केंद्रीय भूजल बोर्ड

जल संसाधन, नदी विकास और गंगा संरक्षण विभाग,

जल शक्ति मंत्रालय

भारत सरकार

Central Ground Water Board

Department of Water Resources, River Development and Ganga Rejuvenation,
Ministry of Jal Shakti
Government of India

AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES

Visakhapatnam District
Andhra Pradesh

ए.पी. राज्य इकाई कार्यालय, विशाखापट्टनम

A.P State Unit Office, Visakhapatnam

November, 2023

भारत सरकार

जल शक्ति मंत्रालय

जल संसाधन, न॰ वि॰ एवं ग॰ जी विभाग

GOVERNMENT OF INDIA

MINISTRY OF JAL SHAKTI

DEPARTMENT OF WATER RESOURCES, RD & GR

REPORT ON

AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES IN VISAKHAPATNAM DISTRICT, ANDHRA PRADESH

(AAP-2023-24)

CENTRAL GROUND WATER BOARD

APSUO, VISAKHAPATNAM

NOVEMBER, 2023

REPORT ON

AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES IN VISAKHAPATNAM DISTRICT, ANDHRA PRADESH

(AAP-2023-24)

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REPORT ON

AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES IN VISAKHAPATNAM DISTRICT, ANDHRA PRADESH

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REPORT ON

AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES IN VISAKHAPATNAM DISTRICT, ANDHRA PRADESH STATE (AAP-2023-24)

AT A GLANCE

S.No.	Item		Particulars
1	District	:	Visakhapatnam
2	Revenue Mandals	:	11
3	Villages	:	122
4	Geographical area	:	1049 km^2
5	Mappable area for NAQUIM Studies	:	1049 km^2
6	Hilly Area	:	126.75 km^2
7	Population (2021 Census)	:	19.59 lakhs
8	Location	:	Latitude: 17°50´52"-18°23´36" N Longitude: 81°12´19"-83°37´7" E
9	Rainfall (Normal)	:	~1117.7 mm
10	Geomorphology	:	Structural hills, Pediplains, Pediment, Dissected hills, Denudation hills, alluvial plains and Coastal alluvial plains.
11	Major Rivers	:	Gosthani & other Tributaries/Gedda (Narava)
12	Land Utilization (Ha)	:	Forest/ hills occupies ~12 % of the total geographical area, remaining area is Land put to non-agricultural uses (38%), barren land is 18%, Urban area is 682 sq.km (6% of total area), Net area sown is 12941 ha (12%).
13	Soils	:	Clayey soils (70%) and rest are Gravelly, Sandy loamy, Red Loamy soils
14	Soil Infiltration rate (cm/hr)	:	Soil Infiltration rate ranges from 1.5 to 3.3 cm/hr, and is soil infiltration capacity is more than rainfall Intensity in this area.
15	Cropping Pattern (2019-20)	:	Main crops grown are Paddy during khariff and rabi seasons followed by Sugarcane and other crops are maize, blackgram, horsegram, ragi, greengram, bajra, jowar, chillies, redgram, papaya, sapota, oil seeds and vegetables etc.
16	Irrigation Sources (Ha)	:	Dug wells: 3,075 No.s Tube wells: 2,125 No.s

17	**Geology**	:	**Khondalite, Granite Gneiss, Chanrockite, Granulite, migmatie and Alluvium.**
18	**Hydrogeological data points**	:	**11 Exploratory wells and 11 number of VES data of CGWB & 09 number of wells data from SGWD.**
19	**Ground water yield (lps) and Transmissivity (m^2/day)**	:	**Formation / Discharge (Q = lps) / Transmissivity (T = m2/day)** **Granite Gneiss: 0.3 to 5.0 / 1 to 11** **Khondalite: 0.12 to 7.0 / 5 to 9** **Charnockite: 0.51 to 1.5 / 1 to 6**
20	**Water Levels:**	:	**33 number of monitoring Wells**
	Depth to water levels (m bgl) (Decadal mean data (2010-2019)	:	**(CGWB: 12 + SGWD: 21 no)** **Pre-monsoon season: 1.04 to 22.08 m bgl (average: 7.37 m bgl) and majority of areas are in the range of 5-10 m covering 92% of the area, followed by 10-20 m bgl (5%) and Shallow water levels <5 m bgl (3%). of the area falling in parts of coastal parts of Visakhapatnam. Deep water levels here between >20 m.bgl occupy 5% of the area in small parts of Padmanabham, Bhemunipatnam and Visakhapatnam Urban mandals.** **Post-monsoon: Majority of the water levels during this season are in the range of <5m covering 53% of the area, followed by 5-10 m bgl (46%) and 10-20 m bgl (1%). Deep water levels in the range of <20 m bgl occupy about 1% of the area falling mostly in parts of Padmanabham mandal (Fig. 2.5). Shallow water level <5 m.bgl occupy 53% of the area in Pedagantyada, Gajuwada and small parts of Visakhapatnam urban & Rural areas, Pendurthi, Anandapuram, Padmanabham and Bhemunipatnam mandals.** **The water-table elevation ranges from 4.52 to 171 during pre monsoon and 5.90 to 176 meter above mean sea level (m amsl) during post monsoon seasons. The general ground flow is towards NW to SE in the southern parts, south east part of the district (98% of area).**

21	**Water Level Fluctuations (May vs. November) (Decadal mean)**	**:**	**The water level fluctuations vary from -12.5 to 17.5 m with average rise of 2.5 m. 91% (30 nos) of the wells show rise in water level and 9% (3 nos) of wells show falling in water level. Fall in water level is recorded only in 3% of the area, whereas rise in water levels is observed throughout the district covering 97% of area. Falls of water levels <-5 m is observed in Bhemunipatnam, Pendurthi and Visakhapatnam rural mandals.**
22	**Geophysical data (down to 200 m)**	**:**	**11 number of VES, Resistivity is in the range of 2 to 15181 ohm (Ω) m for the weathered and fractured granite with an inferred depth of 2 – 140 m, whereas resistivity is in the range of 2 to 15181 Ω m for massive granite with maximum thickness of 50 m to 200 m. The resistivity for the weathered and fractured Khondalite ranges from <2.3 to 90 ohm (Ω) m, while it is in the range of and 106 - 625 Ωm for massive Khondalite with maximum thickness of 90 m to 200 m. Charnockite formations are generally shows high resistivity values more than 500 Ωm. The resistivity of shear zone aquifers is very low 12 to 30 Ωm**

