ASSESSMENT OF DYNAMIC GROUNDWATER POTENTIAL OF AGARTALA MUNICIPALITY AREA

A thesis
Submitted by

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ABSTRACT

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.

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 Agartal 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. 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.

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. 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.

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List of abbreviation

AMC	Agartala municipality Council.
bgl	Below ground level.
BCM	Billion cubic meter
C_{gws}	Change in Groundwater storage in monsoon.
DWS	Drinking water and sanitation
EPA	Environment protection Agency
GEC	Groundwater estimation committee
ha	Hector= 10000 m^2
ha- m	Hector meter (volume)
mha	Million hector.
lps	Litre per second
MCM	Million cubic meters.
MR	Monsoon rainfall
MSL	Mean Sea level
NAGA	Net Annual Groundwater Availability
NMR	normal monsoon rainfall
PD	percent deviation
R_{other}	recharge from other sources
R_{ef}	recharge from rainfall
RIF	rainfall infiltration factor
RIFM	rainfall infiltration method
RGW	Recharge from Groundwater irrigation
RL	Reduce level.
RMR	recharge from monsoon rainfall
RNMR	Recharge from non-monsoon rainfall
R P/T	Recharge from ponds and tanks
RSWI	Recharge from surface water irrigation
S_Y	specific yield
UNEP	United Nation Environment protection.
WLF	water level fluctuation
WLFM	water level fluctuation method
WR	Water Resources

AGARTALA CITY AT A GLANCE

District	:-	West Tripura.
Sub-Division	:-	Sadar.
Latitude	:-	91.2 degree East.
Longitude	:-	23.51 degree North.
Altitude	:-	12.80 metre.
Total Area	:-	58.84 sq.km.
Irrigation Area	:-	795 ha (2009).
Water body	:-	198.5 ha (2009).
Rain fall	:-	2115.74 mm.
Standard Deviation	:-	372.967.
Co-efficient of variation	:-	17.17.268.
Climate	:-	37.6°C 4.2°C.
Dynamic Groundwater resources	:-	2106.61 ha-m.
Net Groundwater availability	:-	1895.94 ha-m.
Groundwater Draft	:-	313.64 ha-m.
Allocation 2025	:-	428.26 ha-m.
Balance for future	:-	1470.63 ha-m.
Stage of Groundwater Development	:-	16.53% (2009).
Average annual flow of Haora	:-	398.78 MCM (1984 to 2004).
No of Deep tube well	:-	70 nos (2009) [63 (DWS)+7 (WR)].
Groundwater withdrawal (deep Aquifer)	:-	77.28 Lac gallon/day (approx).
Water quality index (Surface)	:-	poor.
Water quality index (Ground)	:-	Medium.
Contaminants Iron	:-	>1.0 mg/l.
Hand pump (tube well)	:-	5600 (approx) (2009).
Population	:-	428100 nos (2009).

CHAPTER 1

INTRODUCTION

1.1 GROUNDWATER HYDROLOGY

1.1.1 Earth's Water Storage and Fluxes

Water covers 70% of the earth's surface, but it is difficult to comprehend the total amount of water when we only see a small portion of it. **Fig no 1.1** displays the volumes of water contained on land, in oceans, and in the atmosphere. Arrows indicate the annual exchange of water between these storages.

The oceans contain 97.5% of the earth's water, land 2.4%, and the atmosphere holds less than 0.001%, which may seem surprising because water plays such an important role in weather. The annual precipitation for the earth is more than 30 times the atmosphere's total capacity to hold water. This fact indicates the rapid recycling of water that must occur between the earth's surface and the atmosphere.

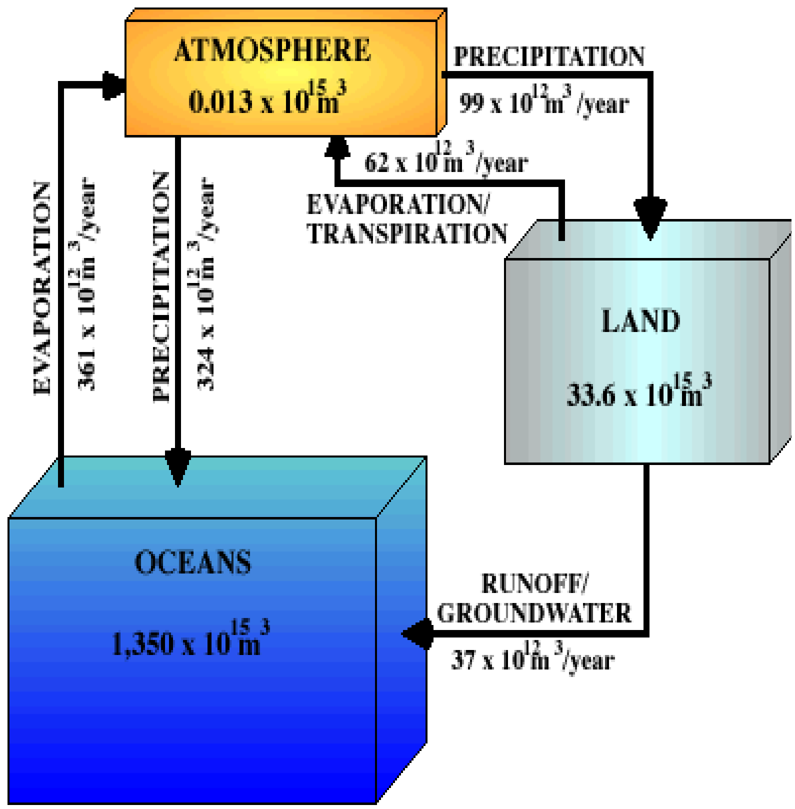


Fig 1.1: Groundwater Hydrology (Peixoto and Kettani 1973)

1.1.2 The Water Cycle: Groundwater Storage

Most of the earth's water sources get their water supplies from precipitation, which may fall in various forms, such as, rain, snow, hail, dew etc. Rains no doubt, form the principal and the major part of the resultant supplies. When rain starts falling, it is first of all intercepted by buildings and other objects. When the rainfall rate exceeds the interception rate, water starts reaching the ground and infiltration starts. This is the source of Groundwater storage as depicted in **Fig no 1.2**.

1.1.3 Groundwater and global water distribution Groundwater occurs only close to the Earth's surface. There must be space between the rock particles for Groundwater to occur, and the Earth's material becomes denser with more depth. Essentially, the weight of the rocks above condenses the rocks below and squeeze out the open pore spaces deeper in the Earth. That is why Groundwater can only be found within a few kilometres of the Earth's surface's as delineated in **Table no 1.1** even though the amount of water locked up in Groundwater is a small percentage of all of Earth's water, it represents a large percentage of total freshwater on Earth .**Fig 1.3** shows that about 1.7 percent of all of Earth's water is groundwater and about 30.1 percent of freshwater on Earth occurs as Groundwater. As the **Fig 1.4** shows 23,400,000 cubic kilometres (km^3), of ground water exist on Earth. About 54% is saline, with the remaining 10,530,000 (km^3) about 46% being fresh water.

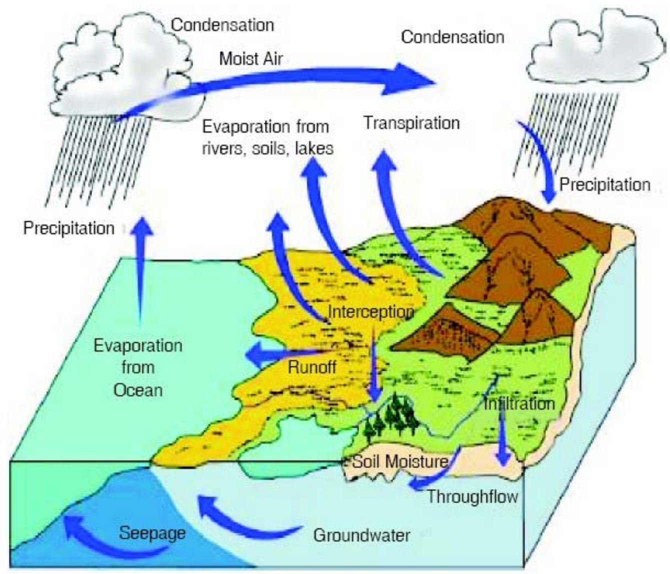


Fig 1.2: Water Cycle

Water in aquifers below the oceans is generally saline, while the water below the land surfaces (where freshwater, which fell as precipitation, infiltrates into the ground) is generally fresh water.

Table 1.1: Estimate of global water distribution			
Water source	**Water volume, in cubic kilometres**	**Percent of total water**	**Percent of total freshwater occurs from Groundwater**
Fresh Groundwater	10,530,000	0.8%	30.1%
Groundwater	23,400,000	1.7%	--
Total global water	1,386,000,000	--	--
Source: Gleick, P. H., 1996: Water resources. In Encyclopedia of Climate and Weather, ed. by S. H. Schneider, Oxford University Press, New York, vol. 2, pp.817-823.			

There is a stable transition zone that separates saline water and freshwater below ground. It is fortunate for us that the relatively shallow aquifers that people tap with wells contain freshwater.

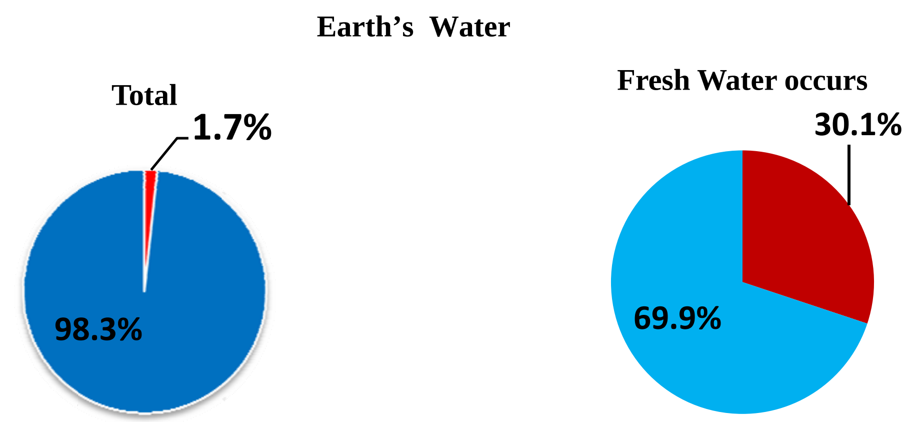


Fig 1.3: Groundwater

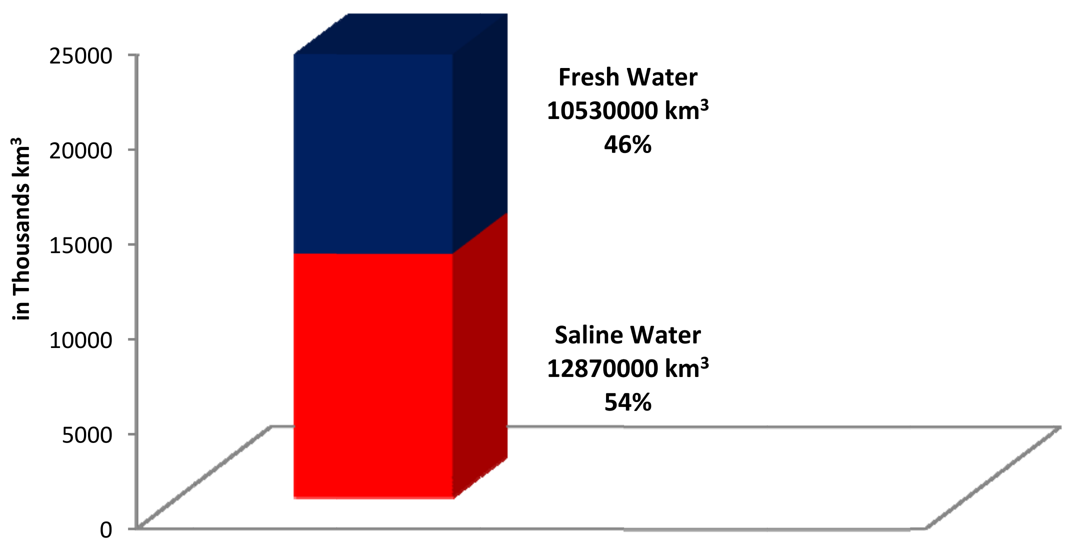


Fig 1.4: Earth's Groundwater

1.1.4 Groundwater use Worldwide, according to a UNEP study (Groundwater its susceptibility to degradation, 2003), over 2 Billion people depend on aquifers for their drinking water. Making it the single most used natural resource. The estimated annual production of Groundwater is between 600 and 700 cubic kilometres (billion cubic metres or billion tonnes). In many areas most drinking water is Groundwater - upto 80 % in Europe and Russia, and even more in North Africa and the Middle East. 40 per cent of the world's food is produced by irrigated agriculture that relies largely on Groundwater. Typically refers to the current use(s) and functions of Groundwater as well as future reasonably expected use(s). Groundwater use can generally be divided into drinking water, ecological, agricultural, industrial/commercial uses or functions, and recreational. Drinking water uses include both public supply and individual (household or domestic) water systems. Ecological use commonly refers to Groundwater functions such as providing base flow to surface water to support habitat; Groundwater (most notably in karst settings) may also serve as an ecologic habitat in and of itself. Agricultural uses generally refer to crop irrigation and live-stock watering. Industrial/commercial uses refers to use in any industrial process, such as for cooling water in manufacturing, or commercial uses such as car wash facilities. Recreational uses generally pertains to impacts on surface water caused by Groundwater; however, Groundwater in karst settings can be used for recreational purposes such as cave diving. All of these uses and functions are considered "beneficial uses" of Groundwater. Furthermore, within a range of reasonably expected uses and functions, the maximum (or highest) beneficial Groundwater use refers to the use or function that warrants the most stringent Groundwater cleanup levels. In **Fig 1.5** shown Groundwater uses.

It is essential to focus on the agriculture in the context of global Groundwater use for the simple reason that volumes used in this sector significantly exceed other uses, e.g. industrial and domestic, at the global scale. Especially in many arid and semiarid regions of the world that coincide with nations in development, such as India, North China and Pakistan, Groundwater use is critical for food security. Here the management challenges are manifold in the sense that a balance between securing Groundwater-dependent livelihood and ensuring the long-term environmental sustainability is required. But even in more developed countries in less arid regions such as the USA, Australia and Mexico, as well as Groundwater Use in a Global Perspective in Mediterranean countries like Spain, Groundwater supplies significant water for agricultural use and its management presents great challenges. High dependence on Groundwater also occurs in humid countries, but more for industrial and domestic uses (e.g.

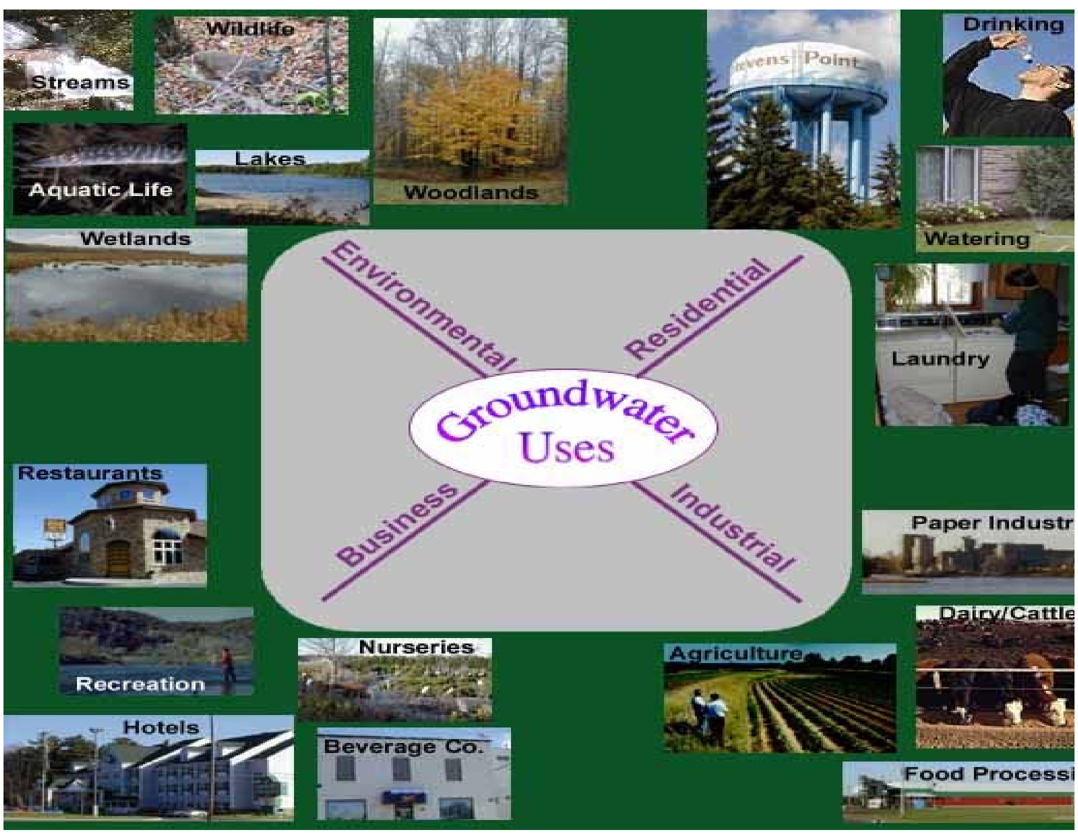


Fig 1.5: Groundwater use

Japan, the former USSR and north European countries like Denmark and the Netherlands. Here, the volumes drawn are generally not threatening the resource base from a quantity point of view – it is more water quality issues that present the major challenges.

