	Location-2 Map location	Probable strata section as interpreted from inverse slope & VES curve			Resistivity nature
5	L-5(1)	L-5(2)	1stlayer	0-70 m	Clay	Low Resistance (Topsoil & Clay
			2ndlayer	70-90 m	Sandy Clay	Low to High Resistance (1stAquifer Fine Sand)
			3rdlayer	90-130 m	Fine Sand	High Resistance
			4thlayer	130-150 m	Fine to Very Fine sand	High to Low Resistance
			5thlayer	150-210 m	Clay Beds	Low Resistance
6	L-6(1)	L-6(2)	1stlayer	0-40 m	Clay	Low Resistance
			2ndlayer	40-70 m	Sandy Clay	Low to Moderate High Resistance
			3rdlayer	70-100 m	Sandy Clay & Fine sand	Moderate High to High Resistance
			4thlayer	100-130 m	Fine to Medium sand (Aquifer Zone for Strainer)	High Resistance
			5thlayer	130-220 m	Clay Beds	High to Low Resistance
7	L-7(1)	L-7(2)	1stlayer	0-30 m	Clay	Low Resistance
			2ndlayer	30-40 m	Fine Sand	Low to Moderate High Resistance
			3rdlayer	40-110 m	sandy Clay	Moderate High to High Resistance
			4thlayer	150-170 m	Fine sand (Aquifer Zone for Strainer)	High Resistance
			5thlayer	170-220 m	Clay Beds	Constant Resistance
8	L-8(1)	L-8(2)	1stlayer	0-70	Shallow Depth Soil and Sand-Dry	Very High to High Resistance
			2ndlayer	70-90 m	Fine Sand	High Resistance
			3rdlayer	90-110 m	Sandy Clay	Moderate High to Low Resistance
			4thlayer	110-140 m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	140-250 m	Clay Beds	Low Resistance

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Table-2(c). Resistivity survey with interpreted results for four locations (LS-9 to LS-12).

S. No.	Location-1	Location-2	Probable Strata section as interpreted from inverse slope & VES curve			Resistivity nature
	Map location	Map location				
9	L-9(1)	L-9(2)	1stlayer	0-30 m	Clay	Low Resistance
			2ndlayer	30-40 m	Fine Sand	High Resistance
			3rdlayer	40-110 m	Clay Beds	Moderate High to Low Resistance
			4thlayer	110-130m	Fine to Medium sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	130-240 m	Clay Beds	Low Resistance
10	L-10(1)	L-10(2)	1stlayer	0-60 m	Clay	Low Resistance
			2ndlayer	60-70 m	Fine Sand	Low to High Resistance
			3rdlayer	70-105 m	Sandy Clay	Moderate High to High Resistance
			4thlayer	105-125m	Fine sand (Aquifer Zone for Strainer)	High Resistance
			5thlayer	125-220 m	Clay Beds	Very High Resistance
11	L-11(1)	L-11(2)	1stlayer	0-20 m	Shallow Depth Soil and Sand-Dry	Very High to High Resistance
			2ndlayer	20-50 m	Fine Sand	High & Low Resistance
			3rdlayer	50-105 m	Clay Beds with slate formations	Moderate High to Low Resistance
			4thlayer	105-125m	Fine sand (Aquifer Zone for Strainer)	Fluctuating Low to High Resistance
			5thlayer	125-220 m	Clay Beds	Low Resistance
12	L-12(1)	L-12(2)	1stlayer	0-30 m	Sandy Clay	High Resistance
			2ndlayer	30-40 m	Fine Sand	High & Low Resistance
			3rdlayer	40-100 m	Fins Sand & Clay Beds	Moderate High to Low Resistance
			4thlayer	100-130m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	130-240 m	Clay Beds	Low Resistance

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Table-2(d). Resistivity survey with interpreted results for four locations (LS-13 to LS-16).

S. No.	Location-1 Map location	Location-2 Map location	Probable Strata section as interpreted from inverse slope & VES curve			Resistivity nature
13	L-13(1)	L-13(2)	1stlayer	0-30m	Shallow Depth Soil and Sand-Dry	Very High to High Resistance
			2ndlayer	30–40 m	Fine Sand	High Resistance
			3rdlayer	40-100 m	Clay Beds	Moderate High to Low Resistance
			4thlayer	100-130 m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	130-220 m	Clay Beds	Low Resistance
14	L-14(1)	L-14(2)	1stlayer	0-30 m	Sandy Clay	Very High to High Resistance
			2ndlayer	30-40 m	Fine Sand & Sandy Clay	High Resistance
			3rdlayer	40-90 m	Fine Sand	Moderate High to Low Resistance
			4thlayer	90-110m	Fine to Very Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	110-200m	Clay Beds	Low Resistance
15	L-15(1)	L-15(2)	1stlayer	0-30m	Clay zones	Low Resistance
			2ndlayer	30-40m	Fine Sand	Low to High Resistance
			3rdlayer	40-120 m	Sandy Clay	Moderate High to Low Resistance
			4thlayer	120-140m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	140-200m	Sandy Clay	High Resistance
16	L-16(1)	L-16(2)	1stlayer	0-30m	Sandy Clay	Very High to High Resistance
			2ndlayer	30-60 m	Fine Sand	High Resistance
			3rdlayer	40-120 m	Clay Beds	Moderate High to Low Resistance
			4thlayer	120-150m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	150-200 m	Clay Beds	Low Resistance

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Table-2(e). Resistivity survey with interpreted results for three locations (LS-17 to LS-19).

S. No.	Location-1	Location-2	Probable Strata section as interpreted from inverse slope & VES curve			Resistivity nature
	Map location	Map location				
17	L-17(1)	L-17(2)	1stlayer	0-30 m	Clay	Low Resistance
			2ndlayer	30-40 m	Sandy Clay	Low Resistance
			3rdlayer	40-110 m	Very Fine sand & Clay	Moderate High to Low Resistance
			4thlayer	110-140 m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	140-210 m	Fine Sand & Sandy Clay	High Resistance
18	L-18(1)	L-18(2)	1stlayer	0-30m	Sandy Clay	Very High to High Resistance
			2ndlayer	30-40 m	Fine Sand	High Resistance
			3rdlayer	40-110 m	Sandy Clay	Moderate High to Low Resistance
			4thlayer	110-140m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	140-250 m	Clay Beds	High to Low Resistance
19	L-19(1)	L-19(2)	1stlayer	0-30m	Surface sand & Sandy Clay	Very High to High Resistance
			2ndlayer	30-50 m	Sandy Clay	High Resistance
			3rdlayer	50-120 m	Clay Beds	Moderate High to Low Resistance
			4thlayer	120-150m	Fine sand (Aquifer Zone for Strainer)	Low to High Resistance
			5thlayer	150-220 m	Clay Beds	Low Resistance

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ESTIMATING GROUNDWATER VOLUMETRIC MASS BALANCE WITH HYDRAULIC HEAD USING GROUNDWATER MODELING SYSTEM IN TRIPURA, INDIA

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AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration between all authors. Author PKR designed the study, wrote the protocol and interpreted the data and produced the initial draft. Author JD anchored the field study, gathered the initial data and performed preliminary data analysis. Authors SH, GB and MP managed the literature searches including preparation of maps and models runs. All authors read and approved the final manuscript.

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ABSTRACT

In this study, a three-dimensional finite-difference groundwater flow model has been developed to investigate the variety of hydro-geological conditions and simulating volumetric flow budget under different stress conditions in the aquifer of Agartala and Khowai city under Agartala and Khowai district respectively in the state of Tripura. MODFLOW package using groundwater Modeling System (GMS) was applied for this study to find out the volumetric flow budget and hydraulic heads for groundwater under steady state analysis method. Lithologs (soil strata), aquifer parameters during pumping test, hydro-meteorological data, catchment characteristics etc. were used to calibrate and validate the conceptual model. The objective of this paper is to develop conceptual models run by GMS MODFLOW for estimating the groundwater volumetric mass balance and hydraulic head at different point with varied withdrawal condition of three seasons. The results conclude the hydraulic heads decrease against discharge wells and it increases towards recharge wells and this model will help to estimate the groundwater volume for water budgeting.

Keywords: Aquifer; river head; GMS; discharge well; recharge well; MODFLOW.

1. INTRODUCTION

Many studies have been carried out to estimate hydraulic parameters for aquifers and to model the effect of stream flow on groundwater flow fields locally and worldwide. To build up a conceptual model and to calculate the aquifer parameters, different types of literature review has been done, stream-aquifer connectedness, GIS technology, MODFLOW conceptual model approach etc. are studied here. Some case studies are being described given below to overview an idea about conceptual Modeling and aquifer parameters.

Lautz and Siegel [1] used a three-dimensional MODFLOW model, paired with MT3D, to simulate hyporheic zones (mixing of shallow groundwater and surface water) both advective transport and

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sink/source mixing of solutes, in contrast to particle tracking (e.g. MODPATH), which only considers advection. Modeling results indicated that movement of surface water into the hyporheic zone is predominantly an advective process. Hyporheic exchange was also found in highly sinuous segments of the experimental reach, but flux rates and the cross-sectional areas of these zones are smaller.

The problem of groundwater contamination is inherently concomitant with the problem of soil contamination. Groundwater being the largest available freshwater source has been under serious threat on maintaining its quality and quantity because of many anthropogenic activities [2]. But for coastal groundwater systems is a dynamic system with certain boundary conditions and it has been coupled between the equations for groundwater flow and solute transport. So, MODFLOW and SEAWAT has overcome the difficulties encountered with tidal boundaries and its dynamically updates the boundary conditions for head and concentration during the simulation depending on a user-defined tidal signal and allows for the development of a seepage face and it has obtained good agreement [3]. Again, 3-D groundwater flow model has been developed by coupling of groundwater flow model MODFLOW 2000 code with Geographic Information System tools to investigate hydrological processes in Zéramdine–BéniHassen Miocene aquifer and it has been validated the groundwater proprieties deduced from the geological, geophysical, hydrodynamic and hydro-chemical studies done in the region. This model simulation showed a good degree of understand to the aquifer hydrogeology and it could be as a useful tool for analyzing the hydrological processes for complex groundwater keeping similar geological and hydro-geological conditions and also this model will help to propose a management rescue plan for aquifer characterised by arid and semi-arid regions [4]. Zhou and Li [5] have been introduced a regional groundwater flow modelling by using geological, hydro-geological and geophysical data with continuous water budget components and groundwater levels to predict regional impacts of human inferences on groundwater systems with present environment to formulate sustainable groundwater resources development scenarios, and to communicate the results to public and decision-makers. Again, MODFLOW packages helps to establish groundwater flow model to simulate hydrologic stresses, inflows and outflows into a groundwater system [6]. Specifically, MODFLOW uses a regional groundwater flow model to process areally distributed recharge and discharge to groundwater to simulate areally distributed precipitation recharge, agricultural discharge and irrigation infiltration recharge in a simple approach. Wang et al. [7] worked with the geological and hydro-geological conditions of the North China Plain (NCP) and the groundwater flow numerical simulation Modeling was constructed with MODFLOW. During the process of constructing the groundwater model, a water budget has been analyzed. When the evaluating and predicting of groundwater flow, these data could read with the help of MODFLOW and the calculated water level and drawdown could be retrieved. Panagopoulos [8] developed an equivalent porous media considering hydraulic conductivity and specific yield with certain known boundary conditions during calibration and simulation the model of Trifilia karst aquifer using MODFLOW. Small mean absolute and RMS piezometric head error of the model under both steady and transient state conditions have been found satisfactorily results. Shi et al. [9] used visual MODFLOW to simulate groundwater flow and transport based on a certain scenario to assess the leakage impact of a sewage plant accidental pool on groundwater using NH_3-N as the assessment factor. Another, SWAT-MODFLOW model has been applied to estimate the groundwater recharge based on water-balance components using the integrated surface water and groundwater [10]. By using this model, the parameter related to the delay time could be optimized by checking the correlation between simulated recharge and observed groundwater levels. SWAT-MODFLOW model results stated that the annual average recharge rate should be estimated by a long-term continuous simulation with a distributed hydrologic modeling technique. Kim et al. [11] suggests a new approach for integrating the quasi-distributed watershed model, SWAT, with the fully-distributed ground-water model, MODFLOW. However, SWAT–MODFLOW has been successfully calibrated and validated, and reproduced the distributed drawdown and reduced stream flow by pumping with multiple wells. Therefore, when considering discharge to streams, springs or marshes, the use of this model would be beneficial in planning for the sustainable development of groundwater. Saravanan et al. [12] developed a concept of a zone of protection from contamination for areas containing groundwater (which is renewable resource) and adopted in a number of countries and a study on dynamic groundwater assessment in Agartala city has been carried out by Debbarma et al. [13] but there was no rigorous study on entire state of Tripura. MODFLOW could be simulated to assign the ranks and weights' indicating the sensitivity zone particularly recharging to the aquifer and thus it has been demarcated as groundwater protection zones which might be designated as pollution free zone for better management of the aquifer [12]. But presently Agartala Municipality area has a higher water demand than any other parts in the state due to its higher density of population. The overall objective of the present paper is to estimate the groundwater volumetric mass balance with hydraulic head with the help of Groundwater Modeling System.

1.1 Study Area

West Tripura district lies in the western part of Tripura state. The district is bounded on the north by the country Bangladesh, on the south by Sepahijala district, on the west by the country Bangladesh and on the east by Khowai district. The district has total area of 983.63 km^2 and it lies between the Latitude 23°16' N to 24°14' N and Longitude 91°47' E to 92°20' E (Fig. 1). The district is divided into 3 sub-divisions and 9 administrative blocks. The district comprises of 1 number of Municipal Corporation, 1 number of Nagar Panchayat. The total population of the West Tripura district as per the 2011 census is 918200 persons. The density of population is 576 persons per sq. km. The district headquarter is located at Agartala, which is also the capital of the state Tripura. Globally it is situated between 23° 45' and 23° 55' N latitude and 91°14' to 91°20' E longitude, in the flood plains of the 'Haora River'. There is also a canal named 'Keta Khal Canal' gone through Agartala parallel to 'Haora River'. Historically, the city has been an important border-trading town having trading linkages with Bangladesh. The area of Agartala model is 137.42 km^2. Agartala receives an annual average rainfall of 2146 mm. The semi-consolidated formations consisting of friable sandstone, sandy shale etc. of Tertiary age forms the main rock types of the area [14].

Khowai district lies in the northern part of Tripura state. The district is bounded on the north by the country Bangladesh, on the south by Gomati district, on the west by Dhalai district and on the east by West Tripura district. The district has total area of 1377.28 km^2 and it lies between the latitude 23°42' N to 24°14' N and longitude 91°39' E to 91°46' E (Fig. 1). The district is divided into 2 sub-divisions and 6 administrative blocks. The district comprises of 3 numbers of revenue circles, 2 numbers of Nagar Panchayats, 79 numbers of maujas and 107 numbers of villages. The total population of the Khowai district as per the 2011 census is 327564 persons. The district headquarter is located at Khowai. Khowai is a town and recently the Khowai Nagar Panchayat has been converted to Khowai Municipal Council in the newly formed Khowai district in the Indian state of Tripura. It is named after the Khowai River passing by the town. It is near the Bangladesh border. Globally the model is situated between 24°03'17", and 24°05'07", N latitude and 91°35'16"to 91°37'03"E longitude, in the flood plains of the 'Khowai River' with a catchment area of 7.38 km^2 [14].