23	**Hydrochemistry**	**: Total 71 data used for analysis Pre-monsoon (2019) (CGWB: 26+ SGWD: 16). Post-monsoon (2019) (CGWB: 0+ SGWD: 29).**
23.1	**Electrical Conductivity (µ Siemens/cm)**	**: Pre-monsoon (2019): The average EC during pre-monsoon is 1502 µ siemens/cm. In 90% of area, EC is within 2000 µ siemens/cm, in 5% area it is in between 2000-3000 µ siemens/cm and in 5% area is >3000 µ siemens/cm. Post-monsoon (2019): The average EC during post monsoon is 1605 µ siemens/cm. In 87% of area EC is within 2000 µ siemens/cm, in 8% area is 2000-3000 µ siemens/cm and in 5% area is >3000 µ siemens/cm.**
23.2	**Fluoride mg/l**	**: Pre-monsoon (2019): Fluoride concentration varies from 0.14-2.71 mg/L and 93% of samples are within permissible limits of BIS and rest is beyond permissible limit of 1.5 mg/L. Post-monsoon (2019): Fluoride concentration varies from 0.06-2.57 mg/L and 93% of samples are within permissible limits of BIS and rest is beyond permissible limit of 1.5 mg/L**
23.3	**Nitrate mg/l**	**: Pre-monsoon (2019): Nitrate concentration varies from 0.05-162.00 mg/L in 19% of samples is beyond permissible limits of 45 mg/L. Post-monsoon (2019): Nitrate concentration varies from 0.11–24.19 mg/L in 0.01% of samples (very negligible) is beyond permissible limits of 45 mg/L.**

24	Conceptualization		Weathered zone	Fractured zone
	Alluvium-Weathered/ Fractured/ Massive Eastern Ghats type of rocks and followed by basement of Granite Gneiss i.e Weathered/ Fractured/ Massive types.		Aquifer-I (~31 m). As per well data analysis weathering depth observed: 0 to >=40 m bgl.	Aquifer-II (~24-200m). As per well data analysis Fractured depth observed: 24 to 200 m bgl.
25	Aquifer Characterization	:	Thickness of weathered zone is in the range of 20-40m occurs in most part of Area (81%). Shallow weathered zone i.e <10 m occurs in 1% of the area, 10-20 m in 9% area and deep weathered zone contours (>40m to max. 54 m depth zone) occurs in rest of the area i.e 9% area.	The occurrence of fractures is in between the depth of ~24 to 200 m bgl and is discrete. Majority of fractures occur at 50-100m depth (59%), followed by 100-150 m depth (23%), >150m in 7% and fractures occur at <50 m in 11% area.
26	Specific Yield	:	< 1.5% to 3%	-
27	Storativity	:	-	3.2×10^{-6} to 1.92×10^{-2}
28	Ground water Resources (2022) MCM	:	Visakhapatnam District (MCM)	GVMC and Urban Area
28.1	Net Dynamic groundwater availability	:	135.40	61.78
28.2	Gross GW Draft	:	59.11	29.47
28.3	Provision for Domestic & Industrial (2025)	:	41.84	32.36
28.4	Average Stage of Ground water development (%)		49%	48%
28.5	Net GW Availability for future irrigation	:	41.84	-
28.6	Categorization of mandals	:	All mandals categorized as Safe	
29	Major Ground Water Issues Identified	:	Low yield (<1 lps) occurs in ~76% of area in the district. Deep water levels in the range of 10-20 m bgl occupy about 4% of the area, Water-logging is	

observed in and around Bhimunipatnam, Visakhapatnam urban village coastal areas during post-monsoon seasons.

High concentration of Flouride >1.5 mg/L during pre-monsoon season in Gajuwaka, Bhemili, Visakhapatnam Rural mandals.

High nitrate (> 45 mg/L) in 3 mandals i.e Visakhapatnam Urban, Rural and Bhimilipatnam mandals during pre-monsoon in range of 47 mg/L to 162 mg/L. Higher concentration of Nitrate is mainly attributed to unscientific Sewage disposal of untreated effluents in urban and rural areas, High use of fertilizers in rural areas.

High concentration of EC (>3000 micro-seimens/cm) in 5% area observed in pre-monsoon

30. Management Strategies : **Repair, Renovation and Restoration of existing Tanks:**

It is recommended for desiltation of all existing artificial recharge structures and water conservation structures for effective utilization of existing structures and storage created through these structures. In addition, there is a feasible area for artificial recharge in 314 sq.km, in which there is a scope for construction of 354 artificial recharge structures (110 CDs and 244 PTs) can be proposed, which can be taken up as per requirement in the district. With this 12 MCM of ground water can be recharged.

In Visakhapatnam district, GVMC & VRDMA urban/town and Industrial area only condisered for rain water harvesting mechanism, the total area is available 144sq.km. There is 98 mcm water savings can be done, if considered a 100% area for recharge or harvesting mechanism. 74mcm, 49mcm, 25mcm water saving may be achieved if the vicinity considers at 75%, 50% and 25% respectively.

<u>Water Conservation Measures (WCM) (Farm Ponds)</u>: The farm ponds are the ideal water conservation structures, which are constructed in the low-lying areas of the farm. The Govt. of Andhra Pradesh had constructed around 1425 no. of farm ponds, other structures 1136 no. found in this district. It is recommended for desilting of existing farm ponds. Further, it is recommended to construct 1580 farm ponds (20 in each village in 79 villages).