Yet another category of countries includes those that potentially could benefit from an intensification of Groundwater use for agriculture and associated development, such as parts of sub-Saharan Africa Nepal and eastern India. In these cases, present limitations to such development seem to be associated with poor energy access, lack of infrastructure and market access, lack of credit possibilities and possible cultural or demographic barriers.

Groundwater is now surpassing surface water in importance in many regions of the world, in terms of water supply for irrigation. The 2005 FAO AQUASTAT database on irrigated area lists the countries Algeria, Bangladesh, India, Iran, Libya, Saudi Arabia, Syria and Yemen, as those depending more on Groundwater than surface water for their irrigation. Expanded Groundwater use in a global context can be seen as a second step in the continued and accelerated quest for water for human development. Basically, surface water was accessed, appropriated and allocated first, as this resource was more visible and readily available and most human settlements confluence with rivers and streams where water was traditionally secured. As surface water resources are being exhausted and strained in terms of quality and the options to dam them have diminished, Groundwater has become the second-generation resource to be captured and appropriated.

1.1.4.1 Groundwater use for agricultural irrigation in selected nations

The proportion of Groundwater and area use for agriculture irrigation in maximum in India i.e.53% in term of irrigated area followed by the other country as depicted in **Fig no 1.6.**

a) Groundwater value is typically considered in three ways: for its current uses; for its future or reasonably expected uses; and for its intrinsic value. Current use value depends to a large part on need. Groundwater is more valuable where it is the only source of water, where it is less costly than treating and distributing surface water, or where it supports ecological habitat. Current use value can also consider the “costs” associated with impacts from contaminated Groundwater on surrounding media (e.g., underlying drinking water aquifers, overlying air - particularly indoor air, and adjacent surface water). Future or reasonably expected values refer to the value people place on Groundwater they expect to use in the future; the value will depend on the particular expected use or uses (e.g., drinking water, industrial, etc.). Society places an intrinsic value on Groundwater which is distinct from economic value. Intrinsic value refers to the value people place on just knowing clean Groundwater exists and will be available for future generations, irrespective of current or expected uses. While the value of Groundwater is often difficult to quantify, it will certainly increase as the expense of treating surface water increases, and as existing surface water and Groundwater supplies reach capacity with continuing development.

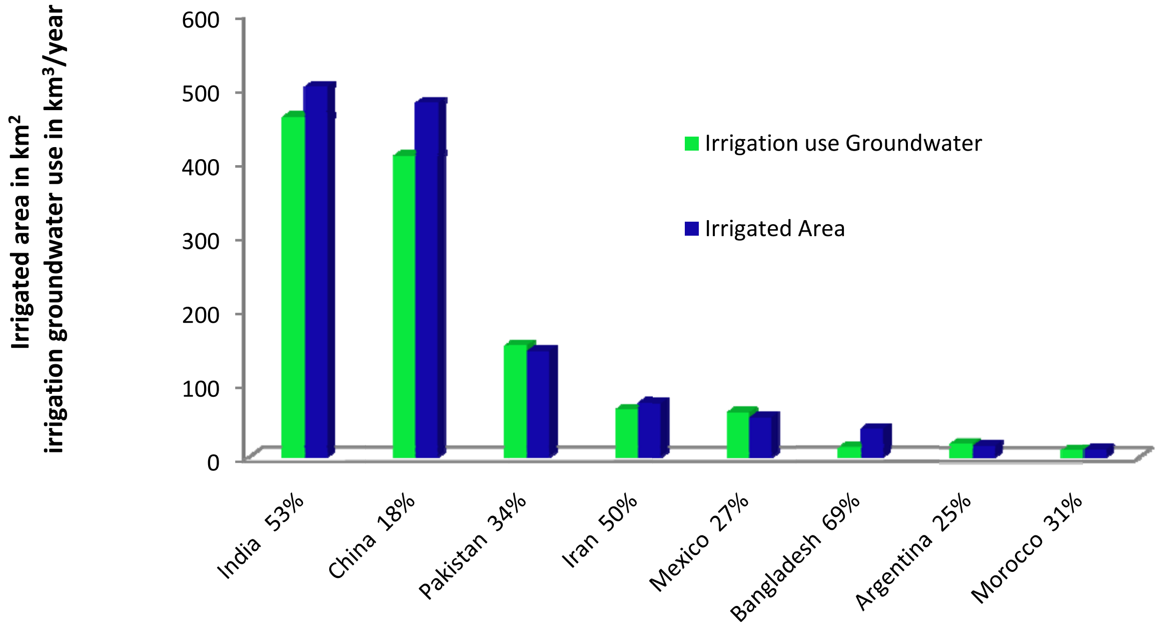


Fig 1.6 : Groundwater and Area use in Agriculture Irrigation of Selected Nations

(source : UN food and agriculture organization 1990-1997)

b) Groundwater vulnerability refers to the relative ease with which a contaminant introduced into the environment can negatively impact Groundwater quality and/or quantity. Vulnerability depends to a large extent upon local conditions including, for example, hydrogeology, contaminant properties, size or volume of a release, and location of the source of contamination.

Shallow Groundwater is generally more vulnerable than deep Groundwater. Private (domestic) water supplies can be particularly vulnerable because (1) they are generally shallower than public water supplies, (2) regulatory agencies generally require little or no monitoring or testing for these wells, and (3) homeowners may be unaware of contamination unless there is a taste or odur problem (EPA, 2003). Furthermore, vulnerability can change over time. For example, anthropogenic activities, such as mining or construction, can remove or alter protective overburden thus making underlying aquifers more vulnerable.

1.2 GROUNDWATER RESOURCES-INDIAN CONTEXT

1.2.1 Hydro geological Situation

India is a vast country having diversified geological climatological and topographic set-up, giving rise to divergent Groundwater situations in different parts of the country. The prevalent rock formations, ranging in age from Achaean to recent, which control occurrence and movement of Groundwater, are widely varied in composition and structure. The Groundwater potential of Tripura is between 25-40 lts/s which are unconsolidated formations as shown in **Fig 1.7** Similarly, not too insignificant, are the variations of land forms, from the rugged mountainous terrains of the Himalayas, Eastern and Western Ghats to the flat alluvial plains of the river valleys and coastal tracts, and the Aeolian deserts of Rajasthan. The rainfall pattern is shown in **Fig 1.8** region-wise variations. The topography and rainfall virtually control runoff and Groundwater recharge. The annual average rainfall of Tripura is   cm.

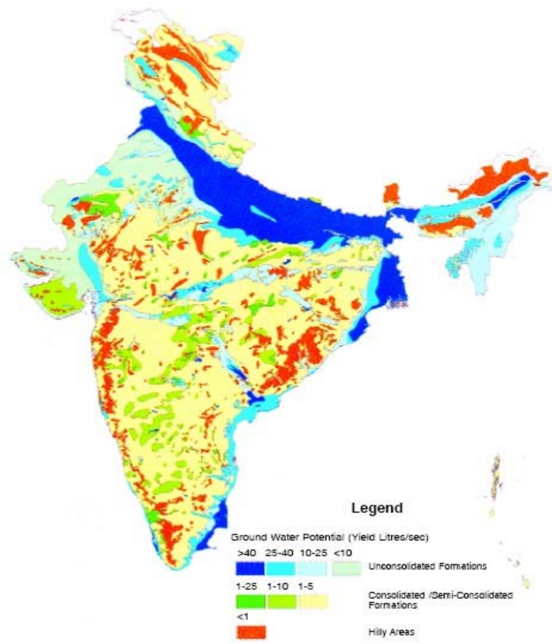


Fig 1.7: Hydrogeological map of India

[Source: Dynamic Groundwater Resources of India (as on March 2004), Central Groundwater Board,Ministry of Water Resources, 2006.]

The high relief areas of the northern and north-eastern regions occupied by the Himalayan ranges, the hilly tracts of Rajasthan and peninsular regions with steep topographic slope, and characteristic geological set-up offer high run-off and little scope for rain water infiltration. The Groundwater potential in these terrains are limited to intermountain valleys.

Almost the entire Peninsular India, is occupied by a variety of hard and fissured formations, including crystalline, trappean basalt and consolidated sedimentaries (including carbonate rocks), with patches of semi consolidated sediments in narrow intracratonic basins. Rugged topography, compact and fissured nature of the rock formations, combine to give rise to discontinuous aquifers, with limited to moderate yield potentials. The near surface weathered mantle forms the all important Groundwater reservoir, and the source for circulation of Groundwater through the underlying fracture systems. In the hard rock terrain, deep weathered pediments, low-lying valleys and abandoned river channels, generally contain adequate thickness of porous material, to sustain Groundwater development under favourable hydrometeo-rological conditions. Generally, the potential water saturated fracture systems occur down to 100 m depth, and in cases yield even upto 30 Litres per Second (lps). The friable semi-consolidated sandstones also form moderate yielding aquifers, and auto flowing zones in these formations are not uncommon shown in **Fig 1.9.**

The large alluvial tract in the Sindhu Ganga - Brahmaputra plains extending over a distance of 2000 kms. from Punjab in the west to Assam in the east, constitutes one of the largest and most potential Groundwater reservoir in the world. The aquifer systems are extensive, thick, hydraulically interconnected and moderate to high yielding. To the north of this tract all along the Himalayan foot hills, occur the linear belt of Bhabar piedmont deposits, and the Tarai belt down slope with characteristic auto flowing conditions. Shown in **Fig 1.10**

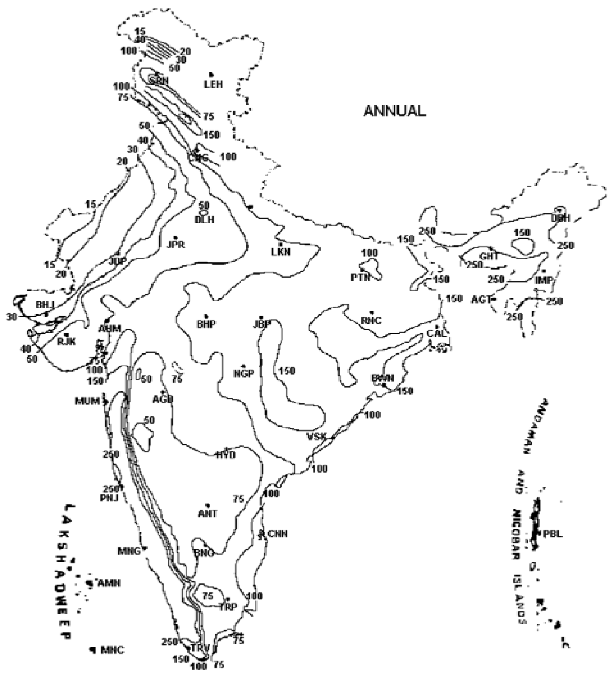


Fig- 1.8 : Annual Normal Rainfall (in cm.) Of India

The coastal and deltaic tracts in the country form a narrow linear strip around the peninsula. The eastern coastal and deltaic tract and the estuarine areas of Gujarat are receptacles of thick alluvial sediments. Though highly productive aquifers occur in these , tracts salinity hazards impose quality constraints for Groundwater development. In this terrain Groundwater withdrawal requires to be regulated so as not to exceed annual recharge and not to disturb hydro-chemical balance leading to sea water ingress.

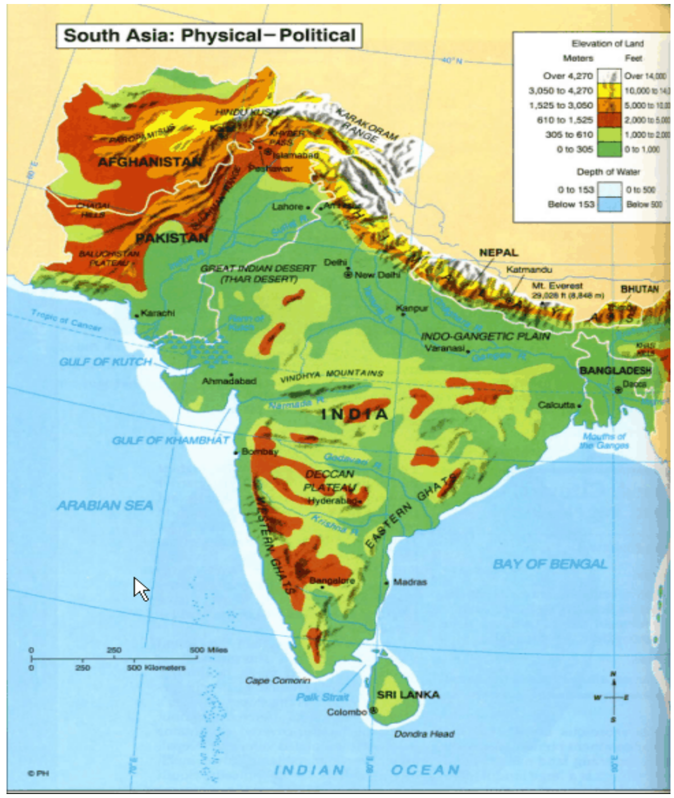
The quality of Groundwater in both hard rock and alluvial terrains is by and large fresh and suitable for all uses. The specific conductance is generally less than 1000 µs/cm at 25 ºC. But in coastal areas, estuarine tracts of Gujarat, Rann of kutch and arid tracts of Rajasthan, the degree of mineralization in Groundwater is rather high and salinity hazards are not uncommon.

The salinity hazards in Groundwater are also noticed in the inland areas of Punjab, Haryana, Uttar Pradesh, Rajasthan and Gujarat, generally confined to arid and semi-arid tracts.

The varied modes of Groundwater occurrence in the country may be broadly summarized as: a) Porous formations comprising unconsolidated and semi consolidated sediments. Aquifers interconnected often extensive, both continuous and discontinuous; moderate to very high yield potentials.

b) Consolidated and fissured formations. Aquifers discontinuous; Limited yield potentials.

1.2.2 Emerging Scarcity of Groundwater Resources



The average annual rainfall in the country is 1170 mm, which corresponds to annual precipitation, including snowfall of 4000 billion cubic meters (BCM). Out of this volume of precipitation, only 1869 BCM appears as average annual potential flow in rivers. Due to various constraints, only 1123 BCM is assessed as the average annual utilizable water – 690 BCM from surface water and 433 BCM from Groundwater.

The present total water use is 634 BCM of which 83% is for irrigation. This is projected to grow to 813 BCM by 2010, 1093 BCM by 2025 and 1447 BCM by 2050, against utilisable quantum of 1123 BCM. Thus the demand will outstrip availability in another 35 to 40 years. The Central Groundwater Board has estimated the present annual Groundwater draft as 230.6 BCM.

Groundwater is essentially a dynamic resource with both passive and active recharge zones. The annual replenishable Groundwater resource (433 BCM) is the recharge to the active recharge zone or dynamic zone (unconfined aquifer where recharge takes place annually from the rainfall and other sources, infiltrating directly to the water table). The static fresh Groundwater resources lie beyond the dynamic zone and is called the passive recharge zone.

The overall stage of Groundwater development in the country is 58%, indicative of a comfortable situation at the aggregate level. This however masks the high degree of variability.