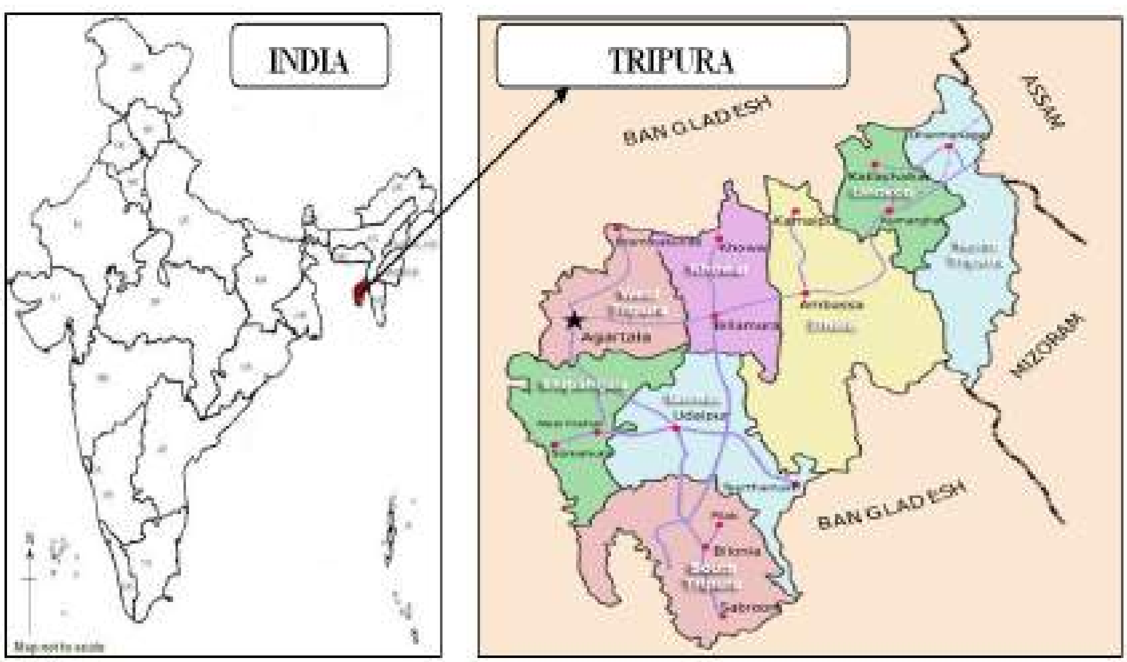

Fig. 1. Location map of study area for Agartala and Khowai

The maximum elevation of Agartala study area is 50 m and minimum is 8 m from sea level. The average elevation is 20 m from sea level. Tripura is predominantly a hilly state. Agartala is also no exception. About 30% of the total Agartala area is hilly, 20% area is undulating in nature and remaining 50% area is composed of plain land. The plain land is not also a dead level land; rather it is broken by many low hills and till as having altitudes ranging between 30-60 m [15]. The ground rises from west to east. There are six important hill ranges in Tripura, all of which are situated almost parallel in a NW-SE direction. Among them the Baramura hill range is situated in the extreme western part of the state from which the Haora has originated. Contour map of the study area indicates that the actual slope of the whole basin has gradually decreased from east (Baramura Hills) to west (Bangladesh boarder). Whereas the maximum elevation of Khowai study area is 43 m and minimum is 26 m from sea level. The average elevation is 32 m from sea level.

First GPS reading are taken in sampling point with attribute data and plotted in Q-GIS software. By using contour plug in contour lines are generated and DEM model was developed. Then the geo referenced DEM model imported in GMS software as base map and other model input data inserted for smooth simulation of flow model (Figs. 2 and 3).

2. METHODOLOGY

The data such as litholog data, pumping test data etc. have been collected from field survey from Water Resource Department, Govt. of Tripura. The time-drawdown data has been analyzed by employing 'Cooper-Jacob method' in order to estimate the aquifer parameters [16] for 50 m-distance observation well when pumped at a rate of 80 m^3/hr. for duration of 1440 min. From analysis of time-drawdown data collected at different observation wells for different discharges, the average value of storativity (*s*) were estimated ranged between 0.00027 and 0.00059 whereas transmissivity (*T*) values were found to be varied between 1100 and 1689 m^2/day based on unconfined nature of the aquifer. The hydraulic conductivity (*K*) of the site is within the range of 15 – 28 m/day.

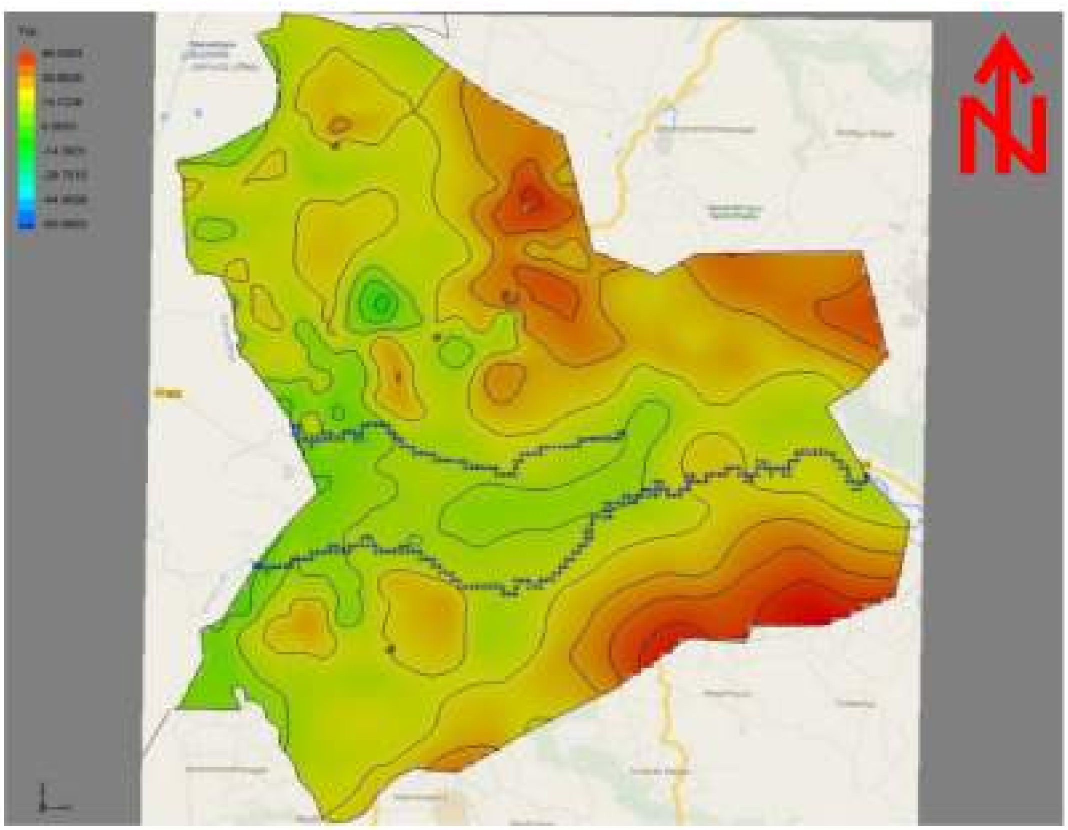

Fig. 2. Contour elevation map of Agartala study area

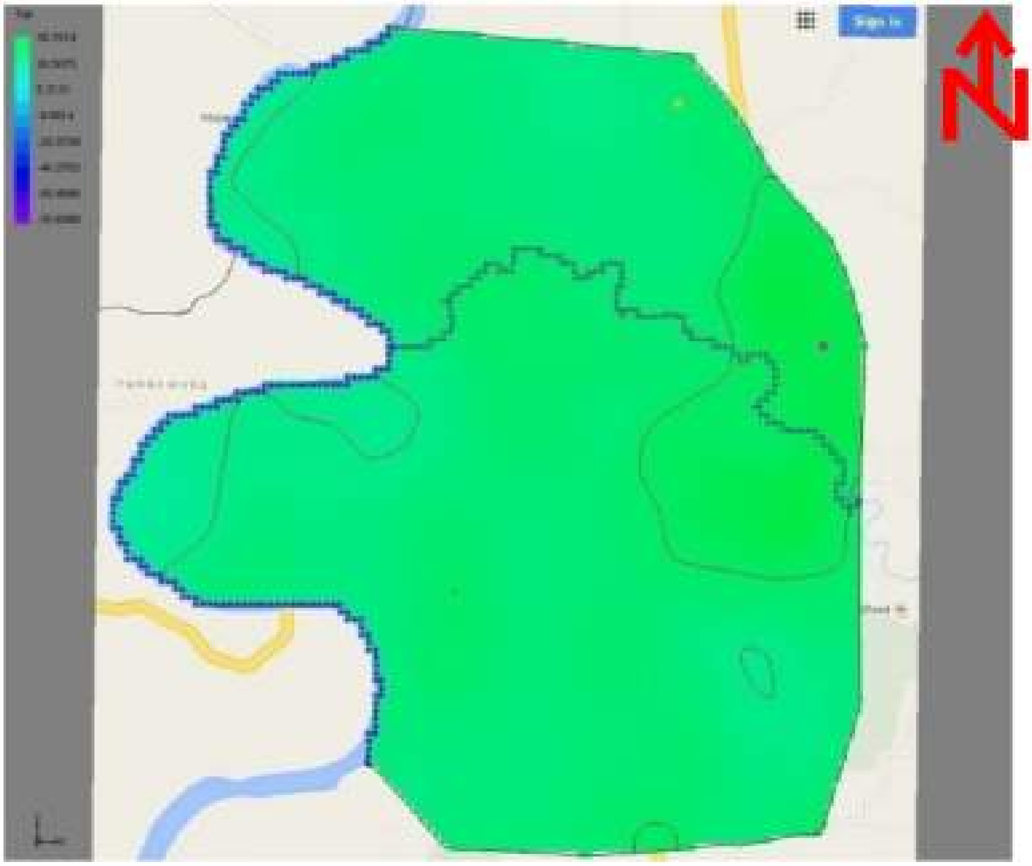

Fig. 3. Contour elevation map of Khowai study area

From the available data two study areas namely Agartala and Khowai are selected from this study area. The study areas are located in Google Earth Software. The area of study area, river details and the terrain elevation data with latitude and longitude are collected from the Google Earth Software. After collecting the raw data during field survey from Water Resource Department, Govt. of Tripura, it is prepared for the software input. Layers are created for both the study areas. The layer data are created from the litholog and pumping test data. Two layers are defined for each model. The input data should be in text document format for input in GMS. Two photographs are made for two study area and located two or three points with their corresponding world coordinate (latitude and longitude) data.

To develop the model at first the photographs are inserted into the model with their world coordinate. Then 2D scatter point data were opened from the text document created for 2D scatter point data. After that new conceptual model is developed in which boundary coverage, recharge coverage, sources/sink coverage, layer-1, layer-2 coverage and grid frame were created. Next 3D grid data was made and new MODFLOW converge was constructed into 3D grid data. The terrain and elevation in 2D scatter point were interpolated to the MODFLOW converge. Before running the model run check option is selected to check the model. After run check and correction the model, it is run and then the model result is analyzed. The flow chart GMS conceptual model with individual parameters collected and estimated from field data collected from Water Resource Department, Govt. of Tripura with different empirical equations is given in Fig. 4. Ten GMS models out of which six for Agartala and four for Khowai, have been developed to estimate the groundwater volumetric mass balance with hydraulic head variation. In case of Agartala, the layer 1 is considered for both confined as well as convertible (neither confined nor unconfined). Five different wells with two rivers namely Haora and Keta Khal have been considered given as source or sink in these models. Whereas for Khowai both layer 1 and layer 2 are considered as convertible with varying numbers of well and two rivers (Khowai and other canal) defined as source or sink in this conceptual model.

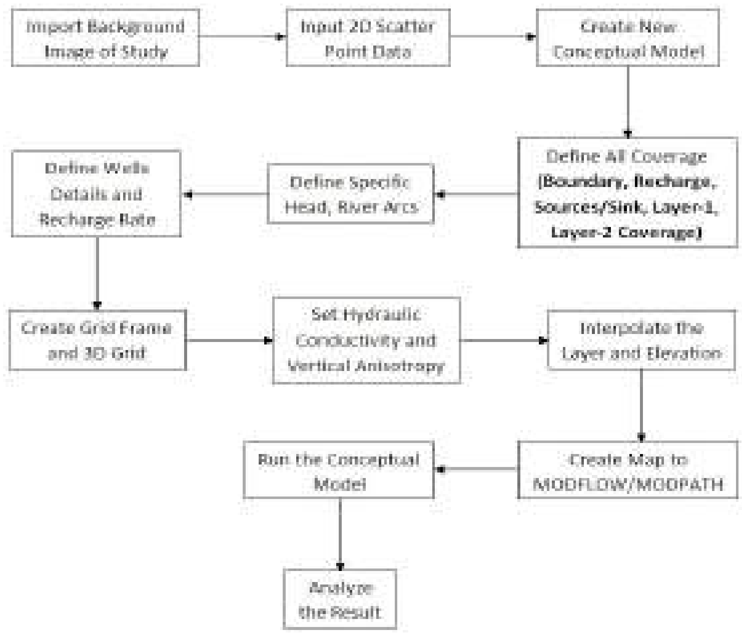

Fig. 4. Flow chart for development of GMS conceptual model [15]

The conceptual model of the study areas have been developed using software GMS (Ground Water Modeling System). This model allows a much better understanding of site conditions to define the groundwater problem. The conceptual model includes the potentiometric surface, hydraulic properties, and recharge and discharge components. Developing the conceptual model is the most important part of the modeling process. It simplifies the field situation and organizes associated field data for easy analysis of the system. It is critical that the conceptual model be a valid representation of the vital hydro-geological conditions and involves definition of the hydro-stratigraphic units, water balances and flow system. This involves identifying sources of recharge, discharge and variation of aquifer properties and variation of hydraulic heads. In the present study model was run with the help of MODFLOW modeling.

The study area has been demarcated with available GPS data collected during survey from Water Resource Department, Govt. of Tripura. Accordingly all hydrologic and hydraulic features have been defined in the MODFLOW conceptual model. From litholog all soil types including depth and place were traced as input parameter in the model. Aquifer characteristics including yield of well have been given in the specified locations. The river head-stage along with bottom elevation on river arc has been assumed to vary linearly along the length of the arc. The ground elevation of the different points in the site has been derived using GPS information available to us based on scatter point techniques. There are two layers in the model. The influx to the system is primarily made through recharge due to rainfall. Since then groundwater level data of the catchment area was not available at regular basis. So the actual groundwater recharge could not be estimated exactly and it was taken as 2% of total precipitation.

MODFLOW conceptual model has been simulated on the basis of hydraulic parameters.

The following assumptions were made to develop the conceptual model:

I. The river is not separated from the aquifer by any confining material.
II. The influx to the system is primarily through recharge due to rainfall.
III. The flow in the aquifer system is steady-state.
IV. There are no evaporation losses into the aquifer (other losses are considered excepting evaporation loss in case of groundwater flow).
V. The rainfall is uniform for the total time span taken for run the model (average rainfall is considered here).

2.1 Input Parameters

There are two tables given (Tables 1 and 2) where all input parameters are highlighted to develop the conceptual model for this study.

Table 1. The input head-stage for the conceptual model of Agartala study area

Name of river	Conductance ($(m^2/d)/m$)	Head-stage (m)		Bottom-elevation (m)	
		Extreme upstream	**Extreme downstream**	**Extreme upstream**	**Extreme downstream**
Haora	700	21	11	17.15	6.91
Keta Khal	650	15	12	12.32	8.76
Additional parameter	Yearly rainfall (mm)	Hydraulic conductivity (m/day)	Vertical anisotropy	Recharge rate (m/day)	Discharge (m^3/day)
Layer-1	2146	20.94	3	0.00011759	1000-4000
Layer-2		25.94	3		

Table 2. The input head-stage for the conceptual model of Khowai study area

Name of river	Conductance ($(m^2/d)/m$)	Head-stage (m)		Bottom-elevation (m)	
		Extreme upstream	**Extreme downstream**	**Extreme upstream**	**Extreme downstream**
Khowai river	550	30.27	24.78	27.8	22.2
Canal	500	28.95	26.95	26.59	24.72
Additional parameter	Yearly rainfall (mm)	Hydraulic conductivity (m/day)	Vertical anisotropy	Recharge rate (m/day)	Discharge (m^3/day)
Layer-1	2718	23.4	4	0.0001468932	4000-5000
Layer-2		28.4	4		

3. RESULTS AND DISCUSSION

Ten MODFLOW conceptual model out of which six models are from the Agartala study area and remaining four models from Khowai area. There are mainly three MODFLOW conceptual models in Agartala study area each divided into two parts, one has confined layer in top and another has convertible layer in top of the conceptual model.

3.1 For Agartala Area

Three models have been considered with different input parameters.

3.1.1 MODFLOW model-A1, A2 and A3

In the Model-A1, A2 and A3, the precipitations are considered as average precipitation in the tune of 2146 mm/year and the values are 2146, 2683 and 2253 mm/year respectively for both confined as well as convertible conditions. So, the recharge rates are to be considered 0.00011759 m/day, 0.017883333 m/day and 0.0003577 m/day for all three models. The maximum hydraulic heads of three models are found to be ranged 20.35 m, 21.84 m and 19.33 m respectively in the extreme upstream side whereas the minimum hydraulic heads are obtained as 11.64 m, 13.17 m and 10.64 m at extreme downstream side.

In GMS MODFLOW convertible layer indicate that the layer may be behave like both confined and unconfined layer. There are no flooded cells in the model which top layer is taken as confined, indicate that the recharge water coming from precipitation is completely percolated downward to the aquifer. In the other hand there are flooded cells are which top layer is taken as convertible, indicate that the recharge water coming from precipitation is not completely percolated downward to the aquifer. In the Agartala study area the water withdrawal from the aquifer is taken as a fixed amount for every well and varied starting specific head and precipitation are taken for three conceptual models. For rainy season both precipitation and starting specific head are taken high. For winter season both precipitation and starting specific head are taken low. The volumetric flow budget in two different conditions for three models are obtained represented as Tables 3, 4 and 5 respectively. The output summary results are found well excepting the model A2 which may be due to insufficient data.