31.	**Expected Results and Out come**	**: With all interventions, the likely benefit would be the net recharge/ conservation of 213 MCM (12 mcm from Artificial Recharge structures @ 20% Uncommited runoff and 201 mcm by rain water harvesting mechanism) of ground water in the district.**

EXECUTIVE SUMMARY

Visakhapatnam district covering an area of 1049 km^2 and administratively, governed by 11 revenue divisions, 11 mandals with 122 in-habitated villages. The population of the district is ~19.59 lakhs (2021 census) with average density of 1869 persons/ sq.km.

The district receives an average annual normal rainfall of 1117.7 mm of which SW monsoon contributes 79% and north-east monsoon contributes 21%. The area is underlain by Khondalites, Granitic Granites, Chanrnockites, Granulite, migmatie and Alluvium. Geomorphologically the district have Structural hills, Pediplains, Pediment, Dissected hills, Denudation hills, alluvial plains and Coastal alluvial plains. The forest occupies ~12% i.e 127 sq.km of the total geographical area, remaining is considered as plain. The gross cropped area during 2019 – 2020 during khariff and rabi seasons is 12941 ha. Main crops grown are Paddy during khariff and rabi seasons followed by Sugarcane and other crops are maize, blackgram, horsegram, ragi, greengram, bajra, jowar, chillies, redgram, papaya, sapota, oil seeds and vegetables etc.

The total area irrigated in the district is 7700 ha, out of which the area irrigated by Surface water is 2868 ha, Ground water is 4777 ha and the area irrigated by other sources are 55 ha. No MI Tanks in the district for irrigation. The major irrigation projects completed in Visakhapatnam district are The ongoing/proposed Indirasagar Polavaram Project (Left Main Canal) and Uttranadhra Sujala Sravanthi Irrigation projects have a proposed for irrigation. Jaggammagedda and Sri Dronam Raju Satyanarayana Mehadrigedda Reservoir projects are being used for irrigation and drinking water supply projects respectively.

The Archaean group of rocks includes Khondalites and Charnockites of Eastern Ghat super group and Granitic gneisses of Migmatite group. The recent alluvium is prevalent along the rivers and coastal areas. Khondalites are occupied 70% of total area and rest is charnockite, calc granulites, quartzites, migmatites, clay and sand.

CGWB constructed 09 numbers of exploratory wells/ observation wells/ piezometers, whereas State Ground Water & Water Audit department constructed 09 wells in Visakhapatnam district. 11 Geophysical studies have been carried out in the district by CGWB. These data from 18 wells and 11 VES have been used are used in preparation of aquifer maps and management plans.

The Water levels are being monitored through 33 number of monitoring wells by both CGWB (12) and GWD & WA (21). During Pre-monsoon season the water levels vary between 1.04 to 22.08 m bgl with an average water level of 11.56 m bgl. In majority of area, the water levels in the depth range of 5-10 m (92% area), followed by 10-20 m bgl and Shallow water levels <5 m bgl occupy about 5% of the area falling in parts of Costal parts of Visakhapatnam. Deep water levels here between >20 m.bgl occupy 3% of the area. Deep water levels here between 10-20 m.bgl occupy 5% of the area in small parts of Padmanabham, Bhemunipatnam and Visakhapatnam Urban mandals.

During post-monsoon period, majority of the water levels during this season are in the range of <5 m (53% area), followed by 5-10 m bgl (46%) and 10-20 m bgl (1%). Deep water levels in the range of <20 m bgl occupy about 1% of the area falling mostly in parts of Padmanabham mandal. Shallow water level <5 m.bgl occupy 53% of the area in Pedagantyada, Gajuwada and small parts of Visakhapatnam urban & Rural areas, Pendurthi, Anandapuram, Padmanabham and Bhemunipatnam mandals. The water-table elevation ranges from 4.52 to 171 during pre monsoon and 5.90 to 176 meter above mean sea level (m amsl) during post monsoon seasons. The general ground flow is towards towards NW to SE in the southern parts, south east part of the district (98% of area).

Ground Water quality is being monitored by CGWB from 26 monitoring stations and GWD & WA from 16 monitoring stations. The EC is within 2000 µ Siemens/cm in 87% to 90% of area in both pre and post monsoon periods. In 93% of samples shows Fluoride within permissible limits during pre and post monsoon periods. In 19% of samples shows Nitrate concentration beyond permissible limits during pre-monsoon period and no samples during post-monsoon.

The aquifers of Visakhapatnam district can be conceptualized in to Aquifer-1, weathered and contiguous semi weathered and fractured zone (~24-31m) and Aquifer-2, the discrete fracture zone with in the depth of 24-200m. However, the thickness of weathered zone is varying and is in the range of 20-40 m in most part of area (81%). The fracture zones are more predominant in depth range of 50-100 m (59%). Specific Yield for weathered zones ranges from <1.5% to 3%. Storativity ranges from 3.2 x 10^{-6} to 1.92 x 10^{-2}. Transmissivity ranges observed in the weathered zones and fractured zones of hard formation ranges from ~1 to ~334 m^2/day.

The annual extractable ground water resource (GWRA-2022) is 135.40 MCM, the gross ground water draft for all uses is 59.11 MCM, provision for drinking and industrial use for the year 2025 is 41.84 MCM and net available balance for future irrigation use is 41.84 MCM. The stage of ground water development varies from 49% i.e Safe category.