As regards use, the extent of extraction has increased significantly over the years, as indicated by the growth in the number of wells and tube wells served by Groundwater. It is estimated that there are currently 19 million wells in the country, out of which 16 million are in use and are drawing about 231 BCM of water—213 BCM for irrigation and 18 BCM for domestic and industrial use-out of net annual Groundwater availability of 399 BCM .is that there is in availability, utilisation and development throughout the country in **Table 1.3(a) and Table no 1.3 (b)** that in Indo-Gangetic and Brahm-aputra plains, Groundwater potential is very high; such areas can support large scale development. In peninsular India and hilly states, however, Groundwater pote-ntial is relatively much lower. Shown in **Fig 1.10**

Fig 1.10: Alluvial tract in the Sindhu Ganga-Brahmaputra plains

Table 1.2 : Coverage and Potential of Groundwater Systems in the Country

System	Coverage	Groundwater potential
Unconsolidated formations - alluvial	Indo-Gangetic, Brahmaputra plains	Enormous quantities up to 600 m. High rain fall and hence recharge is ensured. Can support large-scale development through deep tube wells
	Coastal states	Reasonably extensive aquifers but risk of saline water intrusion
	Part of Desert area – Rajasthan and Gujarat	Scanty rainfall. No recharge. Salinity hazards. Availability at great depths.
Consolidated/semi-consolidated formations - sedimentaries, basalts and crystalline rocks	Peninsular	Availability depends on secondary porosity developed due to weathering and fracturing. Scope for availability at shallow depths (20-40 m) in some areas and deeper depths (100-200 m) in other areas. Varying yields.
Hilly	Hilly states	Low storage capacity due to quick runoff

Table 1.3 (a): State wise Groundwater resources available of India

SI. No.	States / Union Territories (BCM)	Annual Replenishable Groundwater Resource					Natural Discharge during non-monsoon season (BCM)	Net Annual Ground Water Availability (BCM)
		Monsoon Season (BCM)		Non-monsoon Season (BCM)		Total (BCM)		
		Recharge from rainfall	Recharge from other sources	Recharge from rainfall	Recharge from other sources			
	States							
1	Andhra	16.04	8.93	4.20	7.33	36.50	3.55	32.95
2	Arunachal	1.57	0.00009	0.98	0.0002	2.56	0.26	2.30
3	Assam	23.65	1.99	1.05	0.54	27.23	2.34	24.89
4	Bihar	19.45	3.96	3.42	2.36	29.19	1.77	27.42
5	Chattisgarh	12.08	0.43	1.30	1.13	14.93	1.25	13.68
6	Delhi	0.13	0.06	0.02	0.09	0.30	0.02	0.28
7	Goa	0.22	0.01	0.01	0.04	0.28	0.02	0.27
8	Gujarat	10.59	2.08	0.00	3.15	15.81	0.79	15.02
9	Haryana	3.52	2.15	0.92	2.72	9.31	0.68	8.63
10	Himachal	0.33	0.01	0.08	0.02	0.43	0.04	0.39
11	Jammu &	0.61	0.77	1.00	0.32	2.70	0.27	2.43
12	Jharkhand	4.26	0.14	1.00	0.18	5.58	0.33	5.25
13	Karnataka	8.17	4.01	1.50	2.25	15.93	0.63	15.30
14	Kerala	3.79	0.01	1.93	1.11	6.84	0.61	6.23
15	Madhya	30.59	0.96	0.05	5.59	37.19	1.86	35.33
16	Maharashtra	20.15	2.51	1.94	8.36	32.96	1.75	31.21
17	Manipur	0.20	0.005	0.16	0.01	0.38	0.04	0.34
18	Meghalaya	0.79	0.03	0.33	0.005	1.15	0.12	1.04
19	Mizoram	0.03	0.00	0.02	0.00	0.04	0.004	0.04
20	Nagaland	0.28	0.00	0.08	0.00	0.36	0.04	0.32
21	Orissa	12.81	3.56	3.58	3.14	23.09	2.08	21.01
22	Punjab	5.98	10.91	1.36	5.54	23.78	2.33	21.44
23	Rajasthan	8.76	0.62	0.26	1.92	11.56	1.18	10.38
24	Sikkim					0.08	0.00	0.08
25	Tamil Nadu	4.91	11.96	4.53	1.67	23.07	2.31	20.76
26	Tripura	1.10	0.00	0.92	0.17	2.19	0.22	1.97
27	Uttar Pradesh	38.63	11.95	5.64	20.14	76.35	6.17	70.18
28	Uttaranchal	1.37	0.27	0.12	0.51	2.27	0.17	2.10
29	West Bengal	17.87	2.19	5.44	4.86	30.36	2.90	27.46
	Union							
1	Andaman &					0.330	0.005	0.320
2	Chandigarh	0.016	0.001	.005		0.023	0.002	0.020
3	Dadara &	0.059	0.005			0.063	0.003	0.060
4	Daman & Diu	0.006	0.002			0.009	0.0004	0.008
5	Lakshdweep					0.012	0.009	0.004
6	Pondicherry	0.057	0.067	0.007	0.029	0.160	0.016	0.144
	Total	**248.01**	**69.59**	**41.85**	**73.19**	**433.02**	**33.77**	**399.25**

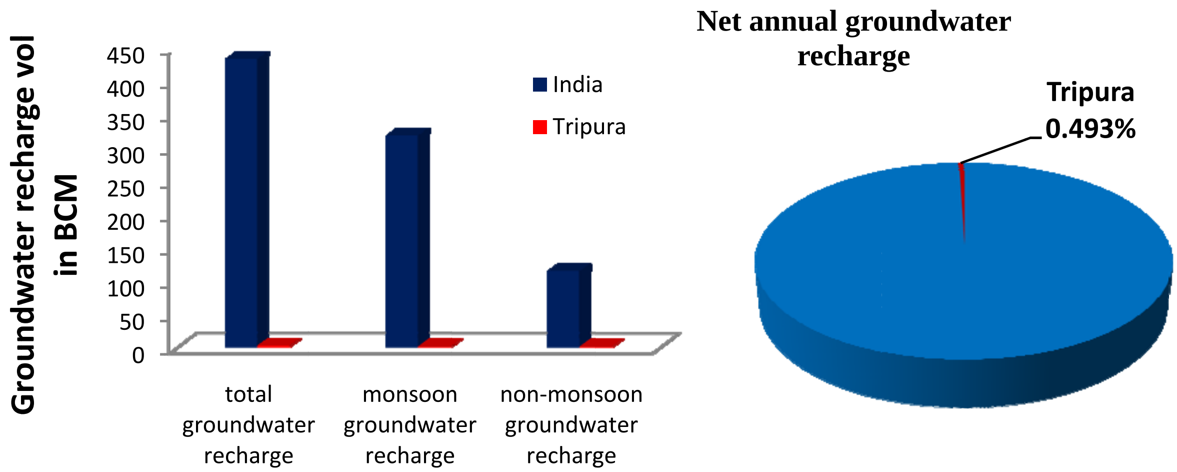


Fig 1.11: Groundwater resources available in Tripura

Table 1.3 (b): State wise Groundwater utilization & stage of development in India (BCM)

SI. No.	States / Union Territories	Annual Groundwater Draft			Projected Demand for Domestic and Industrial uses upto 2025	Ground Water Availability for future irrigation	Stage of Groundwater Development (%)
		Irrigation	Domestic and industrial uses	Total			
	States						
1	Andhra Pradesh	13.88	1.02	14.90	2.67	17.65	45
2	Arunachal Pradesh	0.0008	0	0.0008	0.009	2.29	0.04
3	Assam	4.85	0.59	5.44	0.98	19.06	22
4	Bihar	9.39	1.37	10.77	2.14	15.89	39
5	Chattisgarh	2.31	0.48	2.80	0.70	10.67	20
6	Delhi	0.20	0.28	0.48	0.57	0.00	170
7	Goa	0.04	0.03	0.07	0.04	0.18	27
8	Gujarat	10.49	0.99	11.49	1.48	3.05	76
9	Haryana	9.10	0.35	9.45	0.60	-1.07	109
10	Himachal Pradesh	0.09	0.02	0.12	0.04	0.25	30
11	Jammu & Kashmir	0.10	0.24	0.33	0.42	1.92	14
12	Jharkhand	0.70	0.38	1.09	0.56	3.99	21
13	Karnataka	9.75	0.97	10.71	1.41	6.48	70
14	Kerala	1.82	1.10	2.92	1.40	3.07	47
15	Madhya Pradesh	16.08	1.04	17.12	1.74	17.51	48
16	Maharashtra	14.24	0.85	15.09	1.52	16.10	48
17	Manipur	0.002	0.0005	0.002	0.02	0.31	0.65
18	Meghalaya	0.00	0.002	0.002	0.10	0.94	0.18
19	Mizoram	0.00	0.0004	0.0004	0.0008	0.04	0.90
20	Nagaland	0.00	0.009	0.009	0.03	0.30	**3**
21	Orissa	3.01	0.84	3.85	1.22	16.78	18
22	Punjab	30.34	0.83	31.16	1.00	-9.89	145

23	Rajasthan	11.60	1.39	12.99	2.72	-3.94	125
24	Sikkim	0.00	0.01	0.01	0.02	0.05	16
25	Tamil Nadu	16.77	0.88	17.65	0.91	3.08	85
26	Tripura	0.08	0.09	0.17	0.20	1.69	**9**
27	Uttar Pradesh	45.36	3.42	48.78	5.30	19.52	70
28	Uttaranchal	1.34	0.05	1.39	0.08	0.68	66
29	West Bengal	10.84	0.81	11.65	1.24	15.32	42
	Union Territories						
1	Andaman &	0.000	0.010	0.010	0.008	0.303	**4**
2	Chandigarh	0.000	0.000	0.000	0.000	0.020	**0**
3	Dadara & Nagar	0.001	0.007	0.009	0.008	0.051	14
4	Daman & Diu	0.007	0.002	0.009	0.003	-0.002	107
5	Lakshdweep	0.000	0.002	0.002			63
6	Pondicherry	0.121	0.030	0.151	0.031	-0.008	105
	Grand Total	**212.51**	**18.09**	**230.62**	**29.17**	**162.29**	**58**

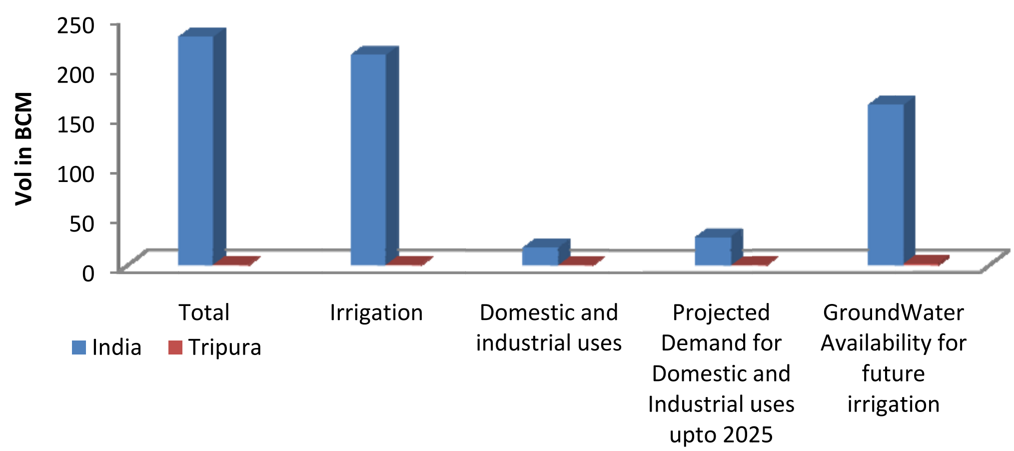


Fig 1.12: Groundwater utilization in Tripura

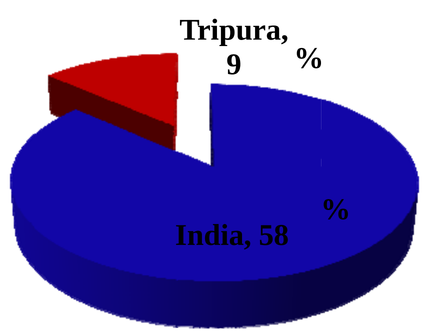


Fig 1.13 : Groundwater development in Tripura

Table 1.4: Dynamic Fresh Groundwater Resource - Basinwise in India (BCM)

Sl. No.	River Basin	Replenishable GW from Normal Natural Recharge	Replenishable GW Due to Recharge from Canal Irrigation	Total Replenishable GW
1	Indus	14.29	12.21	26.5
2	Ganga-Brahmaputra-Meghna			
2a	Ganga sub-basin	136.47	35.1	171.57
2b	Barhmaputra sub-basin	25.72	0.83	26.55
2c	Meghna (Barak) sub-basin	8.52	0	8.52
3	Subarnarekha	1.68	0.12	1.8
4	Brahmani-Baitarani	3.35	0.7	4.05
5	Mahanadi	13.64	2.86	16.5
6	Godavari	33.48	7.12	40.6
7	Krishna	19.88	6.52	26.4
8	Pennar	4.04	0.89	4.93
9	Cauvery	8.79	3.51	12.3
10	Tapi	6.67	1.6	8.27
11	Narmada	9.38	1.42	10.8
12	Mahi	3.5	0.5	4
13	Sabarmati	2.9	0.3	3.2
14	West Flowing Rivers of Kutch and Saurashtra including Luni	9.1	2.1	11.2
15	West Flowing Rivers south of Tapi	15.55	2.15	17.7
16	East Flowing Rivers Between Mahanadi and Pennar	12.82	5.98	18.8
17	East Flowing Rivers Between Panner and Cauvery and those south of Cauvery	12.65	5.55	18.2
18	Area of North Ladakh not draining into Indus	Not Assessed		
19	Rivers draining into Bangladesh	Not Assessed		
20	Rivers draining into Myanmar	Not Assessed		
21	Drainage areas of Andaman, Nicobar and Lakshadweep Islands	Not Assessed		

1.2.2.1 Static Groundwater

A side 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 Tripura101BCM shown in **Table 1.5** and in **Fig 1.14** .

Table 1.5: Static Fresh Groundwater Resource - Statewise (BCM)

No	States	Alluvial/ Unconsolidated Rocks	Hard Rocks	Total
1	Andhra Pradesh	76	26	102
2	Assam	920	0	920
3	Bihar	2557	11	2568
4	Gujarat	92	12	104
5	Haryana	420	1	421
6	Himachal Pradesh	13	0	13
7	Jammu & Kashmir	35	0	35
8	Karnataka	0	17	17
9	Kerala	5	6	11
10	Madhya Pradesh	14	27	41
11	Maharashtra	16	22	38
12	Orissa	162	13	175
13	Punjab	910	0	910
14	Rajasthan	115	13	128
15	Tamil Nadu	98	0	98
16	Tripura	101	0	101
17	Uttar Pradesh	3470	30	3500
18	West Bengal	1625	1	1626
19	Delhi	3	0	3
20	Chandigarh	1	0	1
	Total	**10633**	**179**	**10812**

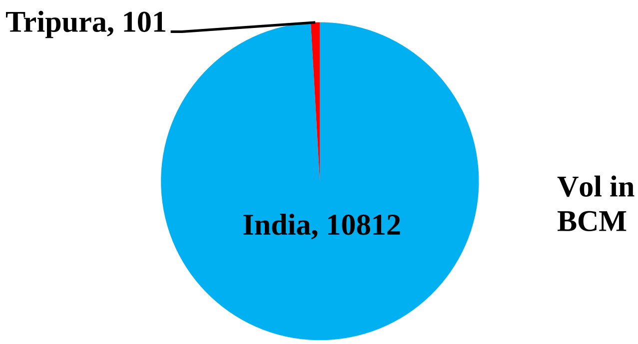
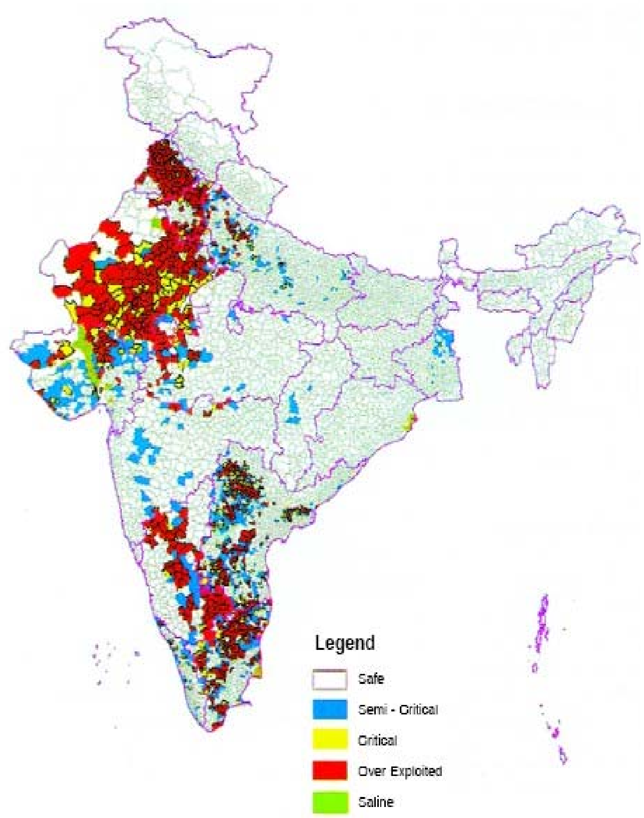


Fig 1.14: Static Fresh Groundwater Resource - Tripura

1.2.3 Over-exploitation: Extent, Causes and Consequences

1.2.3.1 Extent of Over-exploitation

According to the report on 3rd Census of Minor Irrigation Schemes (2005), the ultimate irrigation potential from Groundwater source is 64.05 m.ha., as compared to 46 m.ha. 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). The report (reference year 2000-01) 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 **in Table 1.6 and Fig 1.15.**



in India (as on 2004)

(Source: Dynamic Groundwater Resources of India (as on March 2004), Central Groundwater Board, Ministry of Water Resources, 2006.)

The degree of exploitation has varied widely across the country. Some states have a large number of semi critical, critical and over-exploited assessment units in **Table 1.6** Out of the 5723 assessment units assessed jointly by State

Groundwater Departments and CGWB in the country, 4078 are safe (71%), 550 are semi critical (10%), 226 are critical (4%),30 units are saline and 839 are over-exploited (15%) in **Fig 1.15**. Just six states [Gujarat, Haryana, Maharashtra, Punjab, Rajasthan and Tamil Nadu] comprising 1413 assessment units, have 762 assessment units which are semi critical, critical or overexploited (54% against national average of 29%). The variations in depth to Groundwater level in the country during pre-monsoon and post monsoon period is shown in **Fig- 1.16 & 1.17**. It has been observed that deepest water levels of 40 m and above are common in the western part of the country which is also the zone of low rainfall resulting in meagre natural Groundwater recharge.