Table 3. Volumetric flow budget for model-A1

Layer-1 considered as confined (A1)

Volumetric budget for entire model	
Budget terms	**Flow (m^3/d)**
In:	
Constant heads	0
Rivers	54930.48225
Wells	0
Recharge	15737.73125
Total In	70668.2135
Out:	
Constant heads	0
Rivers	54633.28349
Wells	16034.3999
Recharge	0
Total Out	70667.68339
Summary:	
In - Out	0.530107856
Percent discrepancy	0.000750136

Layer-1 considered as convertible (A1)

Volumetric budget for entire model	
Budget terms	**Flow (m^3/d)**
In:	
Constant heads	0
Rivers	53941.47459
Wells	0
Recharge	15737.73125
Total In	69679.20585
Out:	
Constant heads	0
Rivers	53644.29894
Wells	16034.3999
Recharge	0
Total Out	69678.69884
Summary:	
In - Out	0.507005215
Percent discrepancy	0.000727628

Table 4. Volumetric flow budget for model-A2

Layer-1 is considered as confined (A2)

Volumetric budget for entire model	
Budget terms	**Flow (m^3/d)**
In:	
Constant heads	0
Rivers	38493.69911
Wells	0
Recharge	48001.19112
Total In	86494.89022
Out:	
Constant heads	0
Rivers	70457.19062
Wells	16034.3999
Recharge	0
Total out	86491.59053
Summary:	
In - Out	3.299696863
Percent discrepancy	0.003814904

Layer-1 considered as convertible (A2)

Volumetric budget for entire model	
Budget terms	**Flow (m^3/d)**
In:	
Constant heads	0
Rivers	37668.44071
Wells	0
Recharge	48001.19112
Total In	85669.63183
Out:	
Constant heads	0
Rivers	69632.01784
Wells	16034.3999
Recharge	0
Total out	85666.41774
Summary:	
In - Out	3.214081421
Percent discrepancy	0.003751716

3.2 For Khowai Area

Four models have been considered with different input parameters. In Khowai study area both the layer (top and bottom) are convertible for every conceptual model. So every model shows the flooded cell in top layer.

3.2.1 MODFLOW model-B1, B2, B3 and B4

The maximum and minimum hydraulic head are depicted in the tune of 31.42 m and 25.26 m respectively which are almost same for other three models. The recharge rate, starting specific head and river stage are fixed for every model. The only variation is the withdrawal rate from the aquifer. The number of well and the discharge rate of wells are different for every conceptual model and it is observed that how the static head differ from each conceptual model. The changes of static head are clearly seen for each conceptual model. The volumetric flow budget for each model is found with given condition delineated as Tables 6 and 7 and the difference between input and output of these for models are quite satisfactorily.

Table 5. Volumetric flow budget for model-A3

Layer-1 considered as confined (A3)

Volumetric budget for entire model	
Budget terms	**Flow (m^3/d)**
In:	
Constant heads	0
Rivers	59001.90855
Wells	0
Recharge	958.4554281
Total In	59960.36398
Out:	
Constant heads	0
Rivers	43925.3738
Wells	16034.3999
Recharge	0
Total out	59959.77371
Summary:	
In - Out	0.590270594
Percent discrepancy	0.000984435

Layer-1 considered as convertible (A3)

Volumetric budget for entire model	
Budget terms	**Flow (m^3/d)**
In:	
Constant heads	0
Rivers	57898.80218
Wells	0
Recharge	958.4554281
Total In	58857.25761
Out:	
Constant heads	0
Rivers	42822.31414
Wells	16034.3999
Recharge	0
Total out	58856.71404
Summary:	
In - Out	0.543568075
Percent discrepancy	0.000923536

Table 6. Volumetric flow budget for model-B1 & B2

Layer-1 & 2 considered as convertible (B1)

Volumetric budget for entire model	
Budget terms	**Flow (m^3/d)**
In:	
Constant heads	0
Rivers	40243.4954
Wells	0
Recharge	1093.149571
Total in	41336.64497
Out:	
Constant heads	0
Rivers	32216.18958
Wells	9120
Recharge	0
Total out	41336.18958
Summary:	
In - Out	0.455390712
Percent discrepancy	0.001101663

Layer-1 & 2 considered as convertible (B2)

Volumetric budget for entire model	
Budget terms	**Flow (m^3/d)**
In:	
Constant heads	0
Rivers	46364.67969
Wells	0
Recharge	1093.149571
Total in	47457.82927
Out:	
Constant heads	0
Rivers	28337.36534
Wells	19120
Recharge	0
Total out	47457.36534
Summary:	
In - Out	0.463928018
Percent discrepancy	0.000977558

Table 7. Volumetric flow budget for model-B3 & B4

Layer-1 & 2 considered as convertible (B3)

Volumetric budget for entire model	
Budget terms	**Flow (m^3/d)**
In:	
Constant heads	0
Rivers	49091.5402
Wells	0
Recharge	1093.14957
Total in	50184.68976
Out:	
Constant heads	0
Rivers	26064.22637
Wells	24120.0
Recharge	0
Total out	50184.22637
Summary:	
In - Out	0.463393234
Percent discrepancy	0.000923376

Layer-1 & 2 considered as convertible (B4)

Volumetric budget for entire model	
Budget terms	**Flow (m^3/d)**
In:	
Constant heads	0
Rivers	44533.21616
Wells	11000
Recharge	1093.149571
Total in	56626.36573
Out:	
Constant heads	0
Rivers	32505.90216
Wells	24120
Recharge	0
Total out	56625.90216
Summary:	
In - Out	0.463571846
Percent discrepancy	0.00081865

4. CONCLUSION

The aquifer of both study areas are hydraulically connected with the river and the river played a very important role to this conceptual model. The groundwater recharge to the aquifer is done through rainfall as well as through the river bed. Volumetric groundwater flow model has been designed for both Agartala and Khowai study areas. In the Agartala study area three seasonal variations summer, rainy and winter of river head-stage and precipitation were considered to find out the volumetric flow budgets and hydraulic heads for groundwater. Whereas in Khowai study area, the average river head-stages and rainfall were used to estimate volumetric flow budget and hydraulic heads for groundwater.

Here this study tries to build up a conceptual model with the help of GMS MODFLOW to represent hydraulic head variations with respect to discharge as well as recharge well and also how the surface water could affect on the groundwater system due to changes in the river head so that it will help not only to estimate the groundwater volume for water budgeting but also to make water security plan for sustainable withdrawal and also whether there could be any further development without disturbing confined or neither confined nor unconfined zone in the peripheral region.

This conceptual model has been run using GMS MODFLOW package in steady state analysis method for 24 hours by taking average rainfall and with some assumptions. The hydraulic heads considerably changed near the wells and it also effected at the river heads which were very close to the wells. Thus the results conclude the heads decrease for the discharge wells whereas it increases towards recharge wells.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Estimation of Aquifer Thickness of Groundwater Using Resistivity Survey in Tripura

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Resistivity sounding using Schlumberger array was conducted in different parts of Tripura for locating aquifer zones as a part of water supply scheme for household and irrigation purpose. The areas broadly include Agartala valley, Udaipur valley, Kailasahar valley and Dharmanagar valley. These data were critically examined, processed and interpreted using curve matching technique and resistivity 1-D software of dynamic studies of groundwater in Tripura. Resistivity investigation data of 18 locations in the above valleys, where data collection was excellent, was selected for detail interpretation. Among these, 6 are in Agartala valley, 4 each in Udaipur, Dharmanagar and Kailasahar valley were found to be 71.25 m, 118 m, 85.18 m and 111.13 m, respectively.

KEYWORD

Aquifer thickness, Resistivity survey, Litholog strata, Groundwater.

INTRODUCTION

The area generally receives good annual rainfall (1927 mm) mostly occurring during the period April to September, which greatly recharges the aquifer. Generally, 75% rainfall occurs during south west monsoon, June-September. The areas of survey are having a gentle slope and sometimes occupied by mounds (Tillas). Agartala is a developing and growing city which has the capacity to become the gateway of north-east to south east Asia through an international link (Debbarman *et al.,* 2013). However, it is already facing some scarcity of water in the area during non-monsoon seasons. Soils of these catchment areas have low retention capacity. These areas have the maximum density of urban population in the whole state (as per population census GOI). Earlier Chakraborty (2009) had estimated the groundwater recharge for west Tripura district and also a study on dynamic groundwater assessment in Agartala city has been carried out by Debbarman (2012) but there was no rigorous study on entire state of Tripura. But presently Agartala Municipality area has a higher water demand than any other parts in the state due to its higher density of population.

Vertical electrical sounding (VES) is the most suitable method for groundwater investigation in most geological occurrences. Vertical electrical sounding with the Schlumberger (preferably) configuration is recommended for geophysical exploration of ground water. The Wenner sounding may be used for shallow occurrences, such as the water-saturated zone at the base of a weathered layer. Dipole electric sounding (DES) may be used in exceptional cases, such as large scale artesian basins of sufficient depth (Bhattacharya and Patra, 2008).

Geoelectric explorations (or, more simply, electrical exploration) is a major branch of exploration geophysics. It uses the principles of geoelectricity for geological mapping of concealed structures, for the exploration and prospecting of ores, minerals and oil and in the solution of many hydrogeological and engineering geological problems (Bhattacharyya and Patra, 2008). Resistivity results were also correlated with the existing lithology, which were in close agreements. Based on the depth of bedrock, thickness of the saturated layer and resistivity of the

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second layer, a groundwater potential map was prepared, in which good moderate and poor zones were classified. It was also revealed that the weathered and fractured portions in shale and limestone that occure in the southernmost and central portions of the watershed area constituted the productive water-bearing zones, which were categorized as good groundwater potential aquifers and the vertical electrical sounding data gave reasonably accurate results that could be used to understand the subsurface layers and basement configuration in groundwater exploration (Gowd, 2004). Shanker (1994) was concluded that the resistivities of the 1st and 2nd layer varied from 100 to 400 Ωm and 10 to 100 Ωm, respectively in Karnataka whereas the resistivity values were ranging from 32 to 75.5 Ωm with average value of 52 Ωm referred by Majumdar and Das (2011) in West Bengal. The resistivity increased in deeper zones sometimes above 1000 Ωm. Therefore, the 2nd layer was interpreted as saturated from where sufficient groundwater can be tapped based on the vertical electrical sounding results. Depth to bedrock from geoelectric study conducted by Ojo and Ademilua (2013) was correlated with depth to bedrock from litholog. Also, the thickness of weathered basement obtained from geoelctric section was correlated with thickness of weathered basement from lithologic logs.

It is also stated that 2D interpretation of ID vertical electrical sounding measurements can produce improved subsurface geophysical images and presents a potential useful tool for larger scale geological investigations especially in the case of reprocessing existing vertical electrical sounding data sets referred by Atzemoglou and Tsourlos (2012). The overall objective of this paper is to find out the aquifer thickness in Tripura using resistivity survey and the lithogs used for the some locations for estimation of corrected layer.

Study area

Agartala the capital of Tripura is situated at the western corner of the State. It is connected with mainland by National Highway no. 44 via the State of Assam. Globally it is situated between 23^0 45' and 23^0 55' N latitude and $91^0$15' to $91^0$20' E longitude, in the flood plains of the Haora river. Historically, the city has been an important border-trading town having trading linkages with Bangladesh. Total area of Tripura is 10,477 km^2. It receives an annual average rainfall of 1927 mm. The hill area is 6400 km^2. The semi-consolidated formations consisting of friable sandstone, sandy shale, etc., of tertiary age forms the main rock types of the area. The unconfined aquifer is mainly tapped through shallow wells with a discharge of 5 to 15 Lps in the valley areas whereas in the sandstone, the yield varies from 2 to 4 Lps. The annual replenishable groundwater resource is 2.19 BCM and net annual groundwater availability is 1.97 BCM. The annual groundwater draft is 0.17 BCM and stage of groundwater development is 9%. The entire state has been categorized as safe. Groundwater development in the deeper aquifers has also been established through construction of deep tubewells, the yield of wells tapping the sandstone areas varies from 25 to 40 Lps. There is no over exploited, critical and semi-critical zone. Exploratory tubewells constructed [as on 31.03.2010 (DWS)] are as follows : 948 deep tubewell (DTWs) and 26,086 spot sources. For artificial recharge to groundwater (AR) the numbers of feasible artificial recharge structure are: 300 check dams, 500 weirs, 1000 gabion structures, 240 roof top harvesting and 100 developments of springs. However, in districts of Dhalai, north Tripura, south Tripura and west Tripura are affected (in part) by iron contaminants (for example water having > 1.0 mg/L of iron). As on 2009 the total irrigation utilization potential of Tripura is 52616 ha (MOWR, 2009).

The natural reservoir, underlain by unconsolidated alluvial sediments, (sand, gravel, pebbles, etc.) has immense groundwater potential. The water table depth in Agartala city of the natural reservoir varies between 2 m and 6 m. In the synclinal valley of Agartatla district, aquifers are found in the semi consolidated soft and stones of tertiary age

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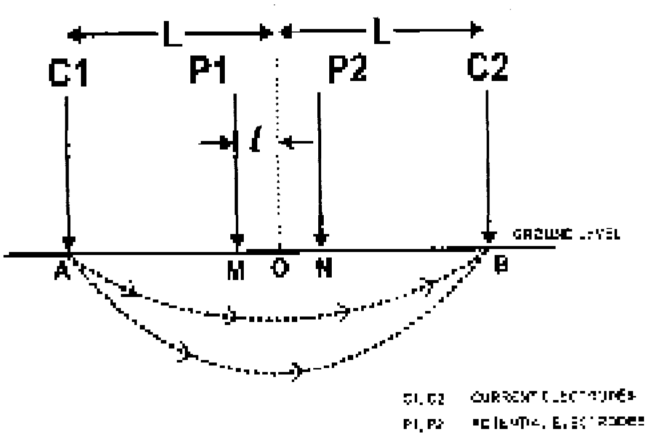

Figure 1. *Electrode configuration in Schlumberger method (assume, a = 1)*

where both shallow (within 30-50 m below ground level with yield 5 to 20 m^3/hr) and deep tube wells (50 to 200 m below ground level deep with yield varying from 50-200 m^3/hr) and deep tubewells (50 to 200 m below ground level deep with yield varying from 50-200 m^3/hr) are feasible. Potential deep aquifers in the upper tertiary areas of Agartala have been identified in Surma, Tipam and Dupitila parts of the district. The latest estimate of ground water potential of Haora river is 353 MCM/year but its current utilization is insignificant (Datta *et al.,* 2008). Lack of road communication, non availability of flat areas in the hills, high iron content, lack of right type of the equipments for drilling bouldry foundation, huge thickness of clay bodies and over burden of weathered residuum are the dominant problems of ground water development in the area. The existing 70 deep tubewell has been found having yield 10,000 to 20,000 GPH.

Tripura state in general and investigated areas in particular is underlain by the geological formations ranging from upper tertiary to quaternary. Subsurface formations are characterized by a succession of argillaceous and arenaceous sedimentary rocks, like sand stone, shale, siltstone, silt and clay belonging to Surma, Tipam and Dupitiala groups. The Surma group occurs at the core of anticline and mostly comprises of shale, siltstone and sandstone and is broadly considered to be not so promising for groundwater. The Tipam group is represented by sandstone, sandy shale and siltstone. Dupitilla group occurs in the form of disconnected mounds and occurs in valleys. This group comprises of coarse to gritty ferruginous sandstone, clay, clayey sandstone and laterites. The recent sediments mostly developed along rivers, comprises of silt, sand silty clay, etc. Seismic surveys in the region reveal the presence of sub-surface flatus. The part of Surma basin in Tripura Mizoram area lies in close proximity to the Shillong plateau in the north and Arakan Yoma belt to the east. Tripura is, therefore, located in a seismically active zone. Because of inherent character of sediments of these areas even a minor shock during earthquake may cause devastating effects, like landslides, etc., (Mukherjee *et al.,* 1998).