The district has no such major issue in terms of ground water, there are few localized issues i.e., low yield (<1 lps) occurs in ~76 % of area, deep water levels in the range of 10-20 m bgl occupy about 4% of the area, water-logging is observed in and around Bhimunipatnam, Visakhapatnam urban village coastal areas with areas of <10 sq.km during post-monsoon seasons. High concentration of Flouride >1.5 mg/L during pre-monsoon season in Gajuwaka, Bhemili, Visakhapatnam Rural mandals. Higher concentration of fluoride in ground water is attributed due to source rock i.e Granite Gneiss and Khondalite, rock water interaction where acid-soluble fluoride bearing minerals (fluorite, fluoro-apatite) gets dissolved under alkaline conditions. Higher residence time of ground water in deeper aquifer may also cause. High nitrate (> 45 mg/L) in 3 mandals i.e Visakhapatnam Urban, Rural and Bhimilipatnam mandals during pre-monsoon in range of 47 mg/L to 162 mg/L. Higher concentration of Nitrate is mainly attributed to unscientific Sewage disposal of untreated effluents in urban and rural areas, high use of fertilizers in rural areas. High concentration of EC (>3000 micro-seimens/cm) in 5% area is observed in pre-monsoon.

The management strategies mainly include both supply side and demand side measures include repair, renovation and restoration of existing tanks, desiltation of all existing, artificial recharge structures. 124 Check dams and 06 Percolation Tanks and water conservation structures for effective utilization of existing structures and storage created through these structures. Construction of 281 artificial recharge structures (67 CDS and 214 PTS) in all mandals, roof top rainwater harvesting structures for all buildings with more than 200 sq.m area, desilting of all existing ponds. In the district 5 MCM of recharge potential volume is varialble in the aquifers. This can be utilized for implementing artificial recharge structures. Govt. of AP under IWMP and MNREGS constructed a total of 124 Check dams and 06 percolation tanks in the district. It is recommended for desiltation of all existing artificial recharge structures and water conservation structures for effective utilization of existing structures and storage created through these structures. In addition, there is a feasible area for artificial recharge in 314 sq.km, in which there is a scope for construction of 354 artificial recharge structures (110 CDs and 244 PTs) can be proposed, which can be taken up as per requirement in the districts. With this 12 MCM of ground water can be recharged. Total Urban and Industrial area is 232 sq.km to be had used for rain water harvesting in Visakhapatnam district. There is 201 mcm water savings can be done, If considered a 100% area for recharge or harvesting mechanism. 130mcm, 100mcm, 50mcm water saving may be achieved if the vicinity considers at 75%, 50% and 25% respectively. In Visakhapatnam district, GVMC & VRDMA urban/town and Industrial area only considered for rain water harvesting mechanism, the total area is available 144sq.km. There is 98 mcm water savings can be done, if considered a 100% area for recharge or harvesting mechanism. 74mcm, 49mcm, 25mcm water saving may be achieved if the vicinity considers at 75%, 50% and 25% respectively. With the above interventions, the likely benefit would be the net recharge/ conservation of 213 MCM (12 mcm from Artificial Recharge structures@20% Uncommitted runoff and 201 mcm by rain water harvesting mechanism) of ground water in the district.

NUMBER OF DATA POINTS USED FOR PREPARATION OF VARIOUS MAPS-

VISAKHAPATNAM DISTRICT, ANDHRA PRADESH STATE

S.No	Data	Aquifer	Total Data Points	Source	
				CGWB	SGWD
1	Panel Diagram (3-D)	Combine	31	Expl: 11	09
				VES: 11	-
2	Hydrogeological Sections	3 no	31	Expl: 11	09
				VES: 11	-
3	Fence/ panel Diagrams	1 no	31	Expl: 11	09
				VES: 11	-
4	Depth of weathering	1 no	31	Expl: 11	09
				VES: 11	-
5	Depth of fracturing	1 no	31	Expl: 11	09
				VES: 11	-
6	Groundwater Potential zones	Weathered zone	31	Expl: 11	09
				VES: 11	-
		Fractured zone	31	Expl: 11	09
				VES: 11	-
7	Transmissivity (m^2/day)	Unconfined to Confined	11	Expl: 11	-
8	Discharge (lps)	Unconfined to Confined	11	Expl: 11	-
9	Depth to Water Level Maps (2019)	Combine	66	12	21
10	Water Level Fluctuation	Combine	66	12	21
11	Long term water level trends	Combine	66	12	21
12	Water quality	Combine	71		-
	Pre-monsoon 2019		Pre: 42	16	26
	Post-monsoon 2019		Post: 29	0	29

1. INTRODUCTION

Aquifer mapping is a multidisciplinary and a holistic scientific approach wherein a combination of geologic, geophysical, hydrologic and chemical analysis is applied to characterize the quantity, quality and sustainability of ground water in aquifers. In recent past, there has been a paradigm shift from "**groundwater development**" to "**groundwater management**". As large parts of India particularly hard rocks have become water stressed due to rapid growth in demand for water due to population growth, irrigation, urbanization and changing life style. Therefore, in order to have an accurate and comprehensive micro-level picture of groundwater in India, aquifer mapping in different hydrogeological settings at the appropriate scale is devised and implemented, to enable robust groundwater management plans. This will help in achieving drinking water security, improved irrigation facility and sustainability in water resources development in large parts of rural and many parts of urban India. The aquifer mapping program is important for planning suitable adaptation strategies to meet climate change also. Thus, the crux of National Aquifer Mapping (NAQUIM) is not merely mapping, but reaching the goal-that of ground water management through community participation.

Hard rocks (Granites/Gneisses) lack primary porosity, and groundwater occurrence is limited to secondary porosity developed by weathering and fracturing. Weathered zone is the potential recharge zone for deeper fractures and excessive withdrawal from this zone leads to drying up in places and reducing the sustainability of structures. Besides these quantitative aspects, groundwater quality also represents a major challenge which is threatened by both geogenic and anthropogenic pollution. In some places, the aquifers have high level of geogenic contaminants, such as fluoride, rendering them unsuitable for drinking purposes. High utilization of fertilizers for agricultural productions and improper development of sewage system in rural/urban areas lead to point source pollution viz., nitrate and chloride.

1.1 Objectives: In view of the above challenges, an integrated hydrogeological study was taken up to develop a reliable and comprehensive

aquifer map and to suggest suitable groundwater management plan on 1: 50,000 scale at mandal/block level information.