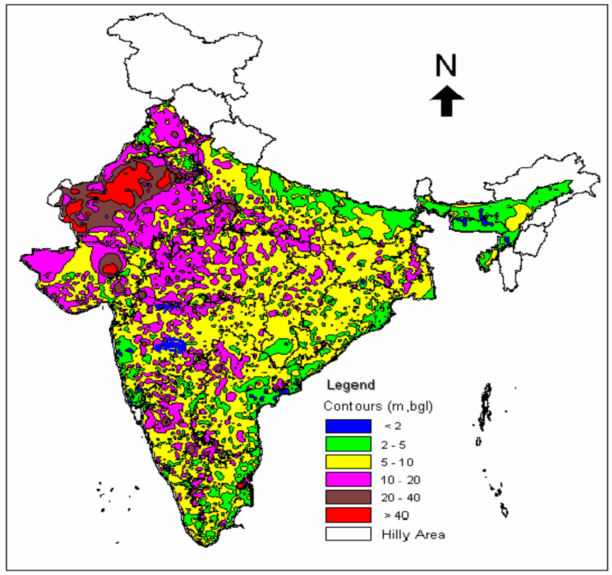


Fig- 1.16 : Depth to Water Level (Pre-Monsoon, 2006) of India

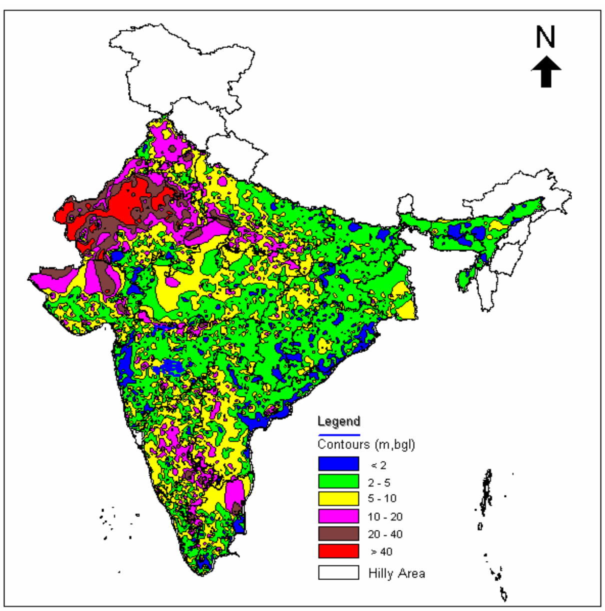


Fig- 1.17: Depth to Water Level (Post-Monsoon, 2006) of India.

How has the Groundwater status of various parts of the country changed over time? Comparable time series data on proliferation of semi-critical, critical and over-exploited blocks in the country is unfortunately not available. In 1995, the Central Groundwater Board published data based on 1984 methodology of classification of such blocks. As per the data, the percentage of over-exploited and dark assessment units to total was about 7%.

Table No 1.6: Safe, Semi-Critical, Critical Over Exploited Units Of India

SI. No.	States /Union Territories	Total No. of Assessed Units	Safe		Semi-critical		Critical		Over-exploited		Remarks
			Nos.	%	Nos.	%	Nos.	%	Nos.	%	
	States										
1	Andhra Pradesh	1231	760	62	175	14	77	6	219	18	
2	Arunachal Pradesh	13	13	100	0	0	0	0	0	0	
3	Assam	23	23	100	0	0	0	0	0	0	
4	Bihar	515	515	100	0	0	0	0	0	0	
5	Chattisgarh	146	138	95	8	5	0	0	0	0	
6	Delhi	9	2	22	0	0	0	0	7	78	
7	Goa	11	11	100	0	0	0	0	0	0	
8	Gujarat	223	97	43	69	31	12	5	31	14	Rest 14 talukas-
9	Haryana	113	42	37	5	4	11	10	55	49	
10	Himachal Pradesh	5	5	100	0	0	0	0	0	0	
11	Jammu & Kashmir	8	8	100	0	0	0	0	0	0	
12	Jharkhand	208	208	100	0	0	0	0	0	0	
13	Karnataka	175	93	53	14	8	3	2	65	37	
14	Kerala	151	101	67	30	20	15	10	5	3	
15	Madhya Pradesh	312	264	85	19	6	5	2	24	8	
16	Maharashtra	318	287	90	23	7	1	0	7	2	
17	Manipur	7	7	100	0	0	0	0	0	0	
18	Meghalaya	7	7	100	0	0	0	0	0	0	
19	Mizoram	22	22	100	0	0	0	0	0	0	
20	Nagaland	7	7	100	0	0	0	0	0	0	
21	Orissa	314	308	98	0	0	0	0	0	0	Rest 6 blocks-
22	Punjab	137	25	18	4	3	5	4	103	75	
23	Rajasthan	237	32	14	14	6	50	21	140	59	Rest 1 block-
24	Sikkim	1	1	100	0	0	0	0	0	0	
25	Tamil Nadu	385	145	38	57	15	33	9	142	37	Rest 8 blocks-
26	Tripura	38	38	100	0	0	0	0	0	0	
27	Uttar Pradesh	803	665	83	88	11	13	2	37	5	
28	Uttaranchal	17	12	71	3	18	0	0	2	12	
29	West Bengal	269	231	86	37	14	1	0	0	0	
	Total States	5705	4067	71	546	10	226	4	837	15	
	Union Territories										
1	Andaman &	1	1	100	0	0	0	0	0	0	
2	Chandigarh	1	1	100	0	0	0	0	0	0	
3	Dadra & Nagar	1	1	100	0	0	0	0	0	0	
4	Daman & Diu	2	0	0	1	50	0	0	1	50	
5	Lakshdweep	9	6	67	3	33	0	0	0	0	
6	Pondicherry	4	2	50	0	0	0	0	1	25	Rest 1 Region-
	Total Uts	18	11	61	4	22	0	0	2	11	
	Grand Total	5723	4078	71	550	10	226	4	839	15	

Talukas - Goa, Gujarat, Karnataka, Maharashtra
Districts - Arunachal Pradesh, Assam, Delhi, Meghalaya, Nagaland
Districts (Valley) - Himachal Pradesh, Jammu & Kashmir
State - Sikkim
Islands - Lakshdweep
UT - Andaman & Nicobar, Chandigarh, Dadra & Nagar Haveli, Daman & Diu, Pondicherry

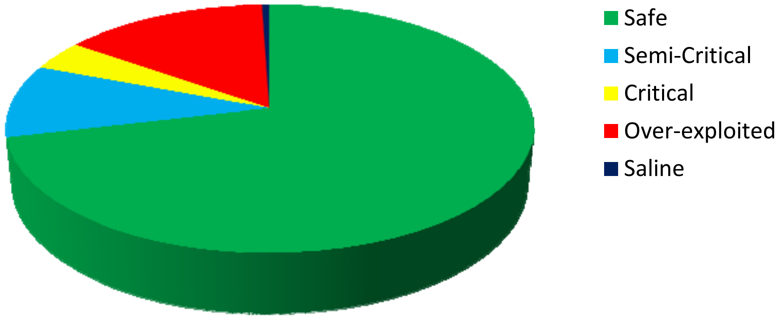


Fig 1.18: Safe, Semi-Critical, Critical Over Exploited Units Of India

(Source Dynamic Groundwater resources in India as on Mar 2004 CGWB,2006)

An estimate for 2004 based on the 1997 methodology, which was somewhat different from the earlier methodology is given in **Table 1.6** . According to the estimate, out of 5723 blocks, 1615 are semi-critical, critical or over-exploited (28%) (State wise details are given in **Table 1.3(a)**. Even though the 2004 estimates are not strictly comparable with the 1995 estimates, they clearly indicate a deterioration, as the differences between the two estimates are too large to be explained by the minor differences in the classification methodology used in the two estimates. The percentage of over exploited blocks, has increased from 4% to 15%, making over-exploitation of Groundwater a matter of concern.

1.2.3.2 Causes of Over-Exploitation

In most parts of the over-exploited areas, the prime cause of over-exploitation is the rising demand for Groundwater from agriculture. [In some parts, it is growing urbanisation and industrialisation.] Further, in many Groundwater irrigated areas, decisions on cropping pattern and cropping intensity, which are the predominant determinants of agricultural demand for Groundwater, are being taken largely independent of the ease of Groundwater availability. Thus, water intensive crops have tended to be grown even in the face of scarcity of Groundwater, if these crops are perceived to be relatively remunerative. Such distortions occur partly due to the legal/ regulatory regime governing Groundwater and partly to the minimum support price policy and agricultural trade policy currently being followed.

The problem has been compounded by the availability of cheap/subsidised or even free power in many states, since power is a main component of the cost of Groundwater. Moreover, electric supply is not metered and a flat tariff is charged depending on the horsepower of the pump. This makes the marginal cost of power zero and provides farmers with little incentive to use power or water more efficiently. Power subsidy has undoubtedly encouraged greater use of Groundwater.

1.2.3.3. Consequences of Over-Exploitation

Overexploitation leads to (i) increase in pumping depths, reduction in well/tube well yields and rise in the cost of pumping Groundwater and (ii) widespread and acute scarcity of Groundwater in summer months for irrigation and drinking uses. This forces farmers to deepen their wells and install larger pumps. Rich farmers may cope with this challenge relatively easily, but small and marginal farmers, many of whose wells are supported by shallow aquifers, often find it difficult.

Quality of Groundwater

As regards to quality, the Groundwater in the major parts of the country is potable and suitable for irrigation and industrial uses, except in few areas where they have been rendered non-potable due to the presence of geogenic contaminants such as Fluoride, Iron, Arsenic etc. in excess of limits prescribed for human consumption. These include Inland salinity problems in the arid and semi-arid regions of Rajasthan, Haryana, Punjab and Gujarat, arsenic hazards in Gangetic alluvial belt, iron contamination in Brahmaputra and Kosi river basins, fluoride problems in hard rock areas of Andhra Pradesh, Tamil Nadu, Madhya Pradesh, Karnataka etc. Excessive withdrawal of Groundwater may also lead to salinity ingress and consequent Groundwater contamination as experienced in coastal areas of Mangrol-Chorwad tract and coastal Saurashtra of Gujarat and in Minjur area south of Chennai in Tamil Nadu.

Groundwater pollution due to domestic and industrial effluents and excessive application of fertilizers and pesticides are also observed, mostly as localized phenomenon. Various issues discussed above bring the complexities involved in managing the Groundwater resources of the country. There is an urgent need to prepare a vision document focusing the efficient measures for Groundwater management to combat the emerging problems of water scarcity. An attempt has been made in this direction.

1.2.4. GROUNDWATER UTILIZATION PATTERN IN INDIA (AS ON 2004)

According to UNEP report 1990-93, 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 of the National Commission on Integrated Water Resources Development (GoI 2004), 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 230.62BCM.

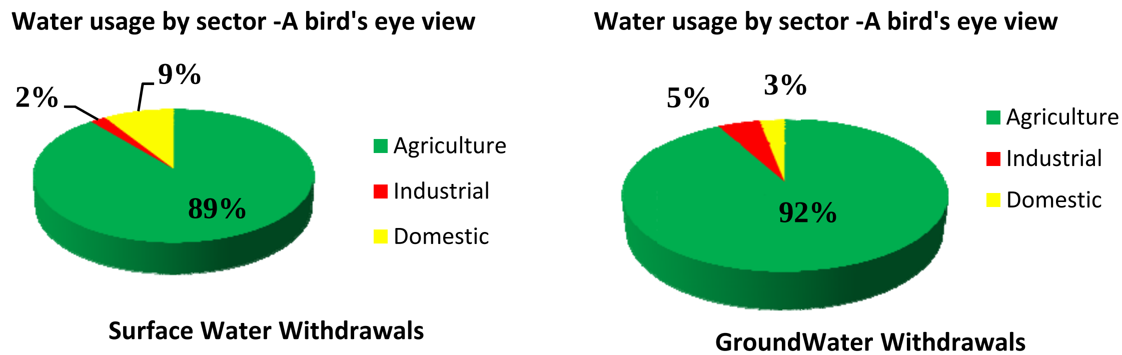


Fig 1.19: Surface and Groundwater utilization pattern in India

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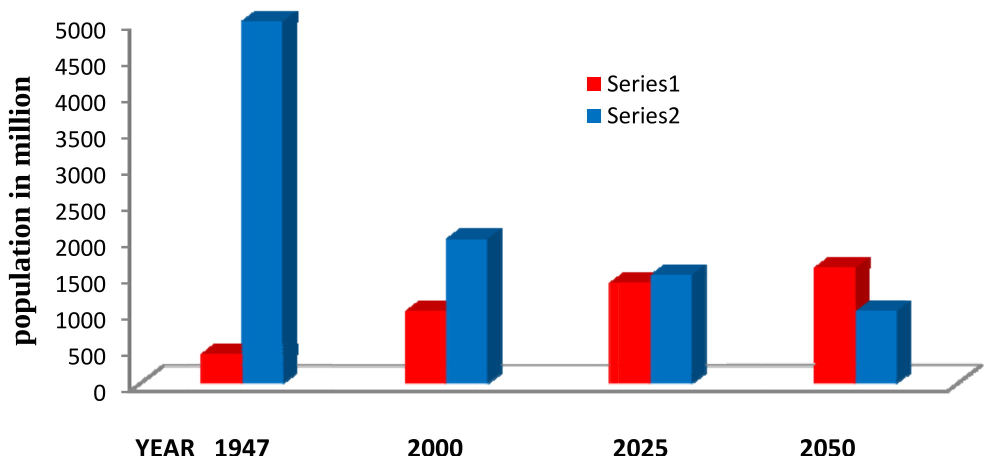


Fig 1.20: Year & Population wise water Availability Trends of India

1.3 GROUNDWATER SCENARIO OF TRIPURA

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 Ips in the valley areas whereas in the sandstone, the yield varies from 2 to 4 Ips. 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 Ips. There is no over Exploited, Critical and Semi- critical zone . Exploratory Tube wells Constructed (as on 31.03.2010 (DWS) are as follows : 948deep tube well (DTWs) and 26,086 Spot sources. For artificial recharge to Groundwater (AR) the number of feasible AR structures are: 300 check dams, 500 weirs, 1000 gabion structures, 240 roof top harvesting, 100 development 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).

Table no 1.7: District wise Groundwater resources availability, utilization and stage of development of Tripura

District	Annual Replenishable Groundwater Resource					Natural Discharge during non-monsoon Season	Net Annual Ground Water Availability
	Monsoon Season		Non-monsoon Season		Total		
	Recharge from rainfall	Recharge from other sources	Recharge from rainfall	Recharge from other sources			
Dhalai		0	17002	622	36457	3646	32812
North Tripura	18911	0	17872	547	37330	3732	33598
South Tripura	34053	0	24499	6730	65281	6528	58753
West Tripura	37923	0	33006	9088	80016	8002	72014
State Total (ha-m)	109720	0	92379	16986	219084	21908	197177
State Total (BCM)	1.10	0.00	0.92	0.17	2.19	0.22	1.97

District	Annual Groundwater Draft			Projected Demand for Domestic and Industrial uses upto 2025	Groundwater Availability for future irrigation	Stage of Groundwater development (%)
	Irrigation	Domestic and Industrial uses	Total			
Dhalai	762	1070	1832	1689	30361	6
North Tripura	867	2135	3002	4639	28091	9
South Tripura	1578	2277	3855	3868	53308	7
West Tripura	5004	3366	8370	9965	57046	12
State Total (ha-m)	8211	8848	17059	20160	168805	9
State Total (bcm)	0.08	0.09	0.17	0.20	1.69	9

Table no 1.8: Static Fresh Groundwater Resource of Tripura (BCM)

Alluvial/ Unconsolidated Rocks (BCM)	Hard Rocks (BCM)	Total (BCM)
101	0	101

1.4 JUSTIFICATION OF THE PROPOSED RESEARCH STUDY

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.

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.T. (2009) 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.

Chapter 2

OBJECTIVES

2.1 SCOPE OF RESEARCH STUDY

- Analysis of the dynamic Groundwater requirements according to the domestic need.
- Estimation of pervious and impervious area by using Remote Sensing and GIS techniques.
- Determination of the Groundwater potential zones using relevant data (rainfall, topography, geology, soil, etc.) using different Groundwater estimation methodology-97.
- Validation of estimated annual Groundwater recharge by different empirical formula.
- Monitoring of Groundwater levels and quality through a network of observation wells.
- Projection of future Groundwater availabilityl.