METHODOLOGY

Schlumberger sounding array was used in the area to know the vertical variation of resistivity along depth and to locate the aquifer zone and proper bore well sites. In this method, all 4 electrodes are kept in one line as shown in figure 1. Current is sent into the ground through two outer current electrodes and the resulting potential difference is measured between two inner electrodes comprising carbon pots. The current electrode spacing is gradually increased. Resistance of the ground is measured for different sets of electrode spacing. As the separation between the current electrodes is increased, current penetrates deeper and the observed resistance pertains to resistivity of the deeper bodies. Depth of investigation depends on the resistivity structure in the subsurface; the higher the resistivity, the more is the depth of investigation. Maximum current electrode spread of 800 m was used in the investigation. Corresponding to each spacing of electrodes, apparent resistivity is calculated at the centre of the spread using the following formula.

$$\rho_a = \Pi n(n + 1)a.(\Delta V/I)$$

Where a is distance between two potential electrodes in m, n is distance between the

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Table 1. *General guideline of litholog strata with resistivity values of different subsurface layer*

Lithology	Resistivity
Compact rock (sand stone)	>350 Ohm.m
Semi compact hard sand/rock/carbonate concretion	200 Ohm.m-350 Ohm.m
Coarse sand with/without pebbles (aquifer)	46 Ohm.m-150 Ohm.m
Medium sand (aquifer)	30 Ohm.m-45 Ohm.m
Fine sand/very fine sand (occasionally aquifer zone)	20 Ohm.m-30 Ohm.m
Clay, sandy clay	<15 Ohm.m

centre of the electrodes and one extreme current electrode in m. Resistance ($\Delta V/I$) has been measured by the resistivity meter. In the present investigation, depth of probing was about 200-300 m. Thus, data for a sounding curve is generated for each sounding point (location). These data (apparent resistivity vs half the current electrode separation) have been plotted on a Log-Log scale. These curves are first interpreted by curve matching technique with a set of master curves of Orellena and Mooney and then interpretation was refined by using 1-D software IPI2WIN. The interpreted parameters, thus obtained are the resistivity and thickness of each subsurface layer upto the depth of investigation. Finally, these resistivity values of the layers are interpreted in terms of geological formations and aquifer zone. Interpreted parameters, namely resistivity and thickness of different subsurface layers are given in table 1. It may be pointed out that resistivity survey technique is indicative and works well under the assumed conditions.

DATA ANALYSIS USING RESISTIVITY SURVEY AND INTERPRETATION WITH BOREHOLE LITHOLOG

Agartala valley

Based on the known geology of the area in borehole litholog, our past experience and present vertical electrical sounding investigation, correlation has been made between the various lithological units including ground water zone and the true resistivity values interpreted in the area. These are generally as follows :

Details of interpreted vertical electrical soundings (VES) in the 4 valleys are given below :

VES-1 (Maddya Boxnagar, Boxnagar block) : Clay and very fine sand occur from surface to a depth of 57.5 m, below which a good aquifer zone comprising coarse sand is interpreted upto 83.8 m followed by another fine sand layer at deeper level. Considering that ground water in the area is abstracted from the depth range 60 m-200 m, total thickness of aquifer zone has been estimated in that depth interval and found to be 23.8 m.

VES-2 (Bhabanipur, Katalia block) : Clay and very fine sand occur upto 51.5 m below which, fine sand is inferred upto 64.7 m. Below this, an excellent aquifer zone comprising coarse sand is interpreted upto 179 m or more. Total thickness of aquifer zone in the depth range 60 m-200 m is estimated as 135.3 m.

VES-3 (Umrai Old Market, Mohanvug block) : Fine sand is predominant upto 80.6 m below which, an excellent aquifer zone comprising coarse sand occurs upto 158.4 m or more. Total thickness of aquifer zone in the depth range of 60 m-200 m is estimated as 69.4 m.

VES-4 (Kulubari, Box Nagar block, Sonamura SD) : Fine to medium sand occurs upto 21.6 m below which, sandy clay is predominant upto 164 m depth followed by a very good aquifer zone comprising coarse sand layer upto 181 m depth. Total thickness of aquifer zone in the depth range 60 m -200 m is estimated as 17 m.

VES-5 (Ghanabill Math, Teliamura block, Khowai district) : An excellent aquifer zone comprising coarse sand is inferred from 12.6 m to 212 m depth. Total thickness of aquifer zone in the depth range 60 m-200 m is

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estimated as 140 m.

VES-6 (Chikancherra, Jampuijala block, Bishalgarh SD) : An excellent aquifer zone comprising coarse sand occurs from 31.5 m to 102 m depth below which, very fine sand is likely. Total thickness of aquifer zone in the depth range 60 m-200 m is estimated as 42 m.

Udaipur valley

VES-1 (South Srinagar, Sabroom block) : A very good aquifer zone comprising mostly coarse sand is interpreted below 7.16 m comprising mostly coarse sand. Considering that ground water in the area is abstracted from the depth range 60 m-200 m, total thickness of aquifer zone has been estimated in that depth interval and found to be 140 m.

VES-2 (Benafa Pattar, Rupaichari block) : Medium sand occurs from 7.6 m to 35.2 m below which, coarse sand is predominant upto 72.4 m followed by another medium sand layer upto 112 m followed by clayey sand at deeper level. Considering that ground water in the area is abstracted from the depth range 60 m-200 m, total thickness of aquifer zone has been estimated in that depth interval and found to be 52 m.

VES-3 (Uttar Bharatchandra Nagar, Rajnagar RD block) : A very good aquifer zone comprising coarse sand is interpreted from 7.86 m to 90.6 m below which, an aquifer comprising medium sand occurs. Considering that ground water in the area is abstracted from the depth range 60 m-200 m, total thickness of aqifer zone has been estimated in that depth interval and found to be 140 m.

VES-4 (Radhanagar no. 4 Tilla, Rajnagar RD 9 block) : A very good aquifer zone comprising mostly coarse sand is likely from 7.8 m downward continuing atleast upto 140 m. Considering that ground water in the area is abstracted from the depth range 60 m. 200 m, total thickness of aquifer zone has been estimated in that depth interval and found to be 19.7 m.

Dharmanagar valley

VES-1 (Brajendra Nagar, Kadamtala block) : Clay and very fine sand occur upto 59.4 m depth followed by a good aquifer zone comprising medium sand upto 98.5 m and coarse sand at deeper level upto 180 m or so. Considering that ground water in the area is abstracted from the depth range 60 m -200 m, total thickness of aquifer zone has been estimated in that depth interval and found to be 140 m.

VES-2 (Gatachera, Penchartal RD block) : Alternate layers of medium and coarse sand occur here. Only one fine sand layer is interpreted between 31.5 m and 58.7 m. Aquifer zone continues throughout with some possible clay intercalations. Considering that ground water in the area is abstracted from the depth range 60 m-200 m, total thickness of aquifer zone has been estimated in that depth interval and found to be 140 m.

VES-3 (North Ganganagar, Jubarajnagar block, Dharmanagar SD) : Coarse sand occurs from 6.1 m to 20.5 m below which, sandy clay is inferred upto 139 m depth followed by a good aquifer zone comprising coarse sand upto 159 m. Further down clay and fine to very fine sand is likely. Considering that ground water in the area is abstracted from the depth range 60 m-200 m, total thickness of aquifer zone has been estimated in that depth interval and found to be 41 m.

VES-4 (Jayantipur, Dosda RD block, Kanchanpur SD) : Clay, sandy clay and very fine sand are mostly present upto 99.3 m. Below this, an aquifer zone comprising medium to coarse sand is inferred upto 119 m. Further down, very fine sand occurs. Considering that ground water in the area is abstracted from the depth range 60 m-200 m, total thickness to aquifer zone has been estimated in that depth interval and found to be 19.7 m.

Kailasahar valley

VES-1 (Sreerampur, Chandipur RD block) : Clay occur upto 2.9 m, then very fine sand upto 9.8 m and fine sand upto 31.5 m. Below this, an excellent aquifer comprising mostly coarse sand is inferred atleast upto 150 m

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depth. Considering that ground water in the area is abstracted from the depth range 60 m-200 m, total thickness of aquifer zone has been estimated in that depth interval and found to be 140 m.

VES-2 (Kuleshnagar, Kumarghat RD block) : Coarse sand occurs from 8.3 m to 21.6 m followed by clay upto 78.5 and a good aquifer zone of coarse sand from 78.5 m to 103 m depth. Further down, very fine sand is inferred. Considering that ground water in the area is abstracted from the depth range 60 m-200 m, total thickness of aquifer zone has been estimated in that depth interval and found to be 24.5.

VES-3 (Ram Durlavpara, Salena block) : Medium sand occurs from 7.2 m to 25.8 m and from 54.3 m to 110 m. Coarse sand is interpreted from 25.8 m to 54.3 m and from 110 m to 138 m and beyond. All these formations contain good amount of ground water. Considering that ground water in the area is abstracted from the depth range 60 m-200 m, total thickness of aquifer zone has been estimated in that depth interval and found to be 140 m.

VES-4 (Karamcherra, Nutan Bazar, Manu block) : A good aquifer comprising mostly coarse sand occurs from 4.5 m downward continuing atleast upto 150 m depth. Considering that ground water in the area is abstracted from the depth range 60 m-200 m, total thickness of aquifer zone has been estimated in that depth interval and found to be 140 m.

CONCLUSION

Subsurface formation are highly variable in the subsurface. Sand of various grades, like fine, medium and coarse, sandy clay, clay, weathered rocks of sand stone, shale, siltstone and laterites as well as traces of carbonate rocks/minerals are interpreted in the subsurface. These formations mostly belongs to upper tertiary to recent age and belong to Surma, Tipam and Dupitilla groups. Groundwater is mostly available in moderate to good quantity at shallow depth in Tipam formations under water table conditions and at deeper level under confined conditions. Groundwater yield is more in borewells where sand is not consolidated and yield is less where formations are semi consolidated or consolidated. Groundwater yield is negligible in sand stones. Shale and silt stones are devoid of groundwater.

Resistivity sounding data (VES) of 18 locations, where data collections were good, spreads over 4-valleys indicate that the subsurface formations in the areas of investigation are having distinct resistivity values with some overlapping. Resistivity in the range of 30-120 m is considered to be reflective of a good aquifer zone comprising medium/coarse grain sands/loosely cemented sand stone. Broad topographic lows are also considered good target areas for ground water. Based on resistivity data, hydrogeological considerations and field experience, yield potential has been predicated which, by and large, tallies with the groundwater yield of subsequent borewells in the area. Also, all borewells drilled on the basis of resistivity survey encountered sufficient ground water.

Above analysis and discussions indicate the utility of geophysical resistivity survey in ground water exploration especially for locating borewell sites, delineation of aquifer zones and depth of boring for borewells. Average thickness of aquifer zones in the depth range 60 m-200 m (from where groundwater is abstracted through borewells) in the Agartala valley, Udaipur valley, Dharmanagar valley and Kailasahar valley are found to be 71.25 m, 118 m, 85.18 m, 111.13 m, respectively.

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Study of Identification of Effective Sand Bed in Aquifer Zones using Resistivity Survey in Tripura: Case Studies

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ABSTRACT: *Growing water scarcity in India is threatening for sustainable water supply source of the inhabitants. As the present water sources are not being able to provide water as per required demand so, groundwater can play an important role in ensuring complementary and sustainable water supply in parallel with the present water sources. Hence sustainable exploitation of this resource is needed and thus studies are needed to be done so that we can reach a sustainable yield of groundwater. Vertical Electrical Sounding (VES) is one such method by which resistivity of earth materials is checked and prospective ground water potential zones are identified along with sub soil stratifications. The resistivity meter (SAR-MP-ATS) was used to collect the VES data by employing Schlumberger electrode configuration and the field data were interpreted in terms of resistivity and the corresponding thickness of various subsurface layers using 'Interpex, IX1D' computer software. The present study focuses on identification of effective sand bed for Khowai District, West Tripura District, Sepahijala District and Gomati District in Tripura and as well as developing resistivity variation curve and interpreting lithologs / sub soil stratification from VES survey data. VES study may be used to find the litholog of the terrain without further making boreholes in the regions thus reducing cost incurred and labour required and thus finding groundwater potential zones economically.*

I. INTRODUCTION

A study was carried out to assess the prevailing groundwater condition in the South, Central, Northern part of Sagar Island region, West Bengal, India using surface resistivity method. Vertical electrical sounding (VES) survey at 38 sites using the Schlumberger array by the resistivity equipment DDR-4 manufactured by the Integrated Geo Instruments and Services Pvt. Ltd., Hyderabad, Andhra Pradesh, India with maximum current electrode spacing of 1200 m used in the study was conducted. The apparent resistivity datasets thus obtained were interpreted using 1D inversion technique by RESIST software with RMS error less than 5%. From the interpreted VES results he found the average upper and lower depths of fresh water bearing aquifer for all location are 187 m and 354 m respectively and the resistivity values were ranging from 32 Ω-m to 75.5 Ω-m with average value of 52 Ω-m. It was also proposed that the probable lithology of the study area which was the top soil, the saline water zone, the brackish groundwater zone and impermeable clay layer, clay with fine sand and silt lenses (Majumdar and Das, 2011). VES surveys were conducted at 44 locations in different hydro-geomorphic units to assess the types and thickness of different geo-electrical layers to understand the aquifer system in each unit at Bonai subdivision of Sundargarh district, Orissa, India. VES studies in the area revealed that the area had high potential for exploitation of groundwater through different kinds of groundwater structures. Depth to the bedrock ranged from 30 m to 70 m in most parts of the geomorphic units and 15 m to 30 m in some places. It was concluded that the dug-cum borewells along with dug wells might be constructed in areas where depth to bedrock lie between 15 m to 30 m and borewells along with dug wells and dug-cum-bore wells were suitable in areas where depth to bedrock was more than 30 m. (Sahu and Sahoo, 2006). 26 VES surveys were conducted by Rai et al., (2005) using Schlumberger electrode configuration in the Dhanbad district in Jharkhand, India. They concluded that the resistivity of water-bearing weathered / fractured rocks varied from 120 Ω-m to 150 Ω-m and the better zones, which were most promising for groundwater exploration could be dug up to depths of (30 ± 5) m. VES studies were carried out by Srinivasa, (2004) in order to delineate groundwater potential aquifers in Peddavanka watershed, a catchment of about 398 km2 in Anantapur District, Andhra Pradesh, India. A total of 99 VES surveys were conducted using the Schlumberger configuration with a maximum current electrode (AB/2) separation of 90 m, covering the entire watershed. It was revealed that the weathered and fractured portions in shale and limestone that occur in the southernmost and central portions of the watershed area constituted the productive water-bearing zones, which were categorized as good groundwater potential aquifers. It was concluded that the VES data gave reasonably accurate results that could be used to understand the subsurface layers and basement configuration in groundwater exploration. The VES surveys were performed by Sharifi et al., (2014) in 10 sounding points in the Tepal area, west of Shahrood, Iran using the Schlumberger array with electrode separations of a maximum 500 m. Then, one-dimensional (1-D) modeling and interpretation of the sounding results, using master curves and IX1D software, and two-dimensional (2-D) modeling and interpretation of the profiling results using Res2DINV were made. As a result of the interpretation and integration of the results, karstic water zones in the study area were recognized, and based on that, suitable locations for drilling to access and extract karstic groundwater were introduced. The research covered four small communities, namely, Zantele, Kanshegu, Nyengbalo and Zei. The Schlumberger electrode configuration was first used in the line profiling. Qualitative interpretation of the geoelectrical resistivity profiling data resulted in the identification of weathered regions. Vertical electrical sounding using the dipole-dipole array were then conducted with at specific points within the weathered zones. The spread length ranged from minimum of 12 m to maximum of 204 m to provide depth information. Interpex 1X1D v2 (Ezomo and Aigbogun, 2012) and v3 software was used to compute layered earth model of the subsurface beneath the sounding points. Interpretation of the one-dimensional inversion of the VES resistivity data provided the overburden and aquifer layering resistivities and thicknesses. The geoelectric sequence revealed predominantly a three subsurface layer which is largely congruous to the weathering profile above the fresh bedrock - thick top soil, the weathered and the variably weathered and fractured bedrock respectively. The geoelectric sections provide no evidence of a descent into the fresh bedrock. The geophysical target is a reasonably thick and extensive zone of saturated weathered rock beneath the overburden. On the basis of the perceived aquifer properties, sites were recommended for drilling water supply boreholes for the communities (Asare and Menyeh, 2013). Sikandar and Christen (2012) established an empirical relationship between the formation factor and hydraulic conductivity which was highly significant and as such can be helpful for the estimation of hydraulic conductivity for groundwater pumping investigations in this area and a study on dynamic groundwater assessment in Agartala city has been carried out by Debbarman et al (2013) to assess the groundwater potential. However, keeping in this view, the objective of this paper is to investigate the aquifer characteristics, thickness, layerwise soil type, and water table depth using Vertical Electrical Sounding (VES) resistivity survey technique and also to interpret resistivity variation curve from the data obtained from Vertical Electrical Sounding (VES) survey in different study areas by using computer software (IX1D).

II. MATERIALS AND METHODS

2. 1. Study Area

2.1.1. Khowai District

Khowai district lies in the northern part of Tripura state. The district is bounded on the north by the country Bangladesh, on the south by Gomati district, on the west by Dhalai district and on the east by West Tripura district. The district has total area of 1377.28 sq. km. and it lies between the Latitude 23°42' N to 24°14' N and Longitude 91°39' E to 91°46' E. The district is divided into 2 sub-divisions and 6 administrative blocks. The district comprises of 3 numbers of revenue circles, 2 numbers of nagar panchayats, 79 numbers of maujas and 107 numbers of villages. The total population of the Khowai district as per the 2011 census is 327564 persons. The district headquarter is located at Khowai (Ghosh, 2014).