1.2 Scope of study: The main scope of study is summarized below.

1. Compilation of existing data (exploration, geophysical, groundwater level and groundwater quality with geo-referencing information and identification of principal aquifer units.
2. Periodic long-term monitoring of ground water regime (for water levels and water quality) for creation of time series data base and ground water resource estimation.
3. Quantification of groundwater availability and assessing its quality.
4. To delineate aquifer in 3-D along with their characterization on 1:50,000 scale.
5. Capacity building in all aspects of ground water development and management through information, education and communication (IEC) activities, information dissemination, education, awareness and training.
6. Enhancement of coordination with concerned central/state govt. organizations and academic/research institutions for sustainable ground water management.

1.3 Area Details: Visakhapatnam district is one of the north coastal districts of Andhra Pradesh. The district is lying between the Eastern Ghats and Bay of Bengal. The district is bounded on the south & south east by the Bay of Bengal, on the north, north east & north west by Vizianagaram district, on the west & south west by Anakapalli district. Howrah - Chennai broad gauge railway line and NH-5 are passing through the district almost parallel to the coastline. The Visakhapatnam district geographical area is 1049 km^2, lies between north latitude 17°50´52"-18°23´36" and east longitude 81°12´19"-83°37´7". It is falling in part of the lower Godavari subbasin and Nagavali river subbasins. Out of total area is urbanized area and hilly area also exists i.e 153 sq.km (i.e 14%). Administratively the district is governed by 11 revenue mandals with 122 villages with a population of 19.595 lakhs (2021 census). The District has Density of population of 1869 per Sq.Km. The district has aerodrome and natural harbor at Visakhapatnam. The setup

of administrative mandal boundaries and base map with road connection is given in **Fig.1.1**.

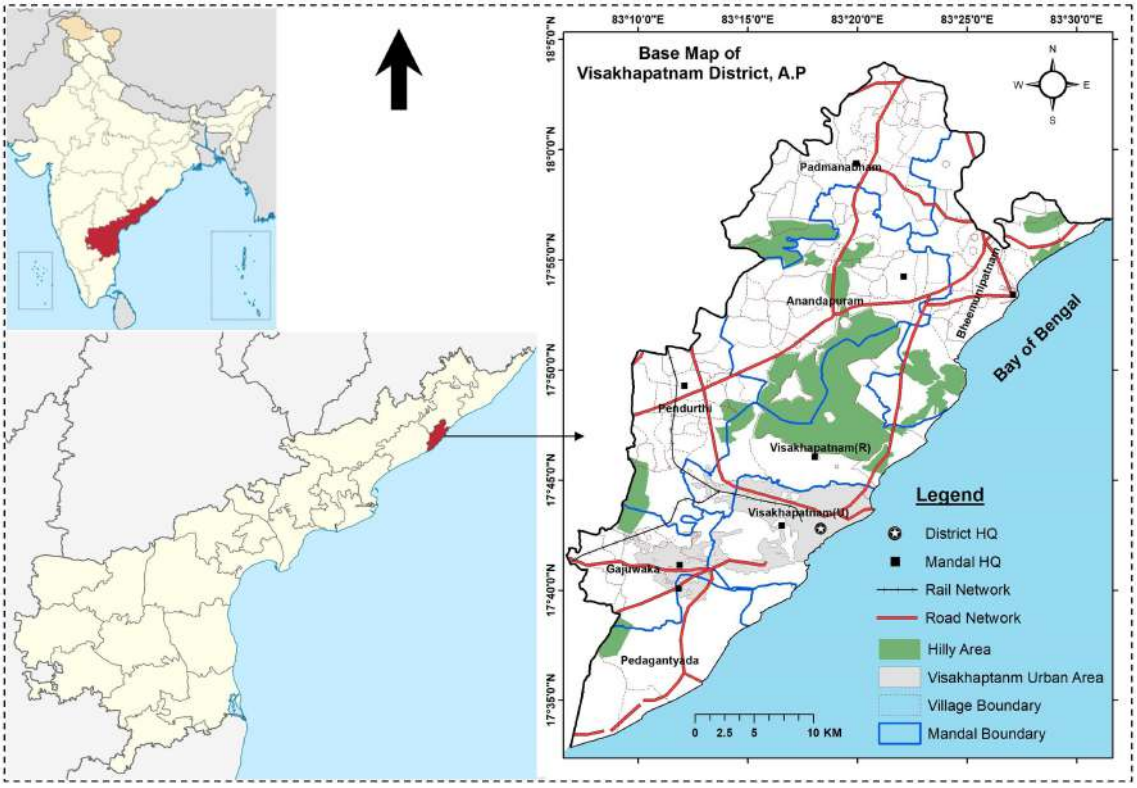


Fig.1.1: Base map of Visakhapatnam district.

1.4 Climate and Rainfall: The district experiences tropical sub-humid type of climate, Near Coast the air is moist and relaxing, but gets warmer towards the interior and cools down in the hilly areas on account of elevation and vegetation. April to June month is warmest. The Temperature (at Visakhapatnam Airport) gets down with the onset of South West Monsoon and tumbles to a mean minimum of 16.8°C by January after which there is reversal trend till the temperature reaches mean maximum of 36° C by the end of June during 2019-20.

The district has receives good seasonal rainfall. The southwest monsoon sets in the second week of June and lasts till September end. October and November receive rainfall from northeast monsoon. Winter season with cool and fine weather prevails from December to February followed by summer season upto early June. The district receives average normal rainfall of 1117.7 mm (2019-20), of which south-west monsoon accounts for 883 mm of

the normal while North-East monsoon contributes 225 mm of the normal rainfall and the rest is shared by summer showers and winter rains. Total annual rainfall received is 1076.9mm during the year 2019-20 which is 3.7% below the normal rainfall. The mandal wise normal rainfall data is used to prepare the isohyetal contour map for Viskahapatnam district (source: IMD data) and shown in **Fig. 1.2**. The rainfall distribution is noted in the Visakhapatnam district is highest rainfall receives in Padmanabham mandal and lowest rainfall receives in Visakhapatnam rural mandal.