2.2 BACK GROUND OF STUDY AREA

2.2.1. Location of the city

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'- 23° 55' N latitude and 91°15'- 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. Shown in **Fig 2.1.**

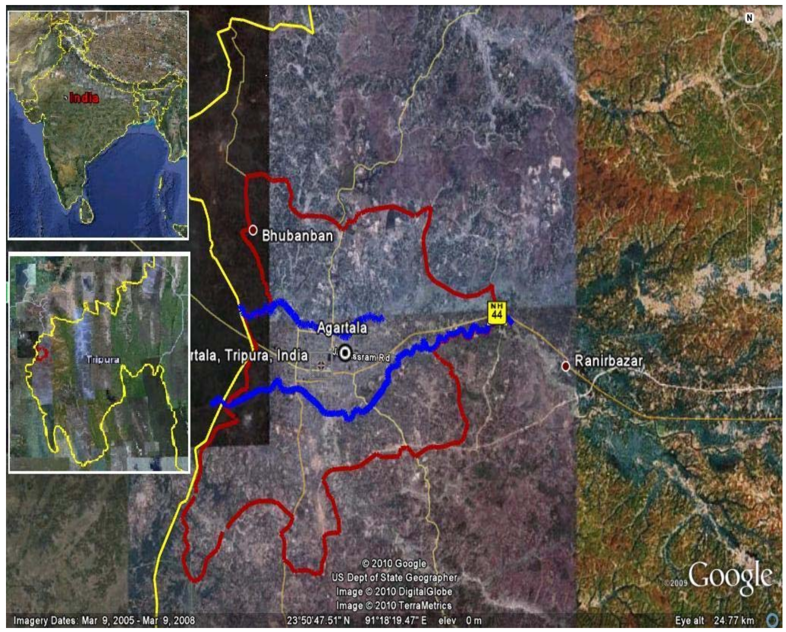


Fig 2.1: Location of Agartala

2.2.2. Climate

The climate of Agartala is of tropical monsoon type. The average annual rainfall is around 211.5 (cm) (39 years average, 1970 to 2008). Average highest rainfall was recorded in the year of 97-98 with 301.52 cm and lowest was recorded in the year of 1993-94 having 128.5 cm. The highest recorded rainfall in a single day was observed in 22nd July 1993 having 25.72 cm and the second highest rainfall was recorded in 15th august 1955 having 23.88 cm. The average no of rainy days is 100 days. The temperature on an average ranges from 4.2°c to 37.6°. Highest recorded temperature was in the year of 1960,1st may having 42.2°c and the lowest was recorded in 1972 30th Dec 2°c . Agartala has a moderate temperature and highly humid atmosphere. Winds are of moderate velocity and blows from the south-to-south – east direction for most of the time. Average velocity of wind varies from 4 km to 9 km per hour. The city enjoys four seasons – winter from December to February, summer from March to May monsoon from June to September and post-monsoon during October and November.. Standard deviation of rainfall 372.967 and co-efficnt of variation 17.628. Average min and maximum temperature and Rainfall in **Fig 2.2.** **(source : based on IMD data analysis from 1970 to 31st Dec 2009)**

2.2.3. Topography

The altitude of Agartala city is 12.8 meters (MSL). The erstwhile AMC area, the central portion of the city is located in an area lower than the surroundings. The central portion of the city is shaped like a saucer. The central portion is bounded by the rivers Haora in the south and Katakhal in the north. Due to its saucer shape, the city is vulnerable to recurrent flooding during monsoons.

2.2.4. Seismicity

Himalayas is one single seismic belt. However, two seismotectonic provinces are recognized in the Himalayas. These are : (a) the Western Himalaya-Nepal seismotectonic province and (b) the Eastern Himalaya seismotectonic province.

The eastern Himalaya seismotectonic province encompasses seismically active Shillong to the South, a syntaxial bend of the NE syntaxis on the eastern extremity and the N.S running seismic belt of Nagaland – Patkai ranges. The tectonic setting makes the whole of NE region including the eastern Himalaya seismically active and complex seismotectonic province. The city is located under the Eastern Himalaya seismotectonic province in seismic zone V. .(**Source; Brahmaputra Board, "Master Plan of Haora Sub Basin", a master plan under part III, March 2003**).

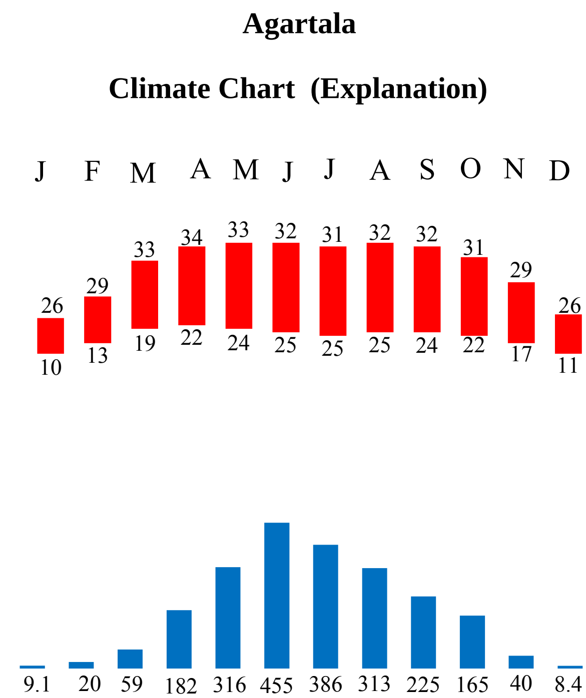


Fig no 2.2: Average Max and Min ,Temperature Precipitation total in mm (Sour IMD Data)

2.2.5. Soil structure

The soil of Tripura are broadly divided into three group (based on the soil genesis)

Forest and hilly lateritic soil, developed as isolated mounds in the Agartala.

Alluvial soil (younger and older) and red loamy soil developed along the river courses and at foothill zones in the synclinal valleys also developed in the Agartala.

Red and young soil developed in the surrounding of Agartala.

Character of this soil are i.) Highly permeable and leached. ii) Low moisture retentivity. iii) parent material are Shale and Sandstone. iv).Average range of pH 4.5 to 6.1 (acid soil). v).Top sopil are sandy and Loamy clay in texture. vi).structure –crumb and sub –angular blocky vii). Low in Nitrogen (available and total both). viii). Low in phosphate available, total is high. ix). Medium to high in potash (available). x). Deficiency of calcium, magnesium and sulphur in the average soil. **(Source: Agriculture atlas of India 1980).**

2.2.6. Geomorphology

The terrain in Tripura is Geomorphologically young and immature. Based on the association of geology and land form the State can be grouped into one geomorphic province i.e.

i. Zone of resistant structural hill ranges (Bhuban Sandstone).

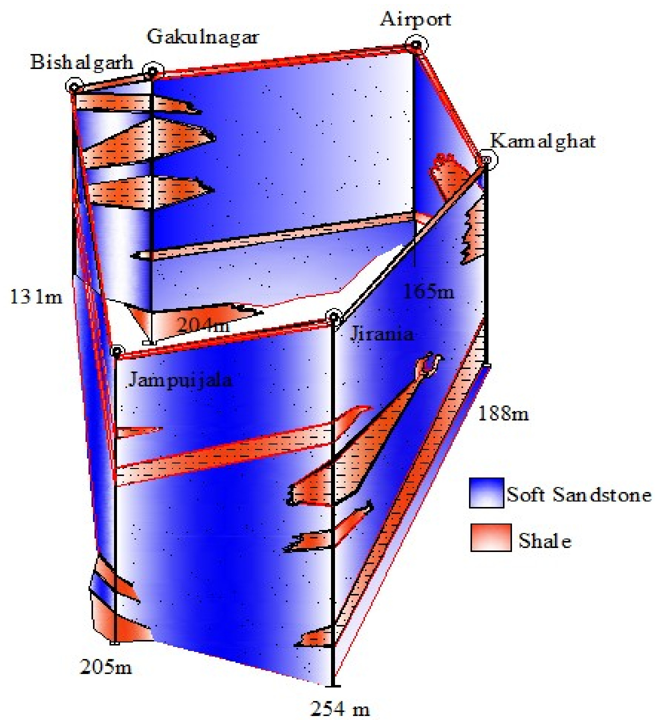
ii. Low lying moderately dissected, semi-round crested strike parallel ridges (Bokabil shale, Siltstone).

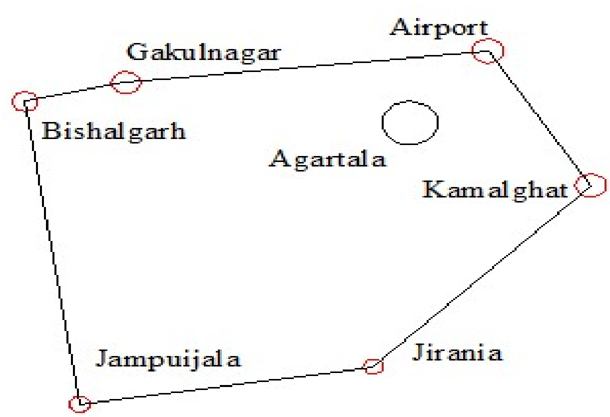
iii. Moderately dissected, round crested to nearly flattopped denudational hills.

iv. Low round to flat topped moderately dissected residual hills with valleys of Tipam sandstone.

v. Undulating plains with low lying flat topped mounds and narrow to wide valley fills of Dupitila Sandstone and Clays.

vi. Flood plains (older and present day) of rivers.





The city is located in geomorphologically group v and vi. The main hydrologic character of these group are a). recharge areas forming shallow to moderately deep aquifers with good Groundwater potentiality and b).surface discharge areas and shallow to moderately deep aquifers with very high Groundwater potentiality. **(Source: NRSA classification 1979).**

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2.2.7. Drainage system

State drainage system is part of the Meghna Basin (basis of Groundwater and base flow). It is mainly classified by three sub-basin. i) Barak sub- basin ii) Gumati sub – basin, iii). Fenny sub-basin. The main part of the city are bounded by the 5 th order rivers Haora and Katakhal is a part of Barak sub- basin **(Source; survey of India map 1990).**

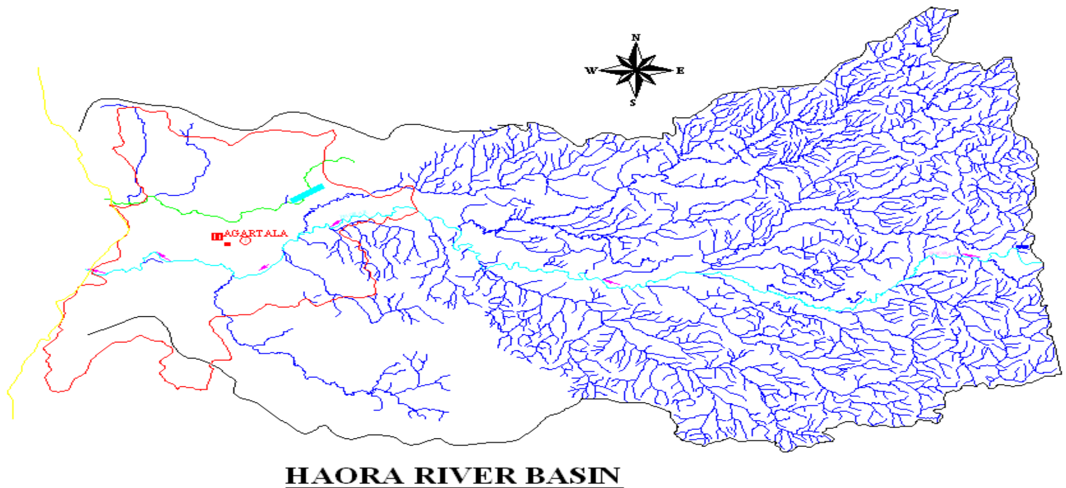


Fig 2.4: Catchment area of Haora river & Agartala municipality area which is considered as study area for present investigations

2.2.8. Evolution history of the city

The municipal area has 16.012 sq. km. with population of 1,89,998 (as per 2001 census). The Agartala Municipal Council has further been extended taking 16 No.of Grams of Dukli R.D.Block,7 No. of Grams of Mohanpur R.D.Block and 2 No.of Grams of Jirania R.D.Block with area of 42.83 sq.k.m and 1,78,495 persons. of population, in addition as on 10.2.2004.

2.2.9. Population growth of the Agartala city

as on 10.2.2004 Population 3,67,822 persons.

Year	Population	Area
1901	6,415	4.83 sq.km
1911	6,831	-do-
1921	7,743	-do-
1931	9,580	-do-
1941	17,693	-do-
1951	42,595	-do-
1961	54,878	-do-
1971	1,00,264	-do-
1981	1,32,186	10.94 sq.k.m.
1991	1,57,358	15.81 sq.k.m.
2001	1,88,540	16.02 sq.k.m.

2.3. DATA SOURCES

In India majority of the field measurements and investigations of Groundwater have been conducted by the Central Groundwater Board, G.o.I. Most work has been done on a cooperative basis with individual states. Results are published by the survey as Circulars, Professional Papers and Water Supply Papers. Since 1979 records of Groundwater measurements from observation wells in various part of the country have been compiled and published in Water-Supply Papers under the title Groundwater Levels in the country. Prior to 1936 (**Chaturvedi formula** in 1936) records, Data are obtained from the wells in the most important Groundwater zones. In some states the basic network more comprehensive observation well program. Govt of India Geological Survey publishes at regular intervals other papers on the geology and Groundwater resources of local areas. Invariably these intensive investigations concern areas containing important Groundwater problems and are carried out incorporation with local agencies. Published information on a particular problem or area can be found in issues of Publication

The National Groundwater Data Storage by CGWB and other state water resources and geophysical data stored by Geological Survey of India in large-scale.

1. Water Quality Analysis of biological, chemical, physical and radiochemical characteristics of different constitutions in Groundwater.
2. Groundwater Site Inventory File- Data on geo-hydrologic characteristics, one-time field measurements such as water temperature, site location and identification and well-construction history for wells, springs and other sources of Groundwater.

A second source of basic data on Groundwater is state geological and water resources agencies. Various states differ widely in their degree of activity.

Professional Literature:

The Professional Literature on Groundwater hydrology embraces many fields of interest. Important contributions can be found in journals of civil engineering, water resources, water supply, geology, geophysics and agriculture and soil science. Pertinent papers on flow in porous media also appear in chemical engineering, mechanics and physics journals. Water Resources Research contain a wealth of Groundwater papers. Similarly, publications of the International Association of Hydrological Sciences, an organization within the International Union of Hydrological Sciences, an organization within the International Union of Geodesy and Geophysics, and Journal of Hydrology serve as the major media for exchange of Groundwater information on a worldwide basis.

Finally, and most importantly, the Groundwater and Water Well Journal, have become indispensable reading for professionals concerned with the development and management of Groundwater resources.

2.3.1 Data requirements for a Groundwater balance study

For carrying out assessment of dynamic Groundwater potential study of a area, following data are required over a given time period:

Rainfall data: Daily (for monsoon, non-monsoon depends on location) rainfall data of sufficient number of rainguage stations lying within or around the study area, along with their locations, should be available.

Land use data and Irrigation data: Land use data are required for estimating the evapotranspiration losses from the water table through forested area. Crop wise irrigation area and source, Cropping pattern data are necessary for estimating the spatial and temporal distributions of Groundwater withdrawals, if required. Monthly pan evaporation rates should also be available at few locations for estimation of consumptive use requirements of different crops. Permanent construction structural data,(like building, permanent road, indoor recreation hall etc)

River data: Monthly river stage and discharge data along with river cross-sections are required at few locations for estimating the river-aquifer interflows.

Canal data: Month wise water releases into the canal and its distributaries along with running days during each month are required. To account for the seepage losses through the canal system, the seepage loss test data are required in different canal reaches and distributaries.

Tank data: Monthly tank gauges and water releases should be available. In addition, depth vs area and depth vs capacity curves should also be available for computing the evaporation and seepage losses from tanks. Field test data are required for computing infiltration capacity to be used to evaluate the recharge from depression storage.

Water table data: Monthly water table data (or at least pre-monsoon and post-monsoon data) from sufficient number of well-distributed observation wells along with their locations are required. The available data should comprise reduced level (R.L.) of water table and depth to water table.

Groundwater draft: For estimating Groundwater withdrawals, the number of each type of wells
operating in the area, their discharge and corresponding average daily running hours are required. If a complete inventory of wells is not available, then this can be obtained by carrying out sample surveys.

Aquifer parameters: Data regarding specific yield are required at sufficient number of locations in the study area.

Topography data: Hilly area, slope of land, flood area water logged (periodical) area etc.

2.3.2 List of data used in project which was collected from various offices and field survey

1. Meteorological Data from regional metrological centret , Govt. of India. Alipur Kolkata (Rain fall, Sun shine hour, Relative Humidity, Minimum Maximum Temperature, Evaporation, wind speed etc) from (1970 to 1992 and 1997 to 2008)
2. Meteorological Data from meteorological center, Govt. of India, Agartala , (Rain fall, Sun shine hour, Relative Humidity, Minimum Maximum Temperature, Evaporation win speed etc) from (1993 to 1996)
3. Groundwater Data from Central Groundwater Board ,Govt. of India, Agartala (Seasonal Groundwater variation, data period from 2001 to 2004 and 2005 to 2008)
4. Haora River discharge Data from Central water Commission, Govt. of India, Agartala period from 1984 to 2004 .
5. Rain Fall data. from State Agriculture Dept., Govt. of Tripura Agartala period from (1972 to 2008),
6. Haora River discharge data from State Water Resources Dept., Govt. of Tripura
7. Agartala, rai fall data from 1985 to 2008, 1985 to 1996, monthly basis and from 1996 to 2000 daily basis and also Howrah river discharge data from 1992 to 2008 daily basis ,Flood data (Hourly basis) from State Water Resources Dept., Govt. of Tripura.
8. Litholog of Groundwater level and soil parameter in various point of Agartala and surrounding Agartala data from Rig Division Agartala Govt. of Tripura
9. Soil analysis data on Agartala and its surroundings data from State Housing Board Agartala Govt. of Tripura.
10. Data from Brahmaputra Board Agartala Govt. Of India, Haora river basin history and character of river Haora flowing on Agartala.
11. Population census office Agartala, Govt. of India (projected total, urban population percent of population data).
12. Hand pump, Deep Tube well, land use pattern etc data from Agartala Municipality Council, Govt. of Tripura
13. History and statistical data from Statistical Dept. Agartala, Govt. of Tripura for of Agartala
14. Data from State Information Centre Agartala, Govt. of Tripura.
15. Water body(pond,lake area) data from State pollution controls Board Science & Technology Agartala Govt. of Tripura
16. Data from field survey (latitude and longitude) by GPS.
17. Data use from www.india water portal.org and www.tutiempo.net (temperature and evapo transpiration data).