2.1.2. West Tripura District

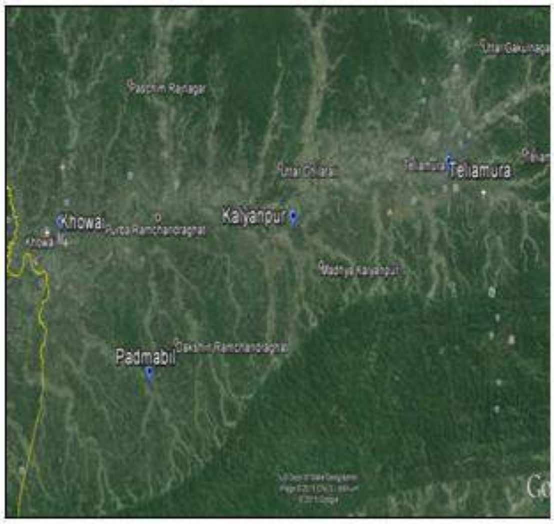
West Tripura district lies in the western part of Tripura state. The district is bounded on the north by the country Bangladesh, on the south by Sepahijala district, on the west by the country Bangladesh and on the east by Khowai district. The district has total area of 983.63 sq. km. and it lies between the Latitude 23°16' N to 24°14' N and Longitude 91°47' E to 92°20' E. The district is divided into 3 sub-divisions and 9 administrative blocks. The district comprises of 1 number of Municipal Corporation, 1 number of Nagar Panchayat. The total population of the West Tripura district as per the 2011 census is 918200 persons. The density of population is 576 persons per sq. km. The district headquarter is located at Agartala, which is also the capital of the state Tripura.

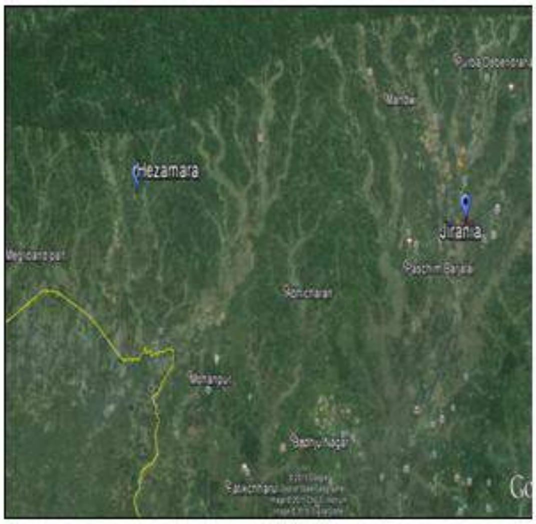
2.1.3. Sepahijala District

Sepahijala district lies in the western part of Tripura state. The district is bounded on the north by West Tripura district, on the south by the country Bangladesh, on the west by the country Bangladesh and on the east by Gomati district. The district has total area of 1043.58 sq. km. and it lies between the Latitude 23°16' N to 24°14' N and Longitude 91°47' E to 92°20' E. The district is divided into 3 sub-divisions and 5 administrative blocks. The district comprises of 2 numbers of Nagar Panchayat. The total population of the Sepahijala district as per the 2011 census is 483687 persons. The density of population is 576 persons per sq. km. The district headquarter is located at Bishramganj.

2.1.4. Gomati District

Gomati district lies in the southern part of Tripura state. The district is bounded on the north by the West Tripura district and Khowai district, on the south by South Tripura district and Bangladesh, on the west by Sepahijala district and on the east by Dhalai district. The district has total area of 2624.35 sq. km., which is about 25% of the total state area. It lies between the Latitude 22°56' N to 24°32' N and Longitude 91°59' E to





92°22' E. The district is divided into 3 sub-divisions and 8 administrative blocks. The district comprises of 7 numbers of revenue circles, 1 number of Municipal Corporation, 1 number of Nagar Panchayat and 157 numbers of villages. The total population of the Gomati district as per the 2011 census is 442336 persons. The district headquarter is located at Udaipur.

III. METHODOLOGY

To examine the geoelectrical properties of the area, electrical resistivity survey has been carried out using the SSR-MP-ATS resistivity meter with the Schlumberger configuration at 4 locations (Teliamura, Kalyanpur, Padmabil, Khowai) in Khowai district, Tripura. A GPS receiver is used in the field to get the position data of each VES site at the study area. All the survey points are shown in Fig.1(a) using Google Earth image.

To examine the geo-electrical properties of the area, electrical resistivity survey has been carried out using the SSR-MP-ATS resistivity meter with the Schlumberger configuration at 2 locations (Jirania, Hezamara) in West Tripura district, Tripura. A GPS receiver is used in the field to get the position data of each VES site at the study area. All the survey points are shown in Fig.1(b) using Google Earth image.

To examine the geoelectrical properties of the area, electrical resistivity survey has been carried out using the SSR-MP-ATS resistivity meter with the Schlumberger configuration at 5 locations (Maheshpur, Kathalia, Paharpur, Sonamura, Boxanagar) in Sepahijala district, Tripura. A GPS receiver is used in the field to get the position data of each VES site at the study area. All the survey points are shown in Fig.1(c) using Google Earth image.

To examine the geoelectrical properties of the area, electrical resistivity survey has been carried out using the SSR-MP-ATS resistivity meter with the Schlumberger configuration at 5 locations (Tepania, Matabari, Amarpur, South Karbook, East Karbook) in Gomati district, Tripura. A GPS receiver is used in the field to get the position data of each VES site at the study area. All the survey points are shown in Fig.1 (d) using Google Earth image.

3.1. IX1D software: Interpretation of VES survey data

The subsurface layering was derived based on the distinct resistivity values of the upper layer (ρ1), second layer (ρ2), third layer (ρ3) and so on. The distinctive characteristics features in the apparent resistivity curves were characterized by the considerable spatial variability of the groundwater quality and inhomogenity of the subsurface aquifer conditions. Therefore, depending upon the shape of the curve, different layer earth data were classified into different types. The shape of the VES curve at any location is controlled by the underlined formation distribution i.e. the resistivity (ρi) and thickness (hi) of the geoelectric layers and the total depth investigated.

Two layer section in resistivity method means the first layer thickness is finite while that of the second layer is infinite. The only two situations that can occur for a two layer section are either the resistivity of the first layer is greater than the second (ρ1 > ρ2) or less than the second (ρ1 < ρ2); the former case is 'Ascending Type' curve and the later is 'Descending Type' curve.

Orellana and Mooney (1966) presented 4 types of interpreted curves based on the 3 layered earth model as given in TABLE 1. Accordingly, the 3 layered earth can be classified into 'Q', 'H', 'K' and 'A' Type curves based on their shapes. The distribution of resistivities associated with different subsurface layers with different settings is described below (Srinavasa, 2004):

Table 1. Details of curve types for three layer case

Sl. No.	Curve Type	Resistivity Details
1	Q type	ρ1 > ρ2 > ρ3
2	H type	ρ1 > ρ2 < ρ3
3	K type	ρ1 < ρ2 > ρ3
4	A type	ρ1 < ρ2 < ρ3

A total 8 types of 4 layer curves are possible depending upon the resistivity distribution of the various layers as highlighted in TABLE 2.

Table 2. Details of curve types for four layer case

Sl. No.	Curve Type	Resistivity Details
1	QQ type	ρ1 > ρ2 > ρ3 > ρ4
2	QH type	ρ1 > ρ2 > ρ3 < ρ4
3	AA type	ρ1 < ρ2 < ρ3 < ρ4
4	AK type	ρ1 <ρ2 < ρ3 > ρ4
5	HA type	ρ1 > ρ2 <ρ3 < ρ4
6	HK type	ρ1 >ρ2 < ρ3 >ρ4
7	KH type	ρ1 < ρ2 > ρ3 < ρ4
8	KQ type	ρ1 < ρ2 > ρ3 > ρ4

Similarly a five layer section can yield 16 possible types of curves and so on. A geological formation may be comprised of more than one geoelectric layers and vice versa.

The apparent resistivity values collected from the study areas are to be plotted against half of the current electrode spacing on a transparent log-log paper at the same scale as of two and three layers standard curves. The interpretation by curve matching technique of VES data is to use the curve of apparent resistivity versus electrode spacing, plotted from field measurements, to obtain the parameters of the geoelectrical section, the layer resistivities and thicknesses. The use of standard curves matching technique requires an identification of the curve type followed by a comparison with standard curves of that type to obtain the best match. Two-layer and three-layer curves can be used for complete interpretation of VES curves of more layers by the Auxiliary Point Method, which requires the use of a small set of auxiliary curves and some constructions. This is the early method of interpreting sounding curves which used curve-matching techniques. A set of standard curves developed by Orellana and Mooney (1966) and Zohdy (1969) is shown in Fig. 2. This technique has also been used by many researchers such as Shankar (1994), Lashkaripour (2003), Lashkaripour et al. (2005) and Oseji et al. (2006). Based on this preliminary interpretation, initial estimates of the resistivities and thickness (layer parameters) of the various geoelectric layers were obtained.

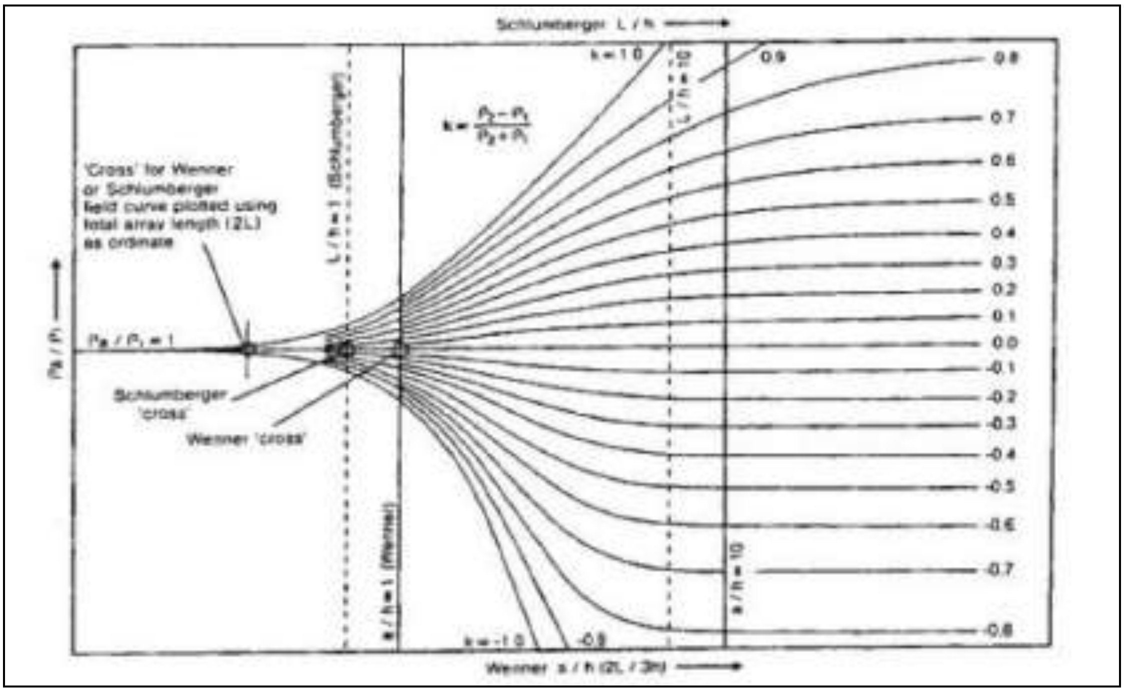


Fig. 2. Master curve for two layered system (Source: Bernard, 2003)

In the second analysis, the layered parameters derived from the graphical curve matching were then matched with the interpreted sounding data in terms of the final layer parameters through 1-D inversion technique software (IX1D v3.0, Interpex, USA). This software produces the resistivity model, fitting the acquired field data with the least root mean square (RMS) error between the synthetic data generated from the model and the actual data themselves. The method of iteration was performed until the fitting errors between field data and synthetic model curve became least and constant. The output of true resistivities (or simply resistivities) values of the subsurface layer, their thickness and depth from the ground surface after interpreting field data (apparent resistivities) by fitting curve to input data using IX1D computer software. The electrical resistivity of sediments depends on lithology, water content, clay content and salinity (Bernard, 2003; Choudhury and Saha, 2004). Some interpretation problems for VES can occur when mapping subsurface salinity, since resistivities for salt water, saturated clay and sand overlaps. It is therefore important to correlate the VES results with the lithological and hydrological information of the same sites.

IV. RESULTS AND DISCUSSION

Since the study area falls on sedimentary tract, the water prospect here is by the saturated water present in the sand aquifers below. The tract is alluvial and water availability here is good, the aquifers zones are unconfined and are very prospectful zones for groundwater development by deep tubewells.

4.1. Khowai District

VES curve at Teliamura and Padmabil is classified as Type Q Curve reflecting the presence of three subsurface layers which gives the resistivity relationship of $\rho 1 > \rho 2 > \rho 3$. VES curve at Kalyanpur is classified as Descending Type Curve reflecting the presence of two subsurface layers which gives the resistivity relationship of $\rho 1 < \rho 2$. VES curve at Khowai is classified as Type K Curve reflecting the presence of three subsurface layers which gives the resistivity relationship of $\rho 1 < \rho 2 > \rho 3$. All the VES curves are presented in Fig. 3 (Fig. 3a to Fig. 3d).

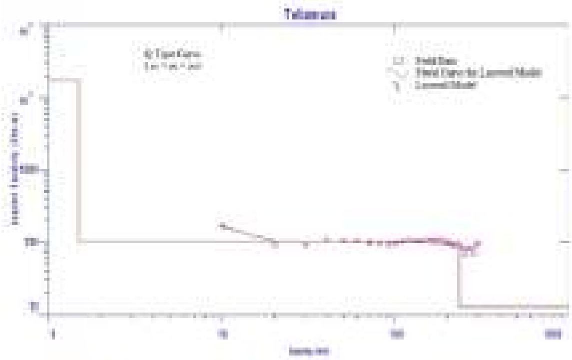


Fig. 3a. VES curve for location Teliamura

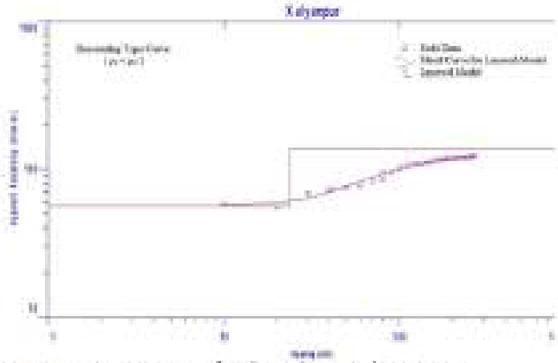


Fig. 3b. VES curve for location Kalyanpur

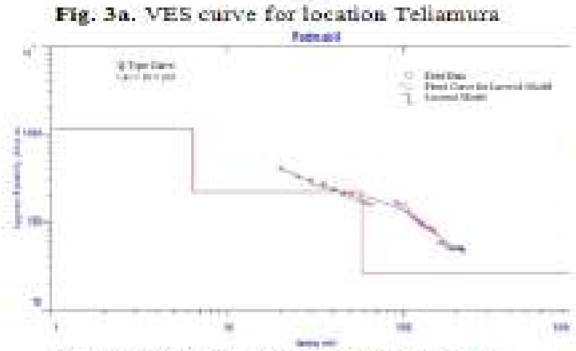


Fig. 3c. VES curve for location Padmabil

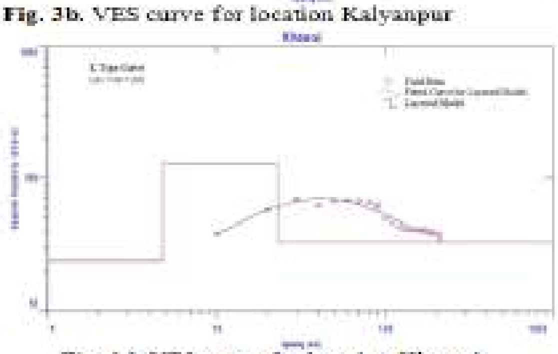


Fig. 3d. VES curve for location Khowai

From the interpreted true resistivities at Khowai district, Tripura, we can see that subsurface formations are highly variable. At Teliamura we can see three subsurface layers out of which the top layer is generally formed with very coarse sand particles with gravel, the second layer is generally formed with clay mixed with fine sand particles and the bottom layer is generally formed with clay. At Kalyanpur we can see two subsurface layers out of which the top layer is generally formed with clay with conserved moisture contents and the bottom layer is generally formed with clay mixed with fine sand particles. At Padmabil we can see three subsurface layers out of which the top layer is generally formed with very coarse sand particles, the second layer is generally formed with dry silty clay and the bottom layer is generally formed with clay. At Khowai we can see three subsurface layers out of which the top layer is generally formed with clay, the second layer is generally formed with clay mixed with fine sand particles and the bottom layer is generally formed with clay with conserved moisture contents.