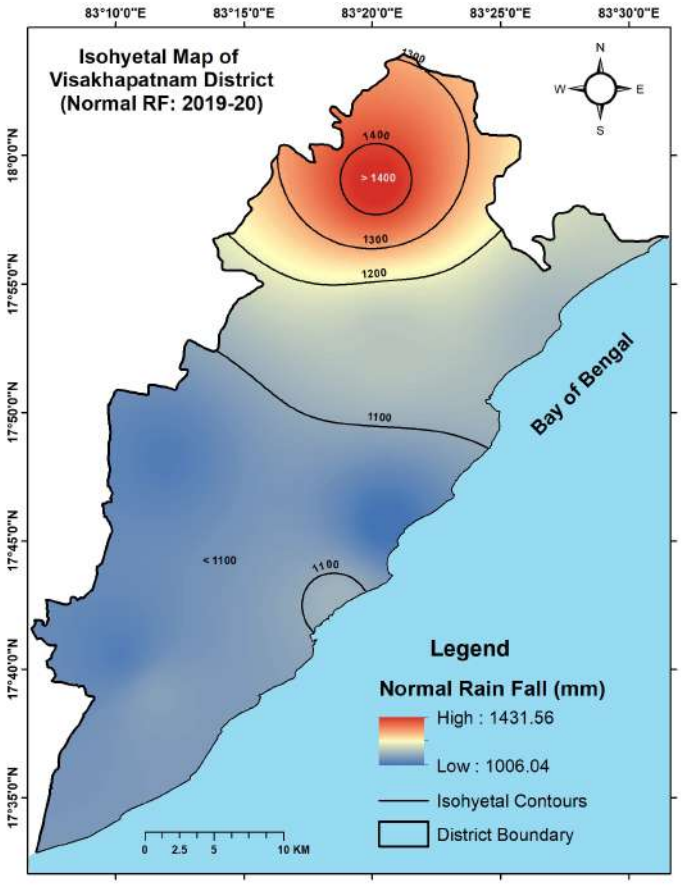


Fig.1.2: Isohyetal map of Visakhapatnam district.

1.5 Geomorphological setup: Geomorphologically, the district can be divided into three types of landscapes, viz. Structural/ denudational hills with valleys, fluvial landforms and alluvial coastal plains. The majority of the district is mainly occupied by the structural/danudational hills with valleys, pediplains, pediments, inselberg, residual hills which are part of the Eastern Ghats. The hill ranges trends parallel to coast, by virtue of their topography; these hilly terrains largely form recharge run off areas. The hard rock terrain exposed in the Megha-Kommadi gadda-Gosthani river basins constitutes the

vast denudational pediplains, exhibiting the gradational phase of denudational-residual-inselberg-pediment areas. Pediment is well developed around the khondalite outcrops, whereas in the charnockite outcrops, it is not extensively developed. The pediment area accelerates surface run off with moderate to less infiltration along the jointed and weathered zone. The Megha, Kommadi gadda and Gosthani river and their tributaries have contributed to the formation of buried channels, channel fills and which have have high infiltration and high permeability which underlain by weathered formations. These areas form good to moderate aquifers depending on their thickness. The district has a coastline of about 70 km. The coastline is broken by a number of bold headlands, which protect the land against constant erosion by the sea. The geomorphology setup of Visakhapatnam district is prepared and shown in **Fig.1.3**.

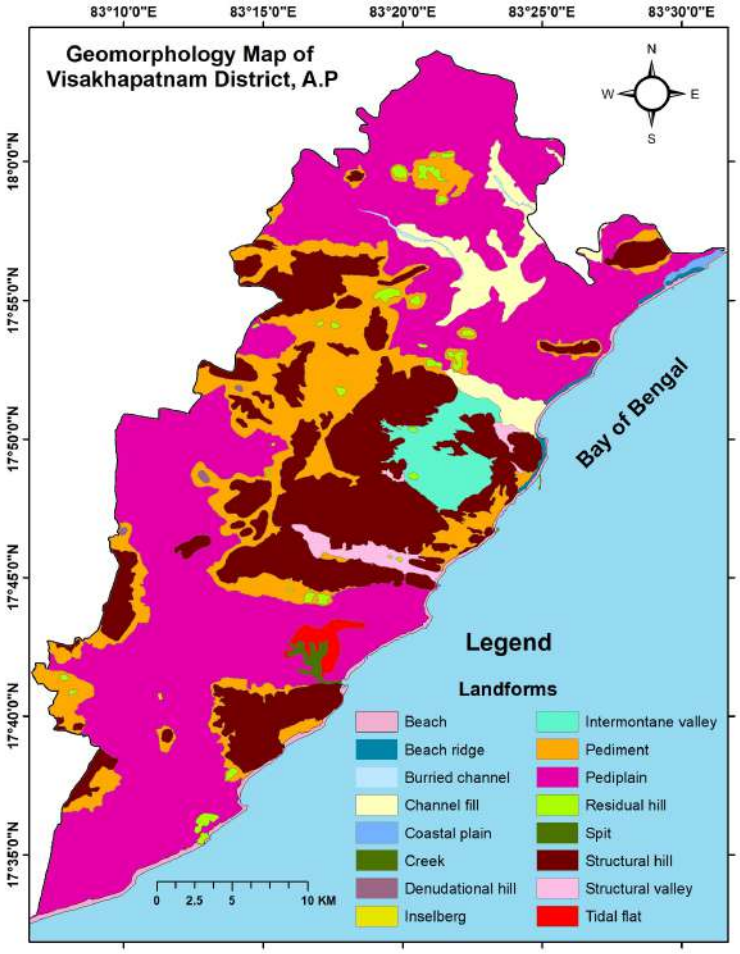


Fig.1.3: Geomorphology of Visakhapatnam district.