Chapter 3

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 semi arid 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 was 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. Also provided a review of recent case studies on Groundwater assessment in various parts of the country and the type of data that is available, both from routine observations and from special studies.

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 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) discusses in his paper 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 Groundwater 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) in their paper 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. The total Groundwater recharge and net Groundwater available of West Tripura.

Mohan. & 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 arrive 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 these 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 fall 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 water shed, 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. He 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.

Groundwater assessment principle, Method: ANCD, (2004) applicability analysis in the use of Groundwater monitoring wells to identify and 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 (piezo metric 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 476×10^9 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) estimated and suggested that Groundwater 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 in their paper highlighting the role of RS (remote sensing), GIS (geographic information System) and MCDM (Multi Criteria Decision Making) 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 in their paper how to Assessment of Groundwater pollution potential 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.

A team under guidance of **Prof. Dr.Khaled M.Abu-Zeid and local specilists Prof. Dr. Nahed Ei Aribi and Prof. Dr. Akram Fekry studied and made an assessment of Groundwater potential in Alexandria governorate (2009)** they found that there was Groundwater difference from surface water because of the contrasting physical chemical enviroment in which it occurs . Groundwater development can have undesirable qualitative and quantitative side effect as well, as environmental problems. A relatively safe sustainable level of exploitation was possible for Groundwater potential. Assessment of the Groundwater potential involves a quantitative and qualitative understanding of the aquifer systems and Groundwater conditions.

Whid et.al. described (2007) 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 hydro(geo)logical 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 4

METHODOLOGY

4.1 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

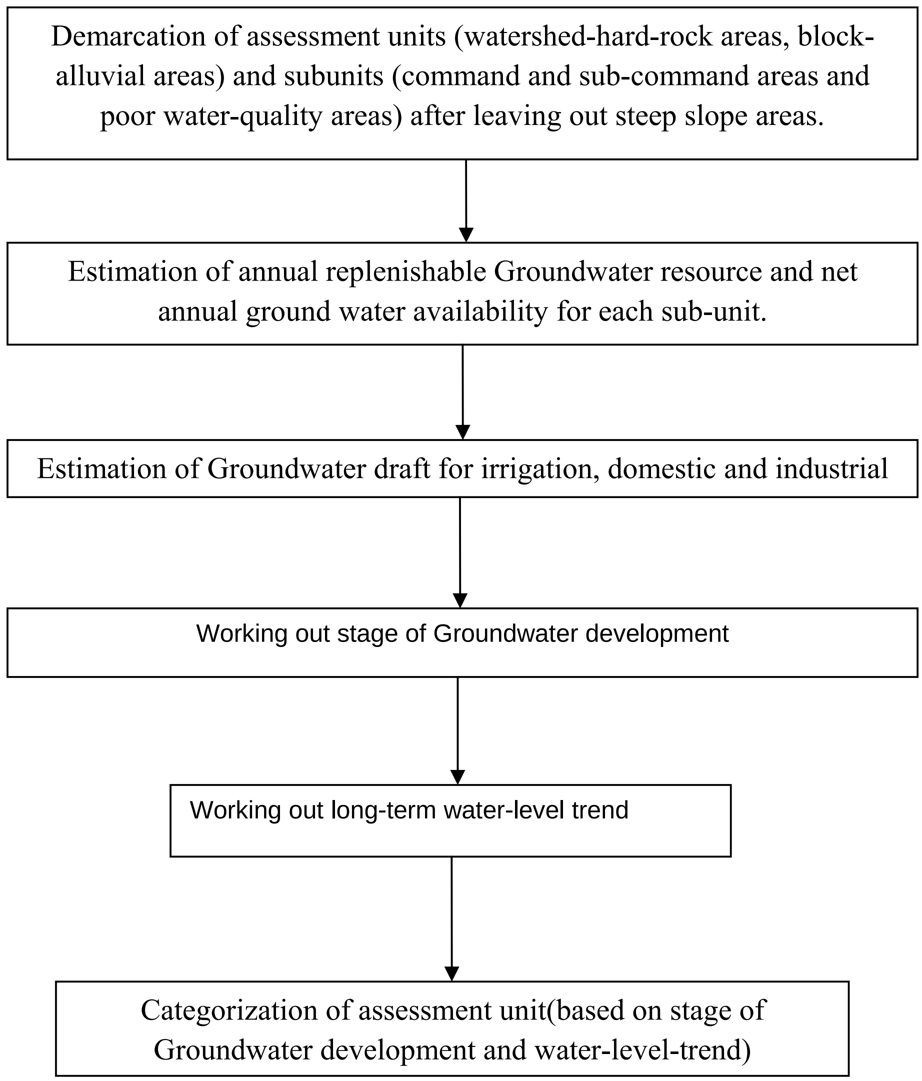
The downloaded image has been imported in ERDAS IMAGINE 10.1 'Viewer'. After importing Radiometric correction Contrast correction has been applied for improving visual impact of the image. Some trial and error enhancements were expected to find the desired results, and then those enhancement values were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

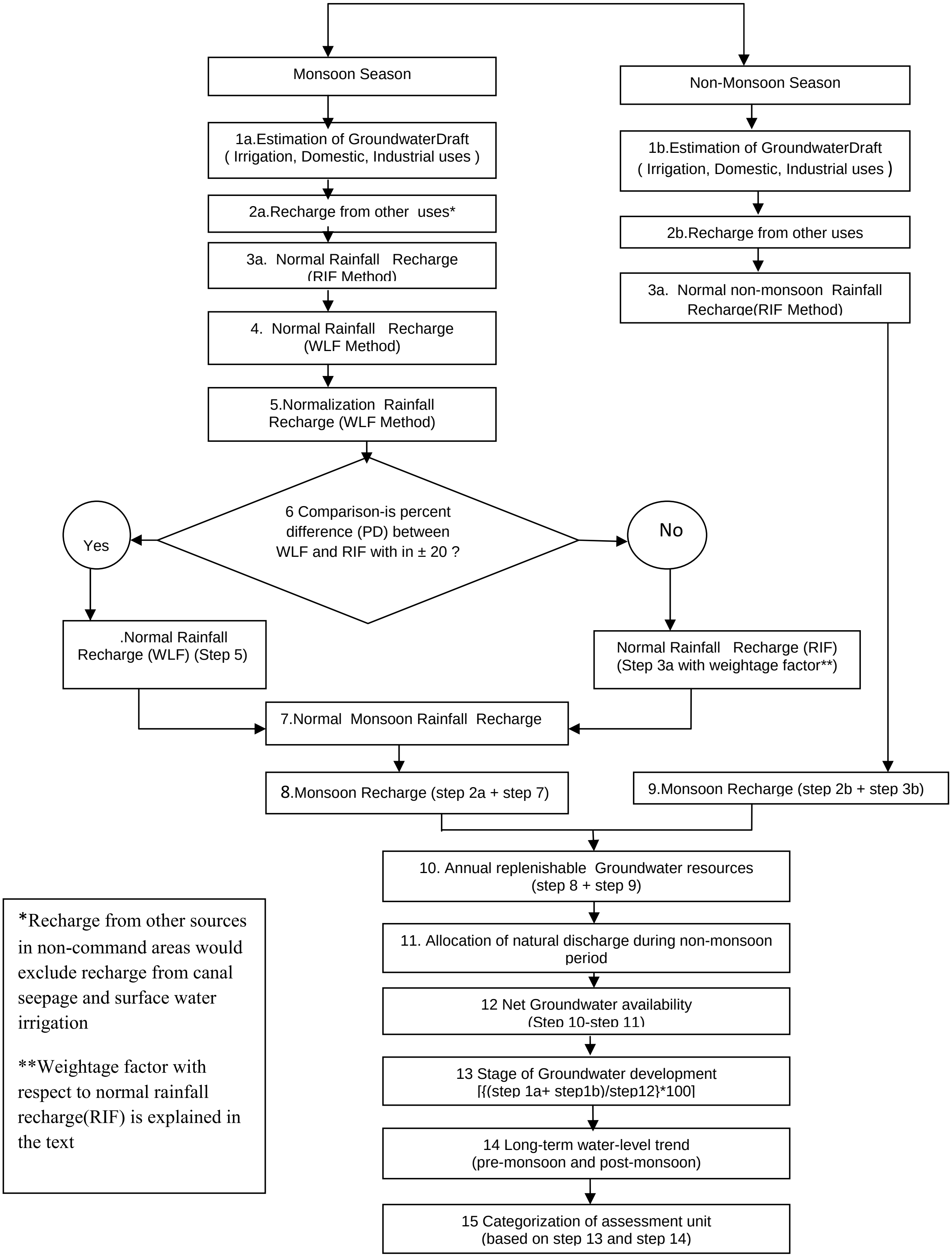
- First, the locations of the boundary were identified from Google Earth with the help of GPS data taken from these locations.
- Then, the screen window was captured with the help of some screen capture software and the captured image was imported into the GIS software.
- The coordinate type was changed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

4.2 FLOWCHART OF GROUNDWATER DEVELOPMENT



Assessment and categorization of replenishable Groundwater resources

4.2.1 Groundwater estimation flowchart



4.3 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 replenish able 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

Table 4.1: Norms for specific yield

S.No	Formation	Recommended value (%)	Minimum Value %)	Maximum Value (%)
(a)	Alluvial areas			
	Sandy alluvium	16.0	12.0	20.0
	Silty alluvium	10.0	8.0	12.0
	Clayey alluvium	6.0	4.0	8.0
(b)	Hard rock areas			
	Weathered granite, gneiss and schist with low clay content	3.0	2.0	4.0
	Weathered granite, gneiss and schist with significant clay content	1.5	1.0	2.0
	Weathered or vesicular, jointed basalt	2.0	1.0	3.0
	Laterite	2.5	2.0	3.0
	Sandstone	3.0	1.0	5.0
	Quartzite	1.5	1.0	2.0
	Limestone	2.0	1.0	3.0
	Karstified limestone	8.0	5.0	15.0
	Phyllites, Shales	1.5	1.0	2.0
	Massive poorly fractured rock	0.3	0.2	0.5
Note : **Usually the recommended values should be used for assessment, unless sufficient data based on field study is available to justify the minimum, maximum or other intermediate values**				

Table 4.2: Recharge from rainfall

S.No	Formation	Recommended value (%)	Minimum Value %)	Maximum Value (%)
	Alluvial areas			
	Indo-Gangetic and inland areas	22	20	25
	East coast	16	14	18
	West coast	10	8	12
	Hard rock areas			
	Weathered granite, gneiss and schist with low clay content	11	10	12
	Weathered granite, gneiss and schist with significant clay content	8	5	9
	Granulite facies like charnockite etc.	5	4	6
	Vesicular and jointed basalt	13	12	14
	Weathered basalt	7	6	8
	Laterite	7	6	8
	Semi-consolidated sandstone	12	10	14
	Consolidated sandstone, quartzite ,limestone (except cavernous limestone)	6	5	7
	Phyllites shales	4	3	5
	Massive poorly fractured rock	1	1	3

Note:. Usually, the recommended values should be used for assessment, unless sufficient information is available to justify the use of minimum, maximum or other intermediate values. 2. An additional 2% of rainfall recharge factor may be used in such areas or part of the areas where watershed development with associated soil conservation measures are implemented. This additional factor is subjective and is separate from the contribution due to the water conservation structures such as check dams, nalla bunds, percolation tanks etc. The norms for the estimation of recharge due to these structures are provided separately. This additional factor of 2% is at this stage, only provisional, and will need revision based on pilot studies.

Table 4.3: Recharge due to seepage from canals

(a) Unlined canals in normal soils with some clay content along with sand :	1.8 to 2.5 cumecs per million sq m of wetted area (or) 15 to 20 ha-m/day/million sq m of wetted area
(b) Unlined canals in sandy soil with some silt content:	3.0 to 3.5 cumecs per million sq m of wetted area (or) 25 to 30 ha-m/day/million sq m of wetted area
(c) Lined canals and canals in hard rock area	20% of above values for unlined canals

Notes :The above values are valid if the water table is relatively deep. In shallow water table and waterlogged areas, the recharge from canal seepage may be suitably reduced..Where specific results are available from case studies in some states, the adhoc norms are to be replaced by norms evolved from these results.

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.

Table 4.4: Recharge as percentage of application

Source of irrigation	Type of crop	Water table below ground level		
		<10m	10-25 m	>25m
Groundwater	Non-paddy	25	15	5
Surface water	Non-paddy	30	20	10
Ground water	Paddy	45	35	20
Surface water	Paddy	50	40	25

Notes: 1. For surface water, the recharge is to be estimated based on water released at the outlet. For ground water, the recharge is to be estimated based on gross draft. 2. Where continuous supply is used instead of rotational supply, an additional recharge of 5% of application may be used.3.Where specific results are available from case studies is some states, the adhoc norms are to be replaced by norms evolved from these results.

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.

Table 4.5: Guideline of Groundwater development

Sl	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

4.4 Validation of the calculated results with the help of 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:** 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 upto 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 to 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.

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

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 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, $\mathbf{R_{ef}}$ 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:

$$\mathbf{R_{ef} = K\ (P - X)}$$

The following relation is stated to hold good for different parts of Karnataka:

$\mathbf{R_{ef}}$ = 0.20 (P - 400) for areas with annual normal rainfall (P) between 400 and 600 mm

$\mathbf{R_{ef}}$ = 0.25 (P - 400) for areas with P between 600 and 1000 mm

$\mathbf{R_{ef}}$ = 0.35 (P - 600) for areas with P above 2000 mm

where, Rr and P are expressed in millimeters.

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.

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4.5 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 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 ground water flow identification is required.

4.6 ALTERNATIVE APPROACH OF THE ADOPTION GROUNDWATER ESTIMATION

Groundwater Balance Approach

In this method, all components of the Groundwater balance equation (1), except the rainfall recharge, are estimated individually. The algebraic sum of all input and output components is equated to the change in Groundwater storage, as reflected by the water table fluctuation, which in turn yields the single unknown in the equation, namely, the rainfall recharge. A pre-requisite for successful application of this technique is the availability of very extensive and accurate hydrological and meteorological data. The Groundwater balance approach is valid for the areas where the year can be divided into monsoon and non-monsoon seasons with the bulk of rainfall occurring in former.

Groundwater balance study for monsoon and non-monsoon periods is carried out separately. The former yields an estimate of recharge coefficient and the later determines the degree of accuracy with which the components of water balance equation have been estimated. Alternatively, the average specific yield in the zone of fluctuation can be determined from a Groundwater balance study for the non-monsoon period and using this specific yield, the recharge due to rainfall can be determined using the Groundwater balance components for the monsoon period.

Soil Moisture Data Based Methods

Soil moisture data based methods are the lumped and distributed model and the nuclear methods. In the lumped model, the variation of soil moisture content in the vertical direction is ignored and any effective input into the soil is assumed to increase the soil moisture content uniformly. Recharge is calculated as the remainder when losses, identified in the form of runoff and evapotranspiration, have been deducted from the precipitation with proper accounting of soil moisture deficit. In the distributed model, variation of soil moisture content in the vertical direction is accounted and the method involves the numerical solution of partial differential equation (Richards equation) governing one-dimensional flow through unsaturated medium, with appropriate initial and boundary conditions.

(a) **Soil Water Balance Method**

Water balance models were developed in the 1940s by Thornthwaite (1948) and revised by Thornthwaite and Mather (1955). The method is essentially a book-keeping procedure which estimates the balance between the inflow and outflow of water. When applying this method to estimate the recharge for a catchment area, the calculation should be repeated for areas with different precipitation, evapotranspiration, crop type and soil type. The soil water balance method is of limited practical value, because evapotranspiration is not directly measurable. Moreover, storage of moisture in the unsaturated zone and the rates of infiltration along the various possible routes to the aquifer form important and uncertain factors. Another aspect that deserves attention is the depth of the root zone which may vary in semi-arid regions between 1 and 30 meters. Results from this model are of very limited value without calibration and validation, because of the substantial uncertainty in input data.

(b) Nuclear Methods

Nuclear techniques can be used for the determination of recharge by measuring the travel of moisture through a soil column. The technique is based upon the existence of a linear relation between neutron count rate and moisture content (% by volume) for the range of moisture contents generally occurring in the unsaturated soil zone. The mixture of Beryllium (Be) and Radium (Ra) is taken as the source of neutrons. Another method is the gamma ray transmission method based upon the attenuation of gamma rays in a medium through which it passes. The extent of attenuation is closely linked with moisture content of the soil medium.

4.7 STATIC GROUNDWATERRESOURCE

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

$$\textbf{Static Groundwater reserve} = \begin{array}{c}\text{Thickness of the aquifer below}\\ \text{the zone of water level fluctua-}\\ \text{tion down to exploitable limit}\end{array} \times \begin{array}{c}\text{Areal extent}\\ \text{of the aquifer}\end{array} \times \begin{array}{c}\text{Specific yield}\\ \text{of the}\\ \text{aquifer.}\end{array}$$

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 $(0.05 \times 0.40) \times 100 = 2\%$ 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.