4.2 West Tripura district

VES curve at Jirania is classified as Type KH Curve reflecting the presence of three subsurface layers which gave the resistivity relationship of $\rho 1 < \rho 2 > \rho 3 < \rho 4$. VES curve at Hezamara is classified as Ascending Type Curve reflecting the presence of two subsurface layers which gave the resistivity relationship of $\rho 1 > \rho 2$. All the VES curves are presented in Fig. 4 (Fig. 4a and Fig. 4b).

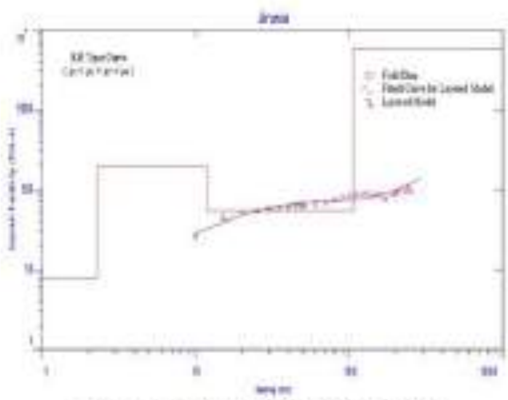


Fig. 4a. VES curve for location Jirania

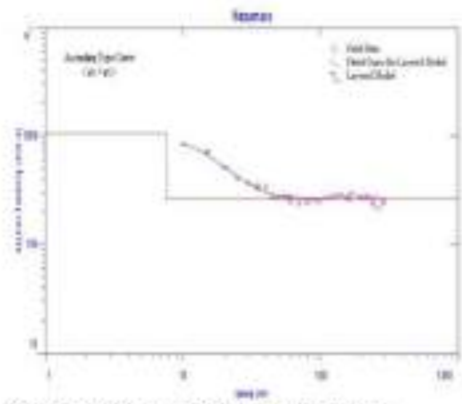


Fig. 4b. VES curve for location Hezamara

From the interpreted true resistivities at West Tripura district, Tripura, we can see that subsurface formations are highly variable. At Jirania we can see four subsurface layers out of which the top layer is generally formed with impervious type clay, the second layer is generally formed with clay mixed with fine sand particles, the third layer is generally formed with clay with conserved moisture contents and the bottom layer is generally formed with very coarse sand particles with gravel. At Hezamara we can see two subsurface layers out of which the top layer is generally formed with very coarse sand particles and the bottom layer is generally formed with silty clay.

4.3 Sepahijala district

VES curve at Maheshpur and Kathalia is classified as Descending Type Curve reflecting the presence of two subsurface layers which gives the resistivity relationship of $\rho1 < \rho2$. VES curve at Paharpur is classified as Type Q Curve reflecting the presence of three subsurface layers which gives the resistivity relationship of $\rho1 > \rho2 > \rho3$. VES curve at Sonamura is classified as K Type Curve reflecting the presence of three subsurface layers which gives the resistivity relationship of $\rho1 < \rho2 > \rho3$. VES curve at Boxanagar is classified as KHK Type Curve reflecting the presence of five subsurface layers which gives the resistivity relationship of $\rho1 < \rho2 > \rho3 < \rho4 > \rho5$. All the VES curves are presented in Fig. 5 (Fig. 5a to Fig. 5e).

From the interpreted true resistivities at Sepahijala district, Tripura, we can see that subsurface formations are highly variable. At Maheshpur we can see two subsurface layers out of which the top layer is generally formed with hard impervious type clay and the bottom layer is generally formed with clay with conserved moisture contents. At Kathalia we can see two subsurface layers out of which the top layer is generally formed with hard impervious type clay and the bottom layer is generally formed with clay mixed with fine sand particles.

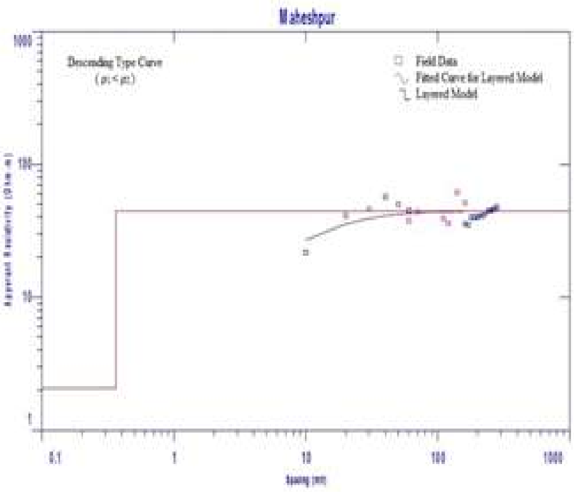


Fig. 5a. VES curve for location Maheshpur

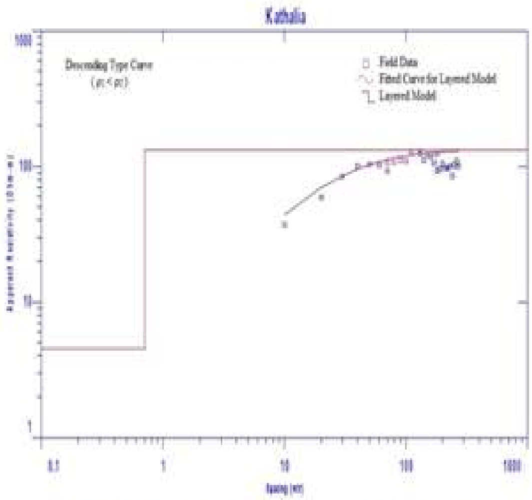


Fig. 5b. VES curve for location Kathalia

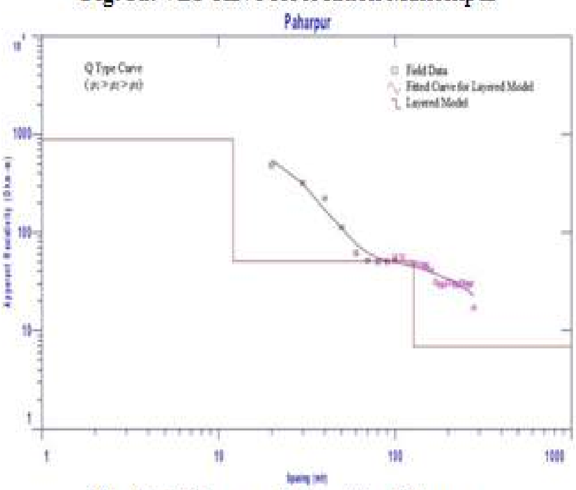


Fig 5c. VES curve for location Paharpur

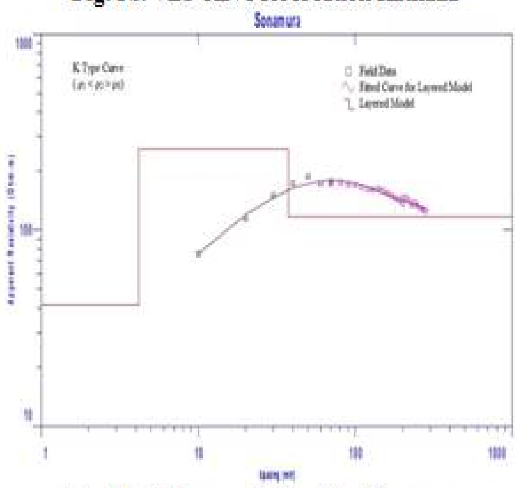


Fig. 5d. VES curve for location Sonamura

At Paharpur we can see three subsurface layers out of which the top layer is generally formed with very coarse sand particles, the second layer is generally formed with clay with conserved moisture contents and the bottom layer is generally formed hard impervious type clay. At Sonamura we can see three subsurface layers out of which the top layer is generally formed with clay with conserved moisture contents, the second layer is generally formed with dry silty clay and the bottom layer is generally formed with clay mixed with fine sand particles. At Boxanagar we can see five subsurface layers out of which the top layer is generally formed with clay, the second layer is generally formed with clay mixed with fine sand particles, the third layer is generally formed with impervious type clay, the fourth layer is generally formed with clay mixed with very fine sand particles and the bottom layer is generally formed with clay with conserved moisture contents.

4.4 Gomati district

VES curve at Tepania is classified as Type QH Curve reflecting the presence of four subsurface layers which gives the resistivity relationship of $\rho1 > \rho2 > \rho3 < \rho4$. VES curve at Matabari and Amarpur is classified as Type Q Curve reflecting the presence of three subsurface layers which gives the resistivity relationship of $\rho1 > \rho2 > \rho3$. VES curve at South Karbook is classified as Type K Curve reflecting the presence of three subsurface layers which gives the resistivity relationship of $\rho1 < \rho2 > \rho3$. VES curve at East Karbook is classified as Ascending Type Curve reflecting the presence of two subsurface layers which gives the resistivity relationship of $\rho1 > \rho2$. All the VES curves are presented in Fig. 6 (Fig. 6a to Fig. 6e).

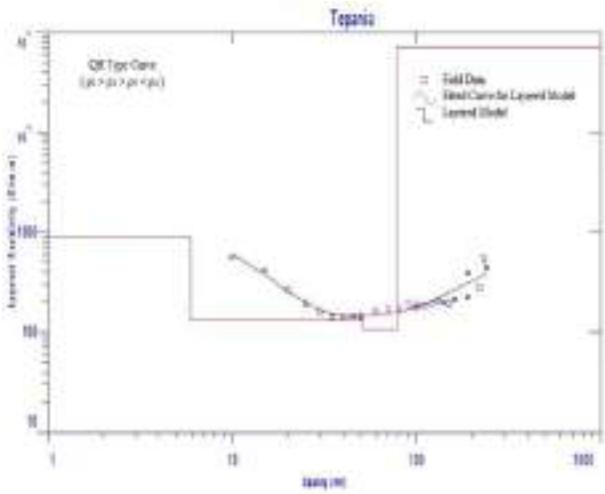


Fig. 6a. VES curve for location Tepania

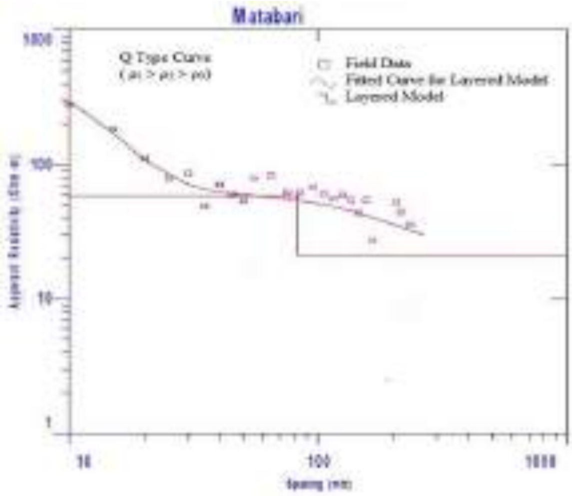


Fig. 6b. VES curve for location Matabari

From the interpreted true resistivities at Gomati district, Tripura, we can see that subsurface formations are highly variable. At Tepania we can see four subsurface layers out of which the top layer is generally formed with coarse sand particles, the second layer is generally formed with clay mixed with fine sand particles, the third layer is generally formed with clay mixed with very fine sand particles and the bottom layer is generally formed with very coarse sand particles with gravel. At Matabari we can see three subsurface layers out of which the top layer is generally formed with coarse sand particles, the second layer is generally formed with clay with conserved moisture contents and the bottom layer is generally formed with clay. At Amarpur we can see three subsurface layers out of which the top layer is generally formed with silty clay, the second layer is generally formed with clay mixed with fine sand particles and the bottom layer is generally formed with clay with conserved moisture contents. At South Karbook we can see three subsurface layers out of which the top layer is generally formed with clay with conserved moisture contents, the second layer is generally formed with clay mixed with fine sand particles and the bottom layer is generally formed with clay. At East Karbook we can see two subsurface layers out of which the top layer is generally formed with coarse sand particles and the bottom layer is generally formed with clay.

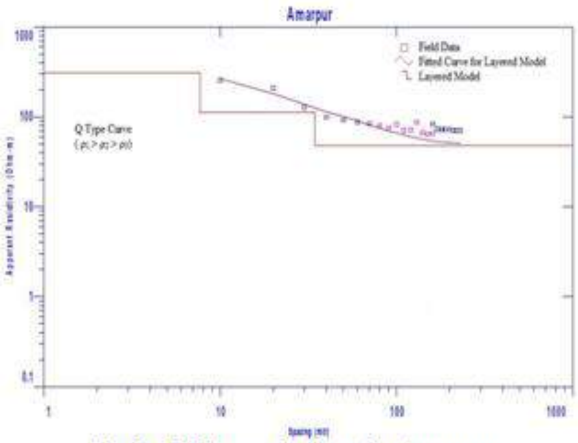


Fig. 6c. VES curve for location Amarpur

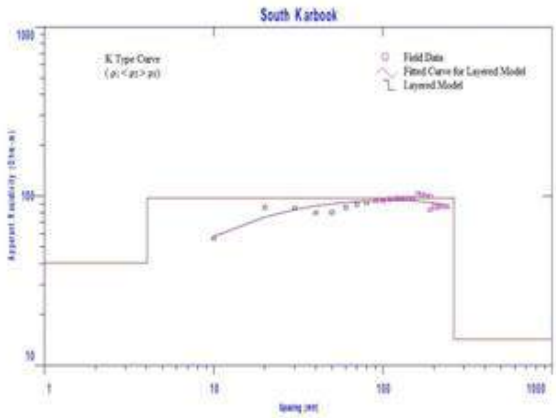


Fig. 6d. VES curve for location South Karbook

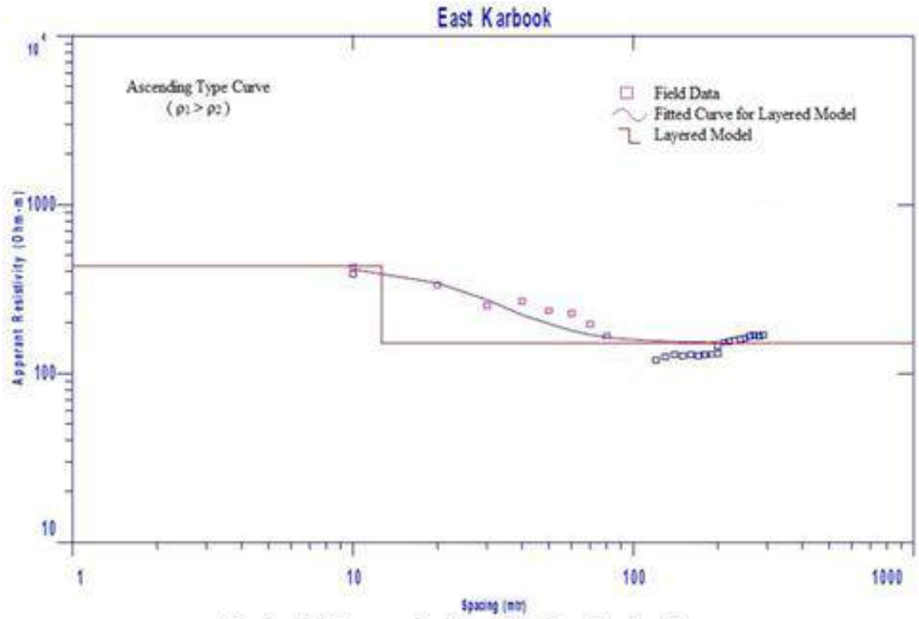


Fig. 6e. VES curve for location East Karbook

The two important Dar Zarouk parameters viz. Total Transverse Resistance and Total Longitudinal Conductance calculated for each VES point for this study area varies within 0.747 ohm-m^2 to 46293.1 ohm-m^2 and 0.00713 Siemens to 2.7599 Siemens respectively. From the values it can be seen that Teliamura, Paharpur and South Karbook are the locations which have both the above said parameters value near the maximum i.e., these are the locations having good groundwater potential and Maheshpur and Kathalia are the locations which have both the above said parameters value near the minimum i.e., these are the locations having poor groundwater potential.

V. CONCLUSION

After studying the geological & geophysical properties of the area and interpreting the field data it is suggested / recommended that, since the area falls on sedimentary tract, the water prospect here is by the saturated water present in the sand aquifers below. The tract is alluvial and water availability here is good, the aquifers zones are unconfined and are very useful zones for groundwater development by deep tubewells.