1.6 Drainage Pattern & Watershed Boundary: Major part of the district falls under Godavari and Vamsadhara major basins and sub-basins are lower Godavari and Nagavali. The district is divided into four local sub drainage basins namely Anakapalli, Narvagadda, Madhuruvada & Gosthani and watershed drainage basins of rivers with their tributaries are clearly demarcated. No major river/perinial rivers are flowing across the district. The overview of drainage network, water bodies, river tributaries of Visakhapatnam district are shown in Fig.1.4. The drainage density is less in these drainage sub basins because of the high infiltration and permeable characteristics of the sediments. The common trend of structural lineaments followed along trending in NE-SW, NW-SE and ENE-WSW directions in this district (**Fig.-1.4)**.

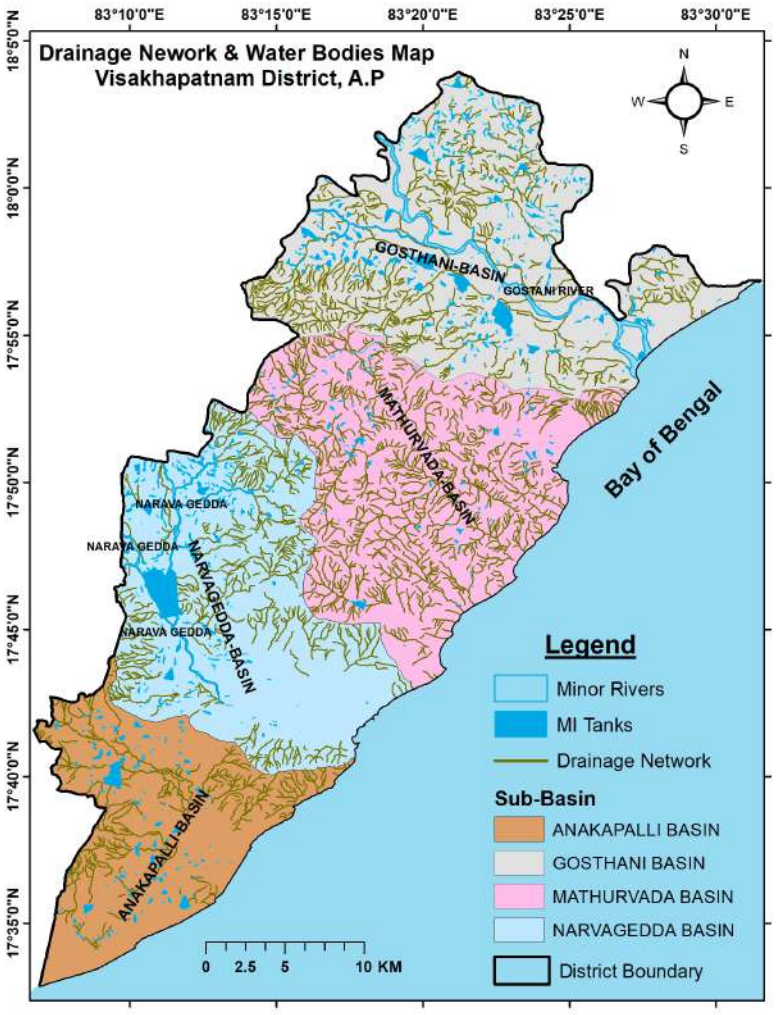


Fig- 1.4: Drainage network, watershed boundary, water bodies of Visakhapatnam district

1.7 Land use and cropping pattern: The hilly/forest cover occupies 12% i.e 126.75 sq.km of of the total geographical area and remaining area is considered as plain. The land cover and land use pattern of Visakhapatnam district is shown in Table-1.1 and Fig.1.7.

S.No.	Category	Area (ha)	%
1	Total geographical area	104862	100
2	Forests	12675	12
3	Barren & uncultivable land	18381	18
4	Land put to non-agricultural uses	39763	38
5	Cultivable waste	2242	2
6	Permanent pastures and other grazing lands	539	1
7	Land under miscellaneous tree crops & groves not included in net area sown	3361	3
8	Current fallows	4040	4
9	Other fallow lands	10920	10
10	Net Area Sown	12941	12

Table-1.1: Land Use pattern of Visakhapatnam District

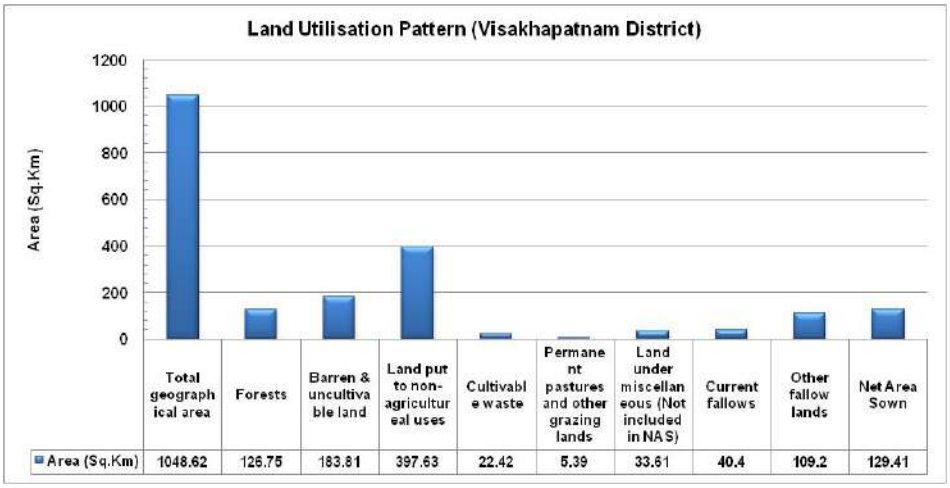


Fig.1.7: Land use and land cover of Visakhapatnam district.

Main crops grown are Paddy during khariff and rabi seasons followed by Sugarcane and other crops are maize, blackgram, horsegram, ragi, greengram, bajra, jowar, chillies, redgram, papaya, sapota, oil seeds and vegetables etc.