Chapter 5

RESULT AND DISCUSSION

Table 5.1: Step wise working Results

Step	Item	Result
Step 1	Area considered for assessment (ha)	5432ha.
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 result of the two methods have been compared Using Percent Deviation .	51.39%
Step	Annual Recharge from Rainfall	1602.18 ha-m
Step	Total GW Recharge	2106.61 ha-m
Step	Net GW Availability	1895.94 ha-m
Step	Stage of GW Development	16.53%
Step 15	Annual allocation of Groundwater for domestic & industrial water supply (2009)	22.246

Groundwater resources of Agartala have been estimated using Groundwater resources estimation methodology -97 (GEC-97)as depicted **Table 5.1**,as described in detailed **(Appendix-A**).

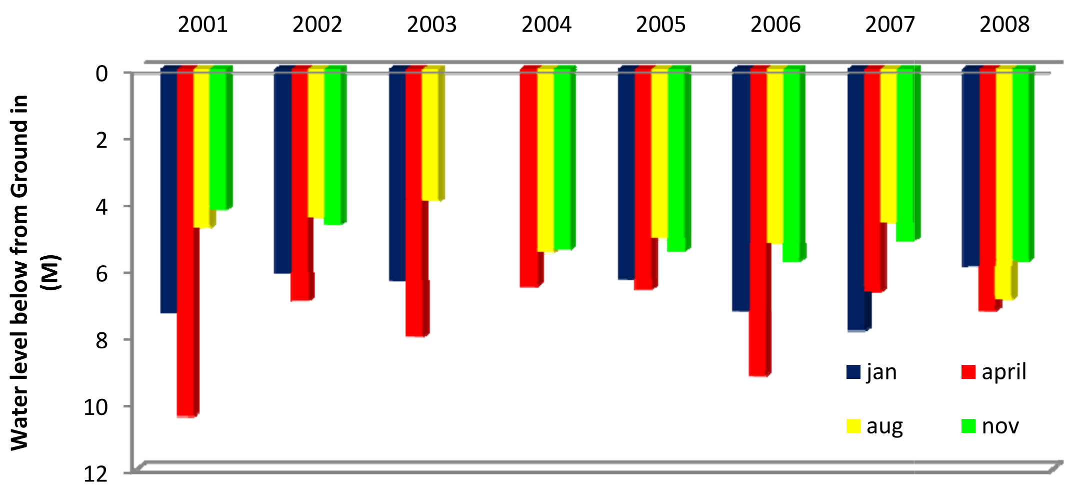


Fig 5.1: Year wise Groundwater level at Agartala

The stage of Groundwater development for Agartala city in case of dynamic is 16.53%.

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 5.1 .

The results show that the water level is declined maximum during non-monsoon almost every year where as in monsoon season it is less.

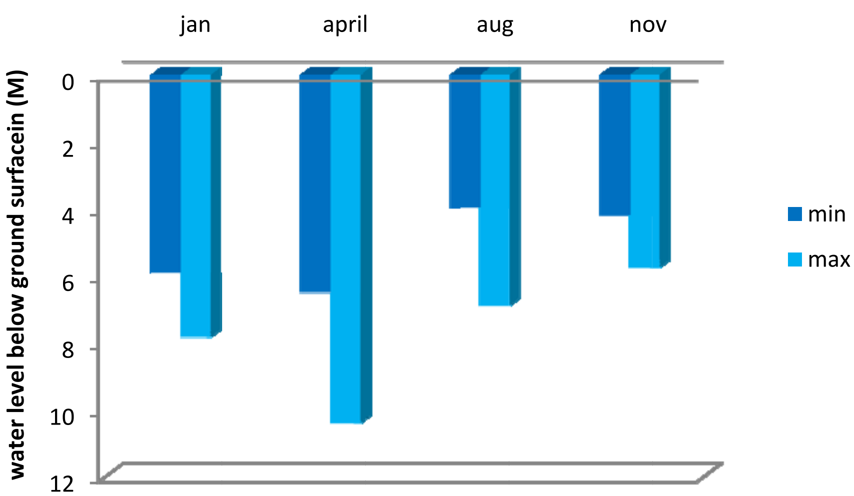


Fig 5.2: Minimum and maximum Groundwater movement level at Agartala from 2001 -08

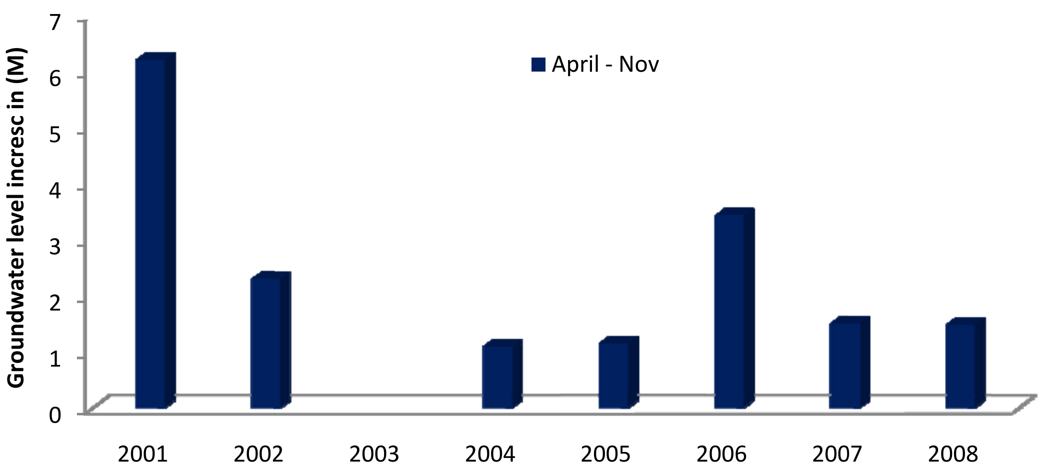


Fig 5.3: Year wise Groundwater recharge at Agartala

Fig 5.2 and **Fig 5.3** show The minimum and maximum Groundwater movement level and year wise recharging at Agartala city **. Fig 5.3** observes the Groundwater recharge is found to be maximum in the year 2001 follow by 2006.

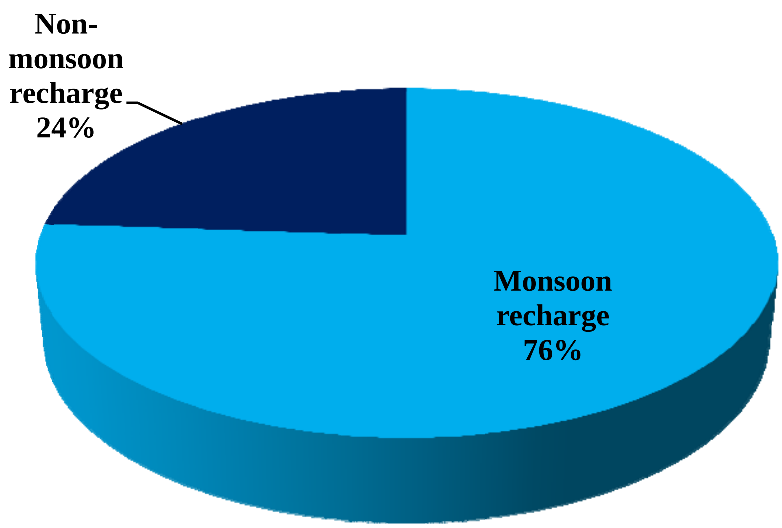
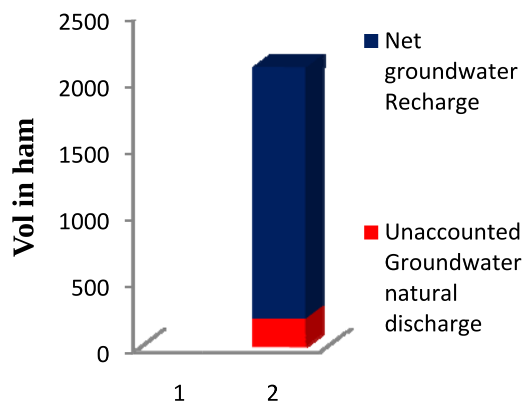
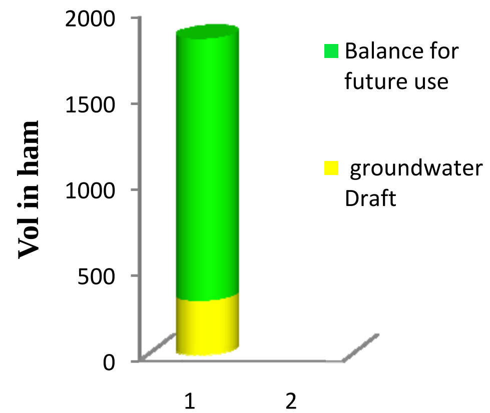


Fig 5.4: Groundwater Monsoon & non-monsoon recharge at Agartala

The annual replenishable Groundwater resources at Agartala is 2106 ha-m overall contribution of rainfall to the Agartala's annual replenishable Groundwater resources is 90% and the share of other sources ,including canal seepage, return flow from irrigation ,seepage from water bodies and water conservation structure taken together 10%. Keeping 313 ha-m as the allocation for Groundwater draft, the net Groundwater withdrawl for future at Agartala city is 1582 ha-m **Fig 5.5.**





Net Groundwater available in Agartala **Groundwater withdrawal at Agartala**

Fig 5.5: Groundwater availability and withdrawal

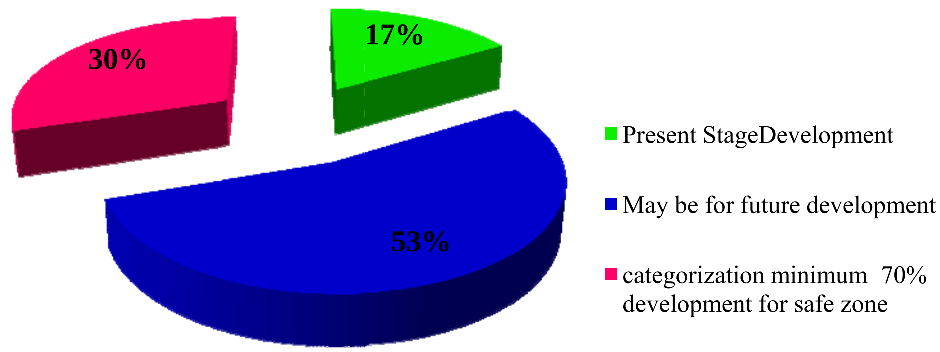


Fig 5.6: Stage of Groundwater development at Agartala

Table 5.2: validation of working results

S.l	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 %) **Fig- 5.6** .Since most of the area in this reason is occupied by soft sandy soil s excessive availability of Groundwater has resulted in growing 70% development of safe zone.

The estimation of allocation of domestic water require based on population upto the year 2026 is highlighted in the **Table 5.3** the future projection for the period of 2026 is also estimated for water required **table 5.3** reveals that as the year increases, the water requirement goes up and it reaches up to 356.89 ha-m in the year of 2026 by lit keeping water demand per capita as 135 lit/d. Even though, the future Groundwater is computed upto 428 ha-m in the year of 2026 by keeping 10% additional development for both irrigation and industry. Accordingly, the net Groundwater available for Future use is estimated based on net available Groundwater resource on given in the **Table 5.4. Table 5.4** reveals that even in the year 2026 ,the usable water is found to be 1470 ha-m which is less then the net available Groundwater resources and it is under safe zone.

Table no 5.3: Annual allocation of Groundwater for domestic , industrial and irrigation water supply upto 2026.

Year	Population	Lg	N	Z	Present use (ha-m)	Year wise uses (ha-m)	Add 10% ind & 10% irr uses (ha-m)
2009	428093	0.1388	7.2755	22.246	**313.64**		
2010	437.8819	0.138988	7.441908	22.75539		336.395	403.6745
2011	447.6706	0.141768	7.608269	23.72936		337.369	404.8432
2012	458.1119	0.144603	7.785722	24.76847		338.408	406.0902
2013	467.9006	0.147495	7.952083	25.80367		339.444	407.3324
2014	478.3419	0.150445	8.129536	26.90707		340.547	408.6565
2015	488.7832	0.153454	8.306988	28.04429		341.684	410.0211
2016	499.2245	0.156523	8.48444	29.21623		342.856	411.4275
2017	509.6658	0.159654	8.661893	30.42384		344.064	412.8766
2018	520.7596	0.162847	8.850436	31.70779		345.348	414.4174
2019	531.2009	0.166104	9.027888	32.99041		346.630	415.9565
2020	541.6422	0.169426	9.20534	34.31165		347.952	417.542
2021	552.7361	0.172814	9.393884	35.7147		349.355	419.2256
2022	563.1774	0.17627	9.571336	37.11715		350.757	420.9086
2023	573.6187	0.179796	9.748788	38.56141		352.201	422.6417
2024	584.7126	0.183392	9.937331	40.09333		353.733	424.48
2025	595.1539	0.18706	10.11478	41.62547		355.265	426.3186
2026	606.2477	0.190801	10.30333	43.24941		356.889	428.2673

Table 5.4: 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

Table 5.5: Static Groundwater recharge and withdrawal from 1970. (L'vovich, 1979)

year	Annual total rainfall in mm	2% of rainfall(mm)	study area in (ha-m)	volume of water recharge in (ha-m)	yearly withdraw in (ha-m)
1970-71	2162.6	43.252	5432	234.9449	184.0522
1971-72	2056.7	41.134	5432	223.4399	193.7391
1972-73	2030	40.6	5432	220.5392	203.9359
1973-74	2202.2	44.044	5432	239.247	214.6694
1974-75	2052	41.04	5432	222.9293	225.9678
1975-76	2181.7	43.634	5432	237.0199	237.8609
1976-77	2763.1	55.262	5432	300.1832	250.3798
1977-78	2463.8	49.276	5432	267.6672	263.5577
1978-79	1713.2	34.264	5432	186.122	277.4292
1979-80	2308.5	46.17	5432	250.7954	292.0307
1980-81	1833	36.66	5432	199.1371	307.4008
1981-82	1440.5	28.81	5432	156.4959	323.5797
1982-83	1552.5	31.05	5432	168.6636	340.6103
1983-84	1958.2	39.164	5432	212.7388	358.5371
1984-85	2210.9	44.218	5432	240.1922	377.4075
1985-86	1647	32.94	5432	178.9301	397.271
1986-87	2021.1	40.422	5432	219.5723	418.18
1987-88	2293.6	45.872	5432	249.1767	440.1895
1988-89	2262.2	45.244	5432	245.7654	463.3574
1989-90	2228.4	44.568	5432	242.0934	487.7446
1990-91	2311.5	46.23	5432	251.1214	513.4154
1991-92	2278.5	45.57	5432	247.5362	540.4373
1992-93	2081.9	41.638	5432	226.1776	568.8813
1993-94	2331.4	46.628	5432	253.2833	598.8224
1994-95	1285	25.7	5432	139.6024	630.3394
1995-96	2600.7	52.014	5432	282.54	663.5152
1996-97	1627.3	32.546	5432	176.7899	698.437
1997-98	3015.2	60.304	5432	327.5713	735.1969
1998-99	1720.4	34.408	5432	186.9043	773.8914
1999-00	2410	48.2	5432	261.8224	814.6226
2000-01	1757.3	35.146	5432	190.9131	857.4974
2001-02	2396.5	47.93	5432	260.3558	902.6289
2002-03	2450.3	49.006	5432	266.2006	950.1357
2003-04	1924.2	38.484	5432	209.0451	1000.143
2004-05	2629.5	52.59	5432	285.6689	1052.782
2005-06	1801.2	36.024	5432	195.6824	1108.191
2006-07	2044	40.88	5432	222.0602	1166.517
2007-08	2591.7	51.834	5432	281.5623	1227.913
2008-09	1876.1	37.522	5432	203.8195	1292.54
2010-11	2115	37.522	5432	203.8195	1357.167
2011-12	2115	37.522	5432	203.8195	1425.025
2012-13	2115	37.522	5432	203.8195	1496.277

2013-14	2115	37.522	5432	203.8195	1571.09
2014-15	2115	37.522	5432	203.8195	1649.645
2015-16	2115	37.522	5432	203.8195	1732.127
2016-17	2115	37.522	5432	203.8195	1818.734
2017-18	2115	37.522	5432	203.8195	1909.67
2018-19	2115	37.522	5432	203.8195	2005.154
2019-20	2115	37.522	5432	203.8195	2105.411
2020-21	2115	37.522	5432	203.8195	2210.682
2021-22	2115	37.522	5432	203.8195	2321.216
2022-23	2115	37.522	5432	203.8195	2437.277
2023-24	2115	37.522	5432	203.8195	2559.141
2024-25	2115	37.522	5432	203.8195	2687.098
2025-26	2115	37.522	5432	203.8195	2821.453
Assume last 39 years average Rainfall will be 2010 to2026					