From the interpreted true resistivities at Khowai district, Tripura, we can see that subsurface formations are highly variable. Very coarse sand particles with gravel, clay mixed with fine sand particles, clayey soil, clay with conserved moisture contents, very coarse sand particles, silty clay are the main subsurface formations of this area. The survey yields that for getting a water quantity of (8000 - 10000) gallon per hour at Teliamura location drilling up to 190 m, at Kalyanpur location drilling up to 180 m, at Padmabil location drilling up to 180 m and at Khowai location drilling up to 170 m is recommended.

From the interpreted true resistivities at West Tripura district, Tripura, we can see that subsurface formations are highly variable. Impervious type clay, clay mixed with fine sand particles, clay with conserved moisture contents, very coarse sand with gravel, very coarse sand particles, silty clay are the main subsurface formations of this area. The survey yields that for getting a water quantity of (10000 - 12000) gallon per hour at Jirania location drilling up to 180 m is recommended and for getting a water quantity of (8000 - 10000) gallon per hour at Hezamara location drilling up to 200 m is recommended.

From the interpreted true resistivities at Sepahijala district, Tripura, we can see that subsurface formations are highly variable. Hard impervious type clay, clay with conserved moisture contents, clay mixed with fine sand particles, very coarse sand particles, silty clay, clayey soil are the main subsurface formations of this area. The survey yields that for getting a water quantity of (8000 - 10000) gallon per hour at Maheshpur location drilling up to 185 m is recommended, for getting a water quantity of (10000 - 11000) gallon per hour at Kathalia location drilling up to 180 m, at Sonamura location drilling up to 180 m, at Boxanagar location drilling up to 175 m is recommended and for getting a water quantity of (10000 - 12000) gallon per hour at Maheshpur location drilling up to 185 m is recommended.

From the interpreted true resistivities at Gomati district, Tripura, we can see that subsurface formations are highly variable. Dry layer of coarse sand, clay mixed with very fine sand particles, very coarse sand particles with gravel, coarse sand particles, clay with conserved moisture contents, clayey soil, silty clay are the main subsurface formations of this area. The survey yields that for getting a water quantity of (8000 - 10000) gallon per hour at Tepania location drilling up to 190 m, at Matabari location drilling up to 180 m, at South Karbook location drilling up to 170 m, at East Karbook location drilling up to 170 m is recommended and for getting a water quantity of (10000 - 11000) gallon per hour at Amarpur location drilling up to 170 m is recommended.

VI. RECOMMENDATIONS

Based on the results of VES resistivity survey, this study leads to the following recommendations:

- ✓ The VES survey has the potential to provide reasonable accurate results that can be used to understand the subsurface layers in groundwater exploration. The results of the VES must be verified with secondary hydro-geological data available in the study area.
- ✓ Other geophysical methods like the Seismic Refraction, Electromagnetic Method and Dipole-dipole electrical resistivity survey can be used to complement the methods used for this study.
- ✓ The VES survey should be avoided in monsoon season as the mobilization of the field personals during the survey becomes difficult due to precipitation as well as the water saturation of the top soil might yield inaccurate results.
- ✓ For getting accuracy horizontal profiling should also be done. Profiling also detects the geological faults and fissures.
- ✓ For development of correlation coefficient and regression analysis equation between results of VES survey and borehole litholog data large number of survey points should be taken so that accuracy could be achieved.
- ✓ For correlation of results obtained from interpreting data of VES data with litholog obtained from borehole drilling, the drilling should be done as nearer possible to the centre of the survey.

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Assessment of Dynamic Groundwater Potential of Agartala Municipality Area

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ABSTRACT

Dynamic groundwater potential of Agartala municipality has been estimated using groundwater resources estimation methodology-97. The methodology uses the rainfall-infiltration method, water-level fluctuation technique and water regression method and the estimated groundwater recharge is validated by using some empirical norms for recharge estimation. The groundwater utilization is also estimated. The stage of groundwater development is worked out and assessment units are categorized based on the stage of groundwater development and long-term water level trend. The annual replensihable groundwater resources of Agartala are 2106.61 ha-m and net annual groundwater availability is 1895.94 ha-m. The annual groundwater draft for 2009 is 313.64 ha-m. Thus the overall stage of groundwater development is 16.53 % for the period of 2009. Accordingly, the future dynamic groundwater stage would be 22.58% based on the population growth and considering 10% agricultural and industrial development. Therefore, this region falls under safe zone. However in addition, a focus of static groundwater recharge and withdrawal of Agartala city is also attempted.

Key words: Dynamic groundwater, GEC-1997, groundwater draft, groundwater recharge, stage of groundwater development.

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INTRODUCTION

Groundwater resource is a replenishable but finite resource. Rainfall is the principal source of recharge, though in some areas, canal seepage and return flow from irrigation also contribute significantly to the groundwater recharge. Groundwater resource comprises of two parts-dynamic which reflects seasonal recharge and discharge of aquifers and static resource below water table [1]. Groundwater has been the mainstay for meeting the domestic needs of more than 80% of rural and 50% of urban population besides, fulfilling the irrigation needs of around 50% of irrigated agriculture. The ease and simplicity of its extraction has played an important role in its development. Recent the problems of decline in water table, contamination of groundwater etc. are being reported at many places [2].

According to the report [3], the ultimate irrigation potential from groundwater source is 64.05 Mha as compared to 46 Mha of land currently under groundwater irrigation, indicating further scope for developing groundwater in some areas (such as the eastern and north-eastern parts of the country). This report has however revealed that in many states, the irrigation potential created has exceeded the ultimate potential, showing that mining of groundwater, that is exploitation beyond the dynamic resource, is already taking place. According to UNEP [4], India had world's highest land under irrigation, at 50.1 Mha, which consumes 460 BCM water, of which 41% came from surface water and 53% from groundwater. According to the report [5], the total replenishable groundwater is estimated as 433 BCM. Out of this, 399.25 BCM is considered utilizable – 18.09 BCM (8%) for domestic, industrial and other uses and 212.51 BCM (92% of the balance) for irrigation out of 230.62 BCM.

The literature study discusses the groundwater assessment methodology on the basis of the 'National Water Policy' adopted by the Government of India in 1987 and revised in 2002, it regards water as one of the most crucial elements in developmental planning with regard to Groundwater, by water balance Concept [6]. Quantification of the rate of natural groundwater recharge is a pre-requisite for efficient groundwater resource management [7]. In India dynamic groundwater recharge is calculated following the GEC' 97 methodology [8] advocated by the Groundwater Estimation Committee (GEC), 1997. For assessing the groundwater potential it's recharge is required to properly tackle the rapid increase in urban, rural, industrial and agricultural water requirements. Hence proper assessment of groundwater potential is warranted. West Tripura is a highly agrarian district of Tripura where both groundwater and surface water resources are utilized for irrigation. For tapping the entire utilizable groundwater, the resource assessment was highly necessitated. Most of the inputs were derived from the field studies and norms/factors considered (as per GEC'97 methodology) wherever necessary [9].

To meet the present and future need with currently available surface and groundwater resources, while at the same time preserving terrestrial and aquatic eco-system, will require a sustainable approach to managing water. The industrialized and developing countries should give importance to groundwater resources, so that associated problems of over-abstraction and groundwater pollution is controlled, with the objective of defining sustainable groundwater development. The sustainable groundwater development at a global and local scale is achieved through the maintenance and protection of groundwater resources balanced against economic, environmental, and human (social) benefits. In recent years, there has been an increasing threat to groundwater quality due to human activities. The adverse effects on groundwater quality are the results of anthropogenic activity at ground surface unintentionally by agriculture, domestic and industrial effluents and unexpectedly by sub-surface or surface disposal of sewage and industrial wastes.

Agartala is a developing and growing city which has the capacity to become the gateway of North-East to South East Asia through an international link. However it is already facing some scarcity of water in the area during non-monsoon seasons. Soils of these catchment areas have low retention capacity. These areas have the maximum density of urban population in the whole state (as per population census GoI). Earlier Chakraborty [9] had estimated the groundwater recharge for west Tripura District but there was no rigorous study on Agartala. But presently Agartala Municipality area has a higher water demand than any other parts in the state due to its higher density of population. Hence, to fill the gap in study and to contribute for sustainable development of groundwater resources, this area was selected for present investigation.

MATERIALS AND METHODS

Agartala, the Capital of Tripura is situated at the western corner of the State. It is connected with mainland by National Highway No.44 via the State of Assam. Globally it is situated between 23° 45’ and 23° 55’ N latitude and 91°15’ to 91°20’ E longitude, in the flood plains of the Haora River. Historically, the city has been an important border-trading town having trading linkages with Bangladesh. Total area of Tripura is 10,477(sq.km). It receives an annual average Rainfall of 1927 (mm). The hill area is (6400 sq.km). The semi-consolidated formations consisting of friable sandstone, sandy shale etc. of Tertiary age forms the main rock types of the area. The unconfined aquifer is mainly tapped through shallow wells with a discharge of 5 to 15 Lps in the valley areas whereas in the sandstone, the yield varies from 2 to 4 Lps. The Annual Replenishable Groundwater Resource is 2.19 BCM and Net Annual Groundwater Availability is 1.97 BCM. The Annual Groundwater Draft is 0.17 BCM and Stage of Groundwater Development is 9%. The entire state has been categorized as Safe. Groundwater development in the deeper aquifers has also been established through construction of deep tube wells, the yield of wells tapping the sandstone areas varies from 25 to 40 Lps. There is no over Exploited, Critical and Semi- critical zone. Exploratory Tube wells Constructed (as on 31.03.2010 (DWS) are as follows: 948 deep tube well (DTWs) and 26,086 Spot sources. For artificial recharge to Groundwater (AR) the numbers of feasible AR structures are: 300 check dams, 500 weirs, 1000 gabion structures, 240 roof top harvesting, and 100 developments of springs. However in districts of Dhalai, North Tripura, South Tripura and West Tripura are affected (in part) by Iron Contaminants (e.g. water having >1.0 mg/L of iron). As on 2009 the total irrigation utilization potential of Tripura is 52616 ha [10,11,12,13].

The natural reservoir, underlain by unconsolidated alluvial sediments, (sand, gravel, pebbles, etc.) has immense groundwater potential. The water table depth in Agartala city of the natural reservoir varies between 2 m and 6 m. In the synclinal valley of Agartala district, aquifers are found in the semi consolidated soft and stones of tertiary age where both shallow (within 30-50 m bgl with yield 5 to 20 m^3/hr) and deep tube wells (50 to 200 m bgl deep with yield varying from 50-200 m^3/hr) are feasible. Potential deep aquifers in the upper tertiary areas of Agartala have been identified in Surma, Tipam and Dupitila parts of the district. The latest estimate of ground water potential of Haora river is 353 MCM/yr but its current utilization is insignificant [14]. Lack of road communication, non availability of flat areas in the hills, high iron content, lack of right type of the equipments for drilling bouldry foundation, huge thickness of clay bodies and over burden of weathered residuum are the dominant problems of ground water development in the area. The existing 70 deep tube well has been found having yield 10,000 to 20,000 GPH.

Estimation of groundwater recharge is a complexity of factors – hydrogeological, hydrological and climatological, control the groundwater occurrence and movement. The precise assessment of recharge and discharge is rather difficult, as no techniques are currently available for their direct measurements. Hence, the methods employed for groundwater resource estimation are all indirect. Groundwater being a dynamic and replenishable resource is generally estimated based on the component of annual recharge, which could be subjected to development by means of suitable groundwater structures.

The groundwater resources in unconfined aquifers can be classified as static and dynamic. The static resources can be defined as the amount of groundwater available in the permeable portion of the aquifer below the zone of water level fluctuation. The dynamic resources can be defined as the amount of groundwater available in the zone of water level fluctuation. The replenishable groundwater resource is essentially a dynamic resource which is replenished annually or periodically by precipitation, irrigation return flow, canal seepage, tank seepage, influent seepage, etc.

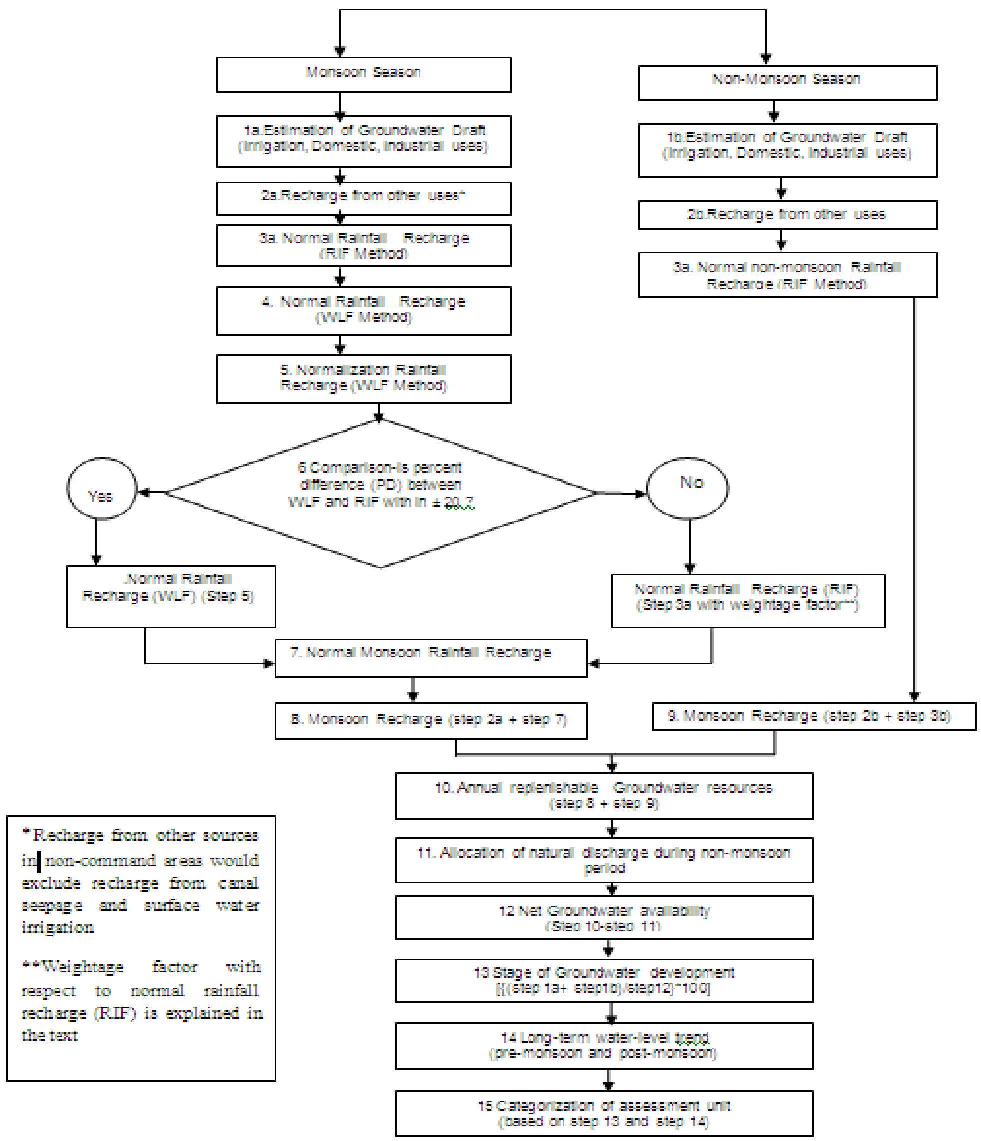

Fig 1: Step for estimation & categorization of annual replenishable groundwater resources [15]

Groundwater recharge of Agartala Municipality under West Tripura district has been computed according to GEC'97 methodology delineated in Fig. 1. Steps for the estimation of annual replenishable groundwater resources and categorization of assessment units/sub-units are presented in Fig. 1. Three rain gauge stations and fifteen wells consisting of three dug well, twelve shallow tube well, five years water level data collected from CGWB and five years observation wells data located in the Agartala Municipality area were used for groundwater resource assessment. Rainfall data for thirty nine years (1970-2008) were utilized mainly for the assessment of groundwater resource. The rainfall infiltration factor and specific yield were considered 0.16% and 8% respectively for calculation of recharge volume.

There are two methods of recharge volume against rainfall data namely water level fluctuation (WLF) and rainfall infiltration method (RIM). These methods are used to estimate the recharge volume from rainfall during monsoonal season and the equations are described in Table 1. The recharge volume during non-monsoonal period is calculated by using RIM only. The other methods of governing equations are highlighted in Table 1 to consider as for calculating the recharge volume for the same study area. The assessment units are categorized according to the status of groundwater utilization and water level trend (Table 2). Some established equations were used to validate the calculated results obtained from GEC, 1997. The formulae along with their limitations are highlighted in Table 3.