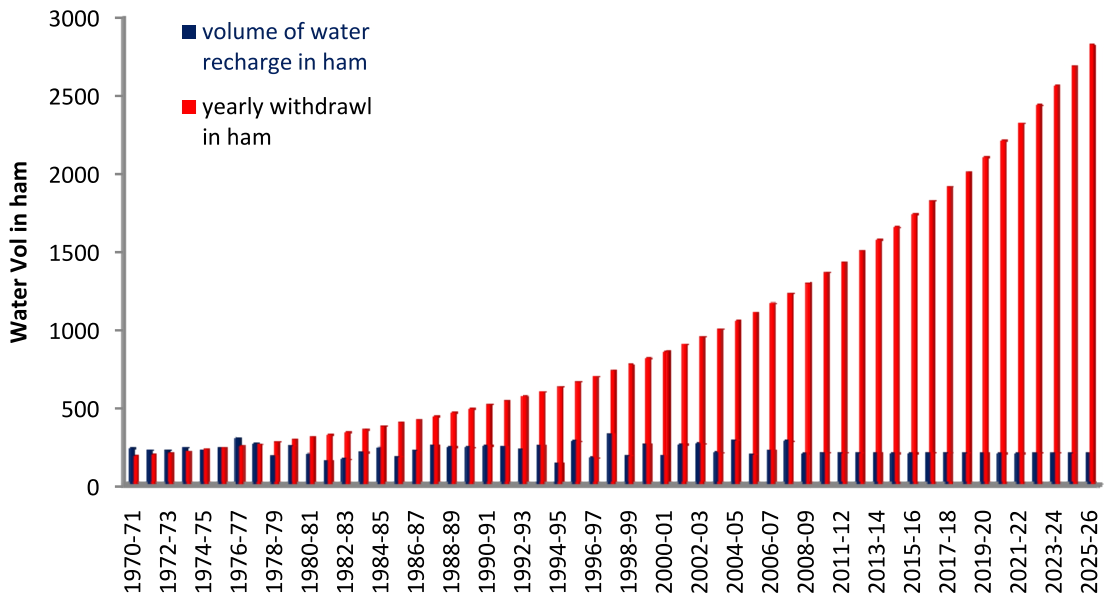


Fig 5.7 Trend Agartala static Groundwater recharge and withdrawal

The volume of static Groundwater recharge is calculated on the basis of 2% of precipitation considered as deep percolation **Table 5.5 and Fig 5.7 .**This table value varies as a function of scale, from local to regional ;furthermore ,it has a tendency to decrease from costal inland regions as states by L'Vovich (1979) .Table 5.5 reveals that the annual withdrawal was almost saturated in the year of 1978 compared to recharge volume. Finally, it is observed that the volume of recharge water is found less compared to the annual withdrawal and it goes upto 2821 ha-m inthe year of 2026. Even 2% of total annual rainfall is considered . 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 Table **5.6 and Fig 5.8 . It** is seen from **Table 5.6** that the annual evaporation for Haora catchment may vary from 29153 to 31807 ha-m . There will be excess precipitation over evaporation on the catchment area .It is interesting to see from this table that the Haora river catchment is the driest with only33% of the precipitation going as runoff. Extending this type of analysis up to the period of 2025. The long term average runoff for Haora catchment is found to be 45%

Table 5.6: Water distribution of Haora river catchment

Year	Precipitation water volume in ha-m	River discharge volume in ha-m	Groundwater recharge in ha-m (RIFM)	Evaporation water volume in ha-m	Surface water uses ha-m.
1985-86	80373.6	26685.94	41974.25	31807.84	10166.41
1986-87	98629.68	32109.64	48133.98	31480.88	16653.1
1987-88	111927.7	34614.82	52844.54	30026.64	22817.9
1988-89	110395.4	44560.15	66285.24	30573.2	35712.04
1989-90	108745.9	39666.24	50998.73	29153.12	21845.61
1990-91	112801.2	52163.83	52809.41	29489.84	23319.57
1991-92	111190.8	50613.47	58082.93	30665.92	27417.01
1992-93	101596.7	29246.66	44258.09	30626.88	13631.21
1993-94	113772.3	47812.84	68605.77	30646.4	37959.37
1994-95	62708	12715.35	32854.5	30622	2232.502
1995-96	126914.2	34188.14	69374.86	30026.64	39348.22
1996-97	79412.24	32521.93	41832.92	30519.52	11313.4
1997-98	147141.8	52409.96	83448.78	29470.32	53978.46
1998-99	83955.52	30421.12	48006.71	30704.96	17301.75
1999-00	117608	41640.58	58566.25	29201.92	29364.33
2000-01	85756.24	41190.5	42245.18	30197.44	12047.74
2001-02	116949.2	42737.99	60637.71	29850.96	30786.75
2002-03	119574.6	52280.54	64199.72	30646.4	33553.32
2003-04	93900.96	42323.16	55147.9	30988	24159.9
2004-05	128319.6	57658.23	77401.48	29328.8	48072.68

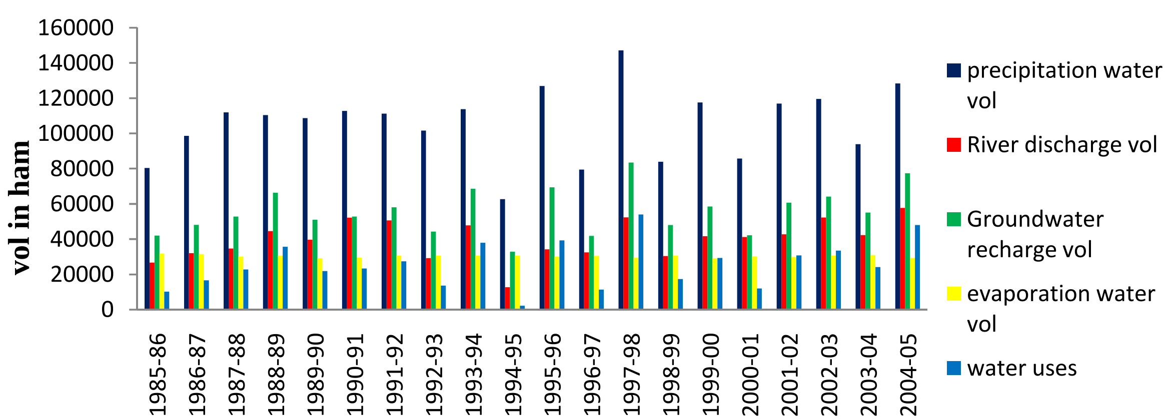


Fig 5.8 Water distribution of Haora river catchment

Chapter 6

CONCLUSION

AND

RECOMMENDATIONS

CONCLUSION AND RECOMMENDATIONS

6.0 CONCLUSIONS

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 and 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.

6.0. Recommendations

The recommendations need urgent measure to address the following critical issues concerning Groundwater sector in India:

- Lack of monitoring of Groundwater levels and need to share the information with the communities regularly

- Lack of monitoring of Groundwater quality and contamination issues and need to share the information with the communities regularly

- Lack of legal instruments to manage the Groundwater by the communities

- Lack of resources for Groundwater recharging schemes

- Lack of mandatory provisions to ensure that those who extract Groundwater have to ensure recharge of Groundwater of at least equal quantity that is being extracted.

- Lack of provisions to ensure that dams release enough water downstream from the diversion point to ensure that the Groundwater recharge function of the river is not affected.

- Lack of provisions to ensure transparency and accountability of the pollution control board to the communities and the nation.

- Lack of provisions to ensure that communities have right to access the industrial premises in their respective areas so that they can check the water use, waste water treatment and disposal and records pertaining to the same. There have been instances where industries even indulge in pumping polluted Groundwater into the aquifers.

- Lack of provision to ensure that local water systems and forests that play such a crucial role in Groundwater recharge are not destroyed.

6.1 Future scope of the study Area

- Considering the changing Groundwater scenario, re-assessment of Groundwater resources will be needed to carry out at regular intervals for further strengthening of the available database. These would 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 assessment may be done by flow net analysis by computing all the parameters and to work out the optimum development of the confined aquifers as well as the recharge area may be demarcated in the state of Tripura.
- Recent data in Agartala indicate 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 may be evaluated.

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Appendix-A

WORK POCEDURE

(Step wise).

Groundwater Resource Estimation Procedure

Step 1

Area considered for assessment (ha) = (total geological area of a block) - (hilly area of the unit)

Total area of A.M.C = 58.84 sq.km. = 5884 ha .(hilly area is zero)

(Constructed area building, road G.C.I, roof etc= 452 ha)

Groundwaterrecharge area = 5884 ha – 432 ha = 5432 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,

= 428093persons-368593persons = 59500 persons

$$\text{As per population} = \frac{(59500 \text{ Persons X } 135 \text{ l X } 365 \text{ days})}{(1000 \text{ l X } 1000.\text{km}^2.)}$$

= 293.19 ha-m

Note,

2009 population 428093 persons, Water supply cover 368593 persons,

Assume remaining 59500 persons depends on ground water,

In town as per I.S. 1.35 l/head/day,

In village as per I.S. 60 l/head/day.

1 hect = 10000m^2.

1 gallon = 4.54 l

56 nos deep tube- well (Groundwater) supply 61.82 lac gallon/day.

Similarly surface water supply 56.15 lac gallon/day

It was covered = 368593 persons,

(Water supply data from Drinking Water & Sanitation Govt of Tripura. planning circle, Kunjaban Agt as on 31.12.2009. and population data from census office Agartala Govt of India, as on 2009 and also Agartala Municipality Council , population 428093.)

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) = 0+293.2+20.44

= 313.64 ha-m.

Step 3.i

Gross GW draft for irrigational uses = (Gross Monsoon GW draft for irrigation) + (Gross Non-monsoon GW draft for irrigation) = 0

Step 3.i.a

Gross Monsoon GW draft for irrigation = Draft of overflows during monsoon = 0

(Data from water resources Sub-Division .Agartala.)

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)
= 0+0+0 = 0

**(Data from water resources Sub-Division .Agartala.) **
(Non-monsoon uses of irrigation water totally 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)

We considered hare item no **(2)** = 293.19 ha-m. (Say 293.20 ha-m)
Only domestic uses, because industrial uses is = 0
(Commercials uses is very negligible)
(In Tripura, industrial uses of Grroundwater is nil, up to 2009.)
Additional uses considered = 100 lit X 5600 nos X 365 days = 20.44 ha-m.

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) = 0+113.= 113.6 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
= 252 X 0.45 + 0.8 X 0.25 = 113.6 ha-m

Step 4.iii

Irrigation water applied for paddy = (Area irrigated under paddy) X 1.2 m

= 210 ha X 1.2 m = 252 ha-m.

(Data from water resources Sub-Division .Agartala.)

Step 4.iv

Irrigation water applied for non-paddy = (Area irrigated under non-paddy) X 0.1 m

= 8 ha X 0.1 m = 0.8 ha-m

(Data from water resources Sub-Division .Agartala.)

***Return flow factor (REF) for paddy is 0.45 (GEC'97 book)**

***Return flow fractor (REF) for non-paddy is 0.25 (GEC'97 book)**

(Total irrigation water used from deep tube-well which is below 500 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) = 0 + 342.21 = 342.21 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 = 684 x 0.5 + 0.7 x0.3

= 342.21 ha-m.

Step 5.iii

Irrigation water applied for paddy = (Area irrigated under paddy) x 1.2 m

= 570 ha x 1.2 m= 684 ha-m

(Data from water resources Sub-Division .Agartala.)

Step 5.iv

Irrigation water applied for non-paddy = (Area irrigated under non-paddy) x 0.1 m

= 7 ha x 0.1 m =0.7 ha-m

(Data from water resources Sub-Division .Agartala.)

Return flow factor (REF) for paddy is 0.50 (GEC'97 book)

Return flow factor (REF) for non-paddy is 0.30 (GEC'97 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) = 0 + 48.62 = 48.62 ha-m

Step 6.i

Recharge from ponds/tanks during monsoon (M Rp/t) =

$$M\ Rp/t = \frac{(1.44 \times \text{Av. Water spread area} \times \text{No. of days water is available})}{1000} = \text{nil}$$

*** Average water spread area of a block is considered as 2% of area considered for assessment of the block (from toposheets/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 198.5 X 70% X 243) / 1000 = 48.62 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)

= 1062.5 + 752.18 = 1814.68 ha-m.

Step 7.i

Monsoon R_{ef} = Area considered for assessment X NMR X RFF

Where,

RFF = Rain Infiltration Factor.

Monsoon R_{ef} = 5432 ha x 1.22249 m x 0.16 = 1062.5 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 Agatala from 1971 to 2000 for 2001 to 2010.
i.e. for 2011 it will be 1980 to 2010.

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 = 5432 ha x 0.86544 m x0.16 = 752.18 ha-m
NNMR = 865.44 mm for Agartala from 1971 to 2000.
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)
(Land use structure data from A.M.C Agartala, up to 2004)
Land use structure data (new extended part of Agartala Municipality area, after 2004)
(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) = 0 + 504.43 = 504.43 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)

= 113.6 + 342.21 + 48.62 = 504.43 ha-m

Step 9

Groundwater Recharge by Water Table Fluctuation Method,
Pre-Monsoon Post Monsoon Water level difference

	2004 MAR(m)	Nov(m)	Level diff(m)	2005 MAR(m)	Nov(m)	Level diff(m)
Agartala	6.51	5.41	1.1	6.6	5.45	1.15
Bishalgarh	2.42	1.34	1.08	1.19	1.37	******
Cha-mpaknagar	4.12	1.84	2.28	2.95	1.74	1.21
Average Level Diff			1.486667			1.18

	2006 MAR(m)	Nov(m)	Level diff(m)	2007 MAR(m)	Nov(m)	Level diff(m)
Agartala	9.2	5.76	3.44	6.66	5.15	1.51
Bishalgarh	3.55	1.96	1.59	0	2.69	2.69
Cha-mpaknagar	4.685	3.1	1.585	3.63	2.02	1.61
Avg Level Diff			2.205			1.93666667

	2008 MAR(m)	Nov(m)	Level diff(m)
Agartala	7.25	Nil	1.1
Bishalgarh	2.27	2.22	0.05
Cha-mpaknagar	3.6	3.77	******
Averageg Level Diff			0.575

***(- ve)data not accepted from field experience
2008 nov Agartala data nil assume lowest data for calculation =1.1

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	S_y	Recharge water storage in ha-m
2004	1.486667	5432	0.08	646.046012
2005	1.18	5432	0.08	512.7808
2006	2.205	5432	0.08	958.2048
2007	1.93667	5432	0.08	841.599315
2008	0.575	5432	0.08	249.872

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)
2004	646.05	313.64	0	959.686012
2005	512.78	313.64	0	826.4208
2006	958.2	313.64	0	1271.8448
2007	841.6	313.64	0	1155.23932
2008	249.87	313.64	0	563.512

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	
2004	1820.9	mm
2005	948.5	mm
2006	1112.9	mm
2007	1805.7	mm
2008	1320.5	mm

Data from(1971-2000 for Agartala meteorological dept)

Year	N.M.R(mm)	Water storage(ha-m)	Actual rainfall(mm)	Actual storage(ha-m)
2004	1222.5	959.6860115	1820.9	644.300375
2005	1222.5	826.4208	948.5	1065.14619
2006	1222.5	1271.8448	1112.9	1397.08649
2007	1222.5	1155.239315	1805.7	782.116913
2008	1222.5	563.512	1320.5	521.687077
			average	**=882.067409**

Recharge corresponding to Normal Monsoon rainfall (WTFM)=

(NMR x Recharge monsoon)/Actual MR= 882.06 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**
2004	1.8209	0.959686012	3.315677	1.74749226
2005	0.9485	0.8264208	0.899652	0.78386013
2006	1.1129	1.2718448	1.238546	1.41543608
2007	1.8057	1.155239315	3.260552	2.08601563
2008	1.3205	0.563512	1.74372	0.7441176
	7.0085	4.776702927	10.45815	6.77692169

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}]= 0.128385852

b=[{(S_2-(a x S_1)}/N]= 0.77542037

rainfall Recharge during Monsoon in hect m (WTFM) method =

(a x NMR+ b) x 1000 = 932.037 ha-m

Step 10

***hence we consider = 882.06 ha-m.

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

= 882 -1814.68)/1814.68 = 51.39%

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 $MR_{ef} = R_{ef(WTfM)}$

P.D is < - 20% M Rrf = 0.8 X $R_{ef(RIFM)}$

P.D is > - 20% M Rrf = 1.2 X $R_{ef(RIFM)}$

* 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} = 1062.5x 0.8 + 752.18 =

1602.18 ha-m

Step 12

Total Groundwater Recharge = Annual Recharge From rain fall (11.) +
Annual Recharge from other sources (8.)
Total GW Recharge = 1602.18 + 504.43 = 2106.61 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 = 2106.61- 0.1x2106.61=1895.94 ha-m

Step 14 **Stage of Groundwater Development** = $\dfrac{\text{Year Groundwater Gross Draft}}{\text{Net Groundwater Availability}} \times 100$

Stage of Groundwater Development = $\dfrac{313.42}{1895.94} \times 100 = 16.53\%$

Step 15

Annual allocation of Groundwater for domestic & industrial water
supply upto next 25 years,
Z = 22 x N x Lg = 22 X 7.2755 X 0.138933 = 22.246.

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)}

Appendix B

Static Groundwaterreserve

			rainfall recharge depth		in ha	total recharge	
(a) Chaturvedi formula 1936	10.20856	inch	259.2975	mm	5432	1408.504	(ha-m)
U.P. Irrigation Research Institute,Roorkee	10.44504	inch	265.30403	mm	5432	1441.131	(ha-m)
(b) Kumar and Seethapathi (2002):	9.202444	inch	233.74207	mm	5432	1269.687	(ha-m)
(c) Amritsar formula	14.43647	inch	366.68625	mm	5432	1991.84	(ha-m)
(d) Krishna Rao	446.635	mm	446.635	mm	5432	2426.121	(ha-m)

Note :- four rain gauge station

i. Airport , Meteorological Deptt.
ii. Battala CWC .
III. BATTALA , Water resources.
Iv. Nagicharra , Agriculture Deptt