Table 1. Governing equations for calculation of recharge volume

Method/Type	Equation	Remarks
Gross groundwater draft in any season (GGWD)	GGWD=n*unit draft where unit draft=draft per day*no of days the structures are in use	n = no of abstraction structures actually in use
Estimation of Recharge for other uses		
Recharge from canals (R_c in ha-m)	R_c=WA*Days*SF where WA=WP*L WP=(2*ASD)/(sin(side angle))+BW	WA=wetted area in Mm^2, WP=wetted perimeter in m, L=length of canal segment in km, ASD-average supply depth in m, side angle-side slope in degree, BW=bed width in m.
Recharge from surface water irrigation (R_{swi} in ha-m) same as groundwater irrigation (R_{gwi} in ha-m)	R_{swi} = IWA*RFF where IWA = AD*days	IWA=irrigation water applied in ha-m, RFF=return flow factor as a fraction, AD=average discharge of the outlet in ha-m/d.
Recharge from tanks & ponds (R_T in ha-m)	R_T = AWSA*days*RFact here RFact= 1.4 mm/d	AWSA=avg water spread area, RFact=a recharge factor in mm/d
Recharge from water conservation structures (R_{WCS} in ha-m)	R_{WCS}=GS*RFact where GS=storage capacity* no of fillings	GS=gross storage
Estimation of Recharge for Rainfall		
Recharge from Rainfall, R_{RF} using Rainfall Infiltration factor method (RIF)	R_{RF} = NMR x A x RFIF	NMR=normal monsoon rainfall, RFIF=rainfall infiltration factor, A=total area of the sub unit
Recharge from rainfall using	R_{RF} = (A x WLF x S_y) + D -	A = area suitable for recharge,

water level fluctuation method (WLF)	R_{other}	WLF=water level fluctuation, S_y =specific yield, D=gross draft and Rother=recharge from other sources.
Estimation of Percent Difference (PD)		
Percent Difference	PD=(R_{Rf} (wtfm)-R_{Rf}(rifm))/ (R_{Rf}(rifm)) * 100	R_{Rf} (wtfm) = rainfall recharge for normal monsoon season estimated from WLF, R_{Rf}(rifm)= rainfall recharge for normal monsoon season estimate from RIF
Total groundwater recharge (TGWR)	TGWR=$R_{RF+}R_c+R_{swi}+R_{gwi}+ R_{WCS}+ R_T$	
Total annual groundwater recharge (TAGWR)	TAGWR= TGWR(monsoon)+ TGWR (non-monsoon)	
Net annual groundwater availability (NAGWA)	NAGWA= TAGWR-UND where UND=unavoidable natural discharges	
Stage of development (SD)	SD=(existing gross draft for all uses/NAGWA)*100	
Allocation of groundwater for domestic and industrial needs (AFDIWR in mm/year)	AFDIWR =22 * N*L_g where $L_g \leq 1.0$	N=projected population density in the sub unit in thousands per km^2
Net annual groundwater availability for future irrigation use (NAGWAFFIU)	NAGWAFFIU=NAGWA-(CGGWDFI+AFDIWR)	CGGWDFI=current gross groundwater draft for irrigation
Static groundwater resources (SGWR)	SGWR=A*(Z_2-Z_1)*S_y	Z_2=max depth of the bottom of the unconfined aquifer, Z_1=max. Extension of zone of water table fluctuation,

Table 2. Criteria for categorization of assessment units [1]

sl. no.	Stage of groundwater development	Significant long term decline		Categorization
		Pre-monsoon	Post-monsoon	
1	<=70%	No	No	Safe
2	> 70% and <= 90%	No	No	Safe
		Yes/No	Yes/No	Semi- Critical
3	> 90% and <= 100%	Yes/No	Yes/No	Semi- Critical
		Yes	Yes	Critical
4	> 100%	Yes/No	Yes/No	Over- Exploited
		Yes	Yes	Over- Exploited

Table 3. Empirical equations for various regions in India

Name of the formula	Equation	Remarks
Chaturvedi formula	$R_{ef} = 2.0 (P - 15)^{0.4}$	R_{ef} = net recharge due to precipitation during the year, in inches; and P= annual precipitation, in inches.
U.P. Irrigation Research Institute, Roorkee	$R_{ef} = 1.35 (P - 14)^{0.5}$	
Kumar and Seethapathi (2002)	$R_{ef} = 0.63(P - 15.28)^{0.76}$	R_{ef} = Groundwater recharge from rainfall in monsoon season (inch); P = Mean rainfall in monsoon season (inch).
Amritsar formula	$R_{ef} = 2.5 (P - 16)^{0.5}$	Where, R_{ef} and P are measured in inches
Krishna Rao	$R_{ef} = 0.35 (P - 600)$	Areas with P above 2000 mm

RESULTS AND DISCUSSIONS

The stepwise calculations with different components have been delineated in Table 4. Groundwater resources of Agartala have been estimated by using GEC-97. The total groundwater recharge volume and the net groundwater availability are found as 2106.31 ha-m and 1895.94 ha-m respectively. Out of these, 76% covers from rainfall component. The stage of groundwater development for Agartala city is 16.53% which is safe as depicted Table 2.

Table 4. Step wise working Results (Fig.1).

Step	Item	Result
Step 1	Area considered for assessment (ha)	5432 ha.
Step 2	Groundwater draft	293.19 ha-m
Step 3	Gross GW draft for all uses	313.64 ha-m
Step 4	Recharge from irrigation water	113.6 ha-m
Step 5	Recharge from irrigation, surface water	342.21 ha-m
Step 6	Recharge from Ponds/Tanks	48.62 ha-m
Step 7	Rainfall Recharge by rainfall infiltration method	1814.68 ha-m.
Step 8	Recharge from other sources	504.43ha-m
Step 9	Groundwater Recharge	882.06 ha-m
Step 10	The results of the two methods have been compared using Percent Deviation.	51.39%
Step 11	Annual Recharge from Rainfall	1602.18 ha-m
Step 12	Total GW Recharge	2106.61 ha-m
Step 13	Net GW Availability	1895.94 ha-m
Step 14	Stage of GW Development	16.53%
Step 15	Annual allocation of groundwater for domestic & industrial water supply (2009)	22.246

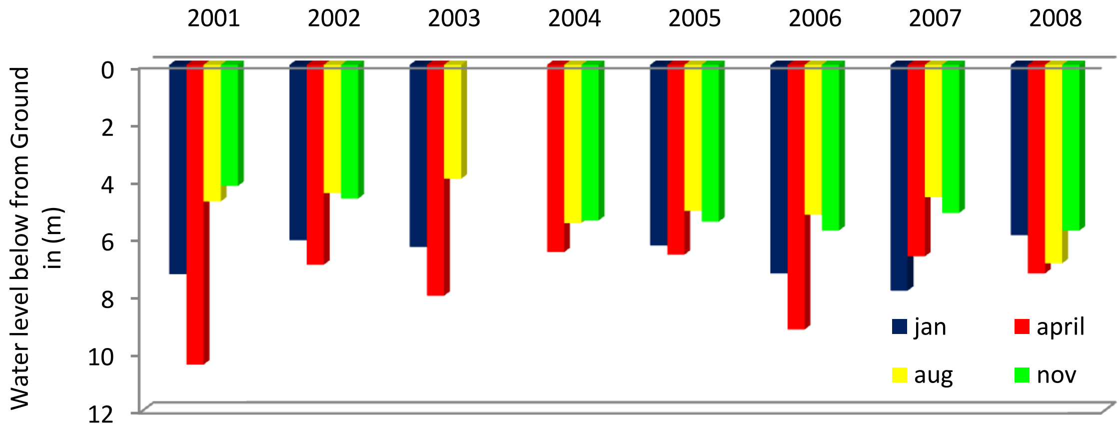

Fig 2. Year wise groundwater level at Agartala

The water level data from the period of 2001 to 2008 of monitoring station of the CGWB at Agartala are collected against four different months wise for the particular year as shown in Fig 1. The results show that the water level is declined maximum during non-monsoon almost every year where as in monsoon season it is less**.** The minimum and maximum groundwater movement level at Agartala city is observed approximately 3 m and 10 m respectively for the month of August and April**.** The groundwater level is observed maximum in the year of 2001 followed by 2006 as shown in Fig.2. About 76% of total volume falls under the category of monsoon season and the rest is for non-monsoon.

The annual replenishable groundwater resource at Agartala is 2106 ha-m considering all the components mentioned in GEC-1997. The overall annual replenishable of groundwater resources contributed from rainfall is 90% and the rest amount is shared for other sources such as canal seepage, return flow from irrigation, seepage from water bodies and water conservation structure. Keeping in view, about 313 ha-m is to be allocated for groundwater draft and thus the net groundwater withdrawal for future at Agartala city is to be 1582 ha-m.

Table 5. validation of working results

Sl. No.	Validation by empirical Formula	Total recharge
1	Chaturvedi formula (1936)	1408.504 ha-m
2	U.P. Irrigation Research Institute, Roorkee	1441.131 ha-m
3	Kumar and Seethapathi (2002)	1269.687 ha-m
4	Amritsar formula	1991.84 ha-m
5	Krishna Rao	2426.121 ha-m

The stage of groundwater draft at Agartala is 17% (16.53 %). From the results it can be stated that still 70% could be developed which would be based on primarily on groundwater to reach at least in a safer zone. Also since this area is basically dominated by soft sandy soils nature so, further development could be made in actual practice.

The allocation of domestic water has been estimated based on population up to the year 2026. The results reveals that the water requirement has become increased with increase in year and it has reached up to 356.89 ha-m in the year of 2026 considered water demand as 135 L/capita/d. Similarly, the future groundwater available has been computed as 428 ha-m in the year of 2026 by considering 10% additional development for both irrigation and industry. Accordingly, the net groundwater available for future use has been estimated based on net available groundwater resource as given in the Table 6. Table 6 reveals that even in the year 2026, the usable water is found to be 1470 ha-m which is less than the net available groundwater resources and it is under safe zone (Table 2).

Table 6. Net groundwater available for future use

Year	Net available (ha-m)	Total use (ha-m)	For future uses (ha-m)
2010	1898.94	403.6745	1495.266
2011	1898.94	404.8432	1494.097
2012	1898.94	406.0902	1492.850
2013	1898.94	407.3324	1491.608
2014	1898.94	408.6565	1490.284
2015	1898.94	410.0211	1488.919
2016	1898.94	411.4275	1487.513
2017	1898.94	412.8766	1486.063
2018	1898.94	414.4174	1484.523
2019	1898.94	415.9565	1482.984
2020	1898.94	417.542	1481.398
2021	1898.94	419.2256	1479.714
2022	1898.94	420.9086	1478.031
2023	1898.94	422.6417	1476.298
2024	1898.94	424.48	1474.460
2025	1898.94	426.3186	1472.621
2026	1898.94	428.2673	1470.673

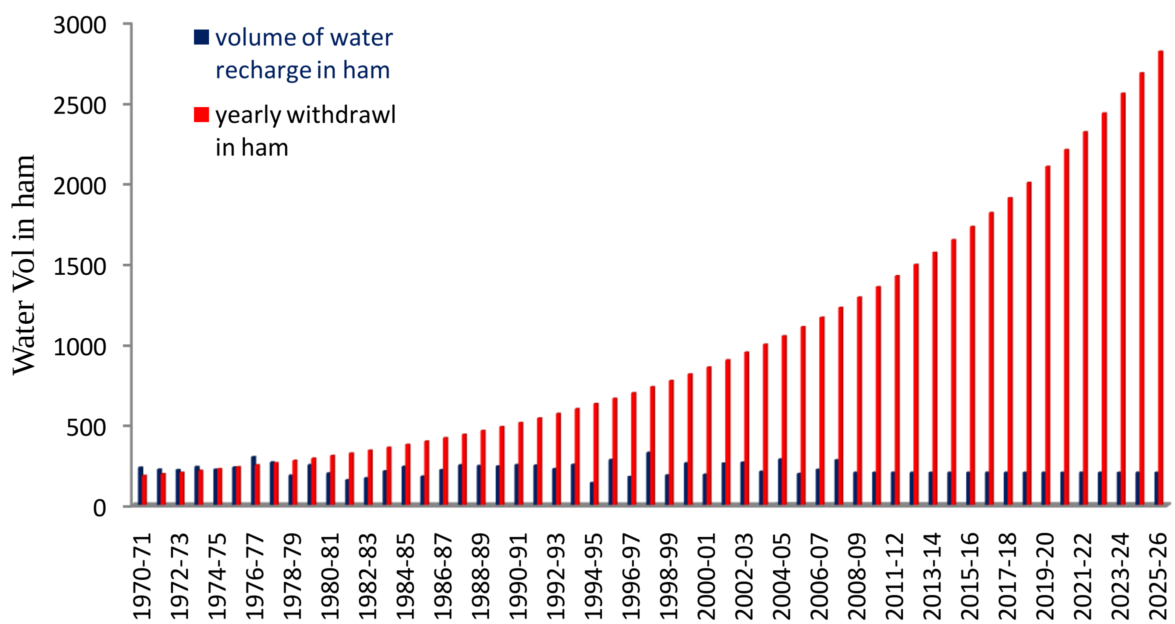

Fig 3. Trend Agartala static groundwater recharge and withdrawal

The volume of static groundwater recharge is calculated on the basis of 2% of precipitation considered as deep percolation. Fig. 3 reveals that the annual withdrawal has almost saturated in the year of 1978 compared to recharge volume. It is also observed that the volume of recharge water has found less compared to the annual withdrawal and it goes upto 2821 ha-m in the year of 2026. Thus it is imperative to say that the static groundwater recharge should be done after delineating the aquifer thickness and specific yield of the aquifer material.
The water distribution of Haora river catchment is depicted in the Fig 4. Fig.4 shows that the annual evaporation for Haora catchment has varied from 29153 to 31807 ha-m. The results also highlights that about 33% of the total precipitation has converted to surface runoff and thus the long term average runoff for Haora catchment is found to be 45%.

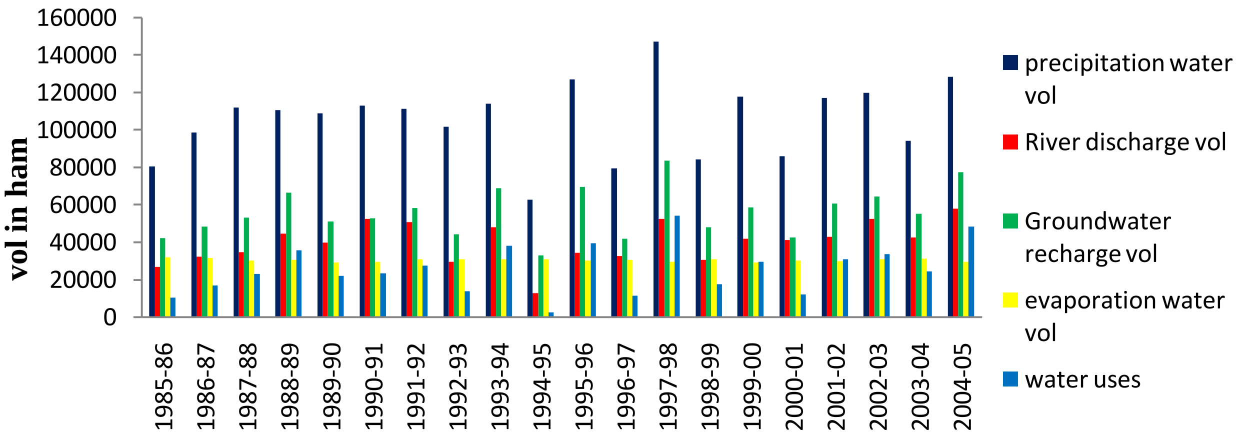

Fig.4. Water distribution of Haora river catchment

CONCLUSION

GEC-1997 is essentially a simplistic lumped parameter system approach. Some of the inflow and outflow components of water balance like evaporation and evapotranspiration, inflow and outflow across the assessment boundary, baseflow, etc. have been ignored in this methodology. Since database on these components is not readily available with the state governments at present efforts should be made for the generation of database of these components, so that at micro-level assessment, complete water balance of the assessment unit can be attempted.

Groundwater resources estimation is a continuing process, since the natural recharge and discharge pattern of the aquifer changes with changing groundwater scenario. Therefore, there is an urgent need for the formulation of a long-term action plan for periodical re-assessment of groundwater resources of the country. The intervening periods between successive re-assessment should be devoted to further strengthening of the database, well census, baseflow, etc. and special studies on estimation of parameters like specific yield, rainfall infiltration factor, canal seepage factor, return flow factor, etc. The generation of database should be followed with pilot estimation studies in identified assessment units and finally with country –wide re-assessment.

In view of increasing demand of groundwater, systematic assessment of the additional sources of groundwater needs to be carried out. In the hilly terrain, where springs are important source of water supply, exploitable quantity of spring discharge needs to be estimated. In the shallow water-table areas, where in spite of regular groundwater extraction, the water level dose not decline the sustainable yield of the aquifers needs to be determined. In the Indo-Gangetic alluvial belt where multilayered aquifer systems exist studies need to be carried out to fine out the sustainable yield of the deeper aquifers.

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