1.8 Soils: The soils in the district are red loams, sandy loams, sandy soils, silty soils and clayey soils with rock outcrops. Clayey soils with are pre-dominant and occupy about 70% in the district. Gravelly, Sandy loamy soils are largely confined to the coastal areas and to certain stretches in the interior mandals of Anandapuram, Gajuvaka, Bhumunipatnam and Pedagantyada. Red Loamy soils are poor textured and easily drained. Sandy loamy soils largely confined to the coastal areas (Visakhapatnam, Pedagantyada, Gajuwaka and Bheemunipatnam Mandals). 45% of the soils in the district are low in organic content and 55% in Phosphorous content. The distribution of soil types in Visakhapatnam district is shown in **Fig.1.8**.

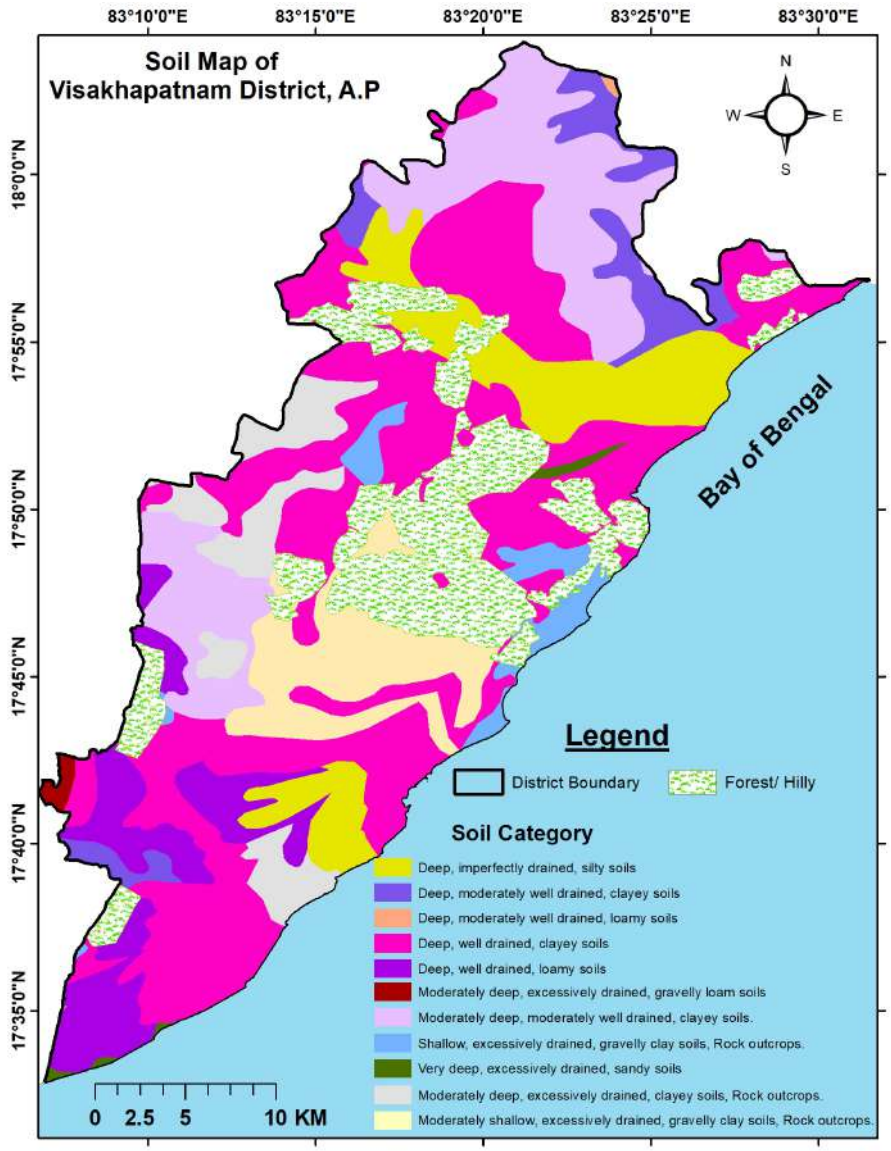


Fig.1.8: Soil map of Visakhapatnam district.

1.8 Soil Infiltration Capacity: Soil infiltration tests were conducted in five different soil types in different locations of Visakhapatnam district to know the infiltration capacity of soils by using double ring infiltrometer at various locations. Depending on the soil types, the basic infiltration rate varies from 1.5 to 3.3 cm per hour, low infiltration rate generally observed in clay and silty type soils and high infiltration rate observed in sandy type of soils. Apart from type of soil, the soil compactness, porosity, permeability and vegetation play a dominant role in the infiltration rate.

Average normal rainfall for monsoon season in Visakhapatnam rural/ urban is ~620 mm for 31 to 33 rainy days. During monsoon, the rainfall intensity is calculated per hour ranges from 0.6 to 0.8 mm/hr, but the regional soils of Visakhapatnam urban and rural area's soil infiltration capacity is measured averagely ~2.5 cm/hour. It indicates that soils infiltration capacity is more than rainfall intensity in this area. The summary of soil infiltration and details of individual soil infiltration test site wise results were given in **Table 1.2** and soil infiltration curve were given in **Fig. 2.9**.

Table-1.1: Summary of Soil Infiltration rate in parts of Visakhapatnam district.

S. No	Village	Mandal	Co-ordinates	Infiltration Rate (cm/hr.)	Soil Type
1	Rishikonda	Visakhapatnam Urban	83º 23' 06'', 17º 47' 39''	3.0	Silty Clay with Sand mixed (Brown colour)
2	Bhemunipatnam	Bhemunipatnam	83º 26' 30'' 17º 54' 14''	1.5	Silty Clay with fine Sand mixed (Brown colour)
3	Adavivaram	Simhachalam	83º 15' 16'' 17º 47' 28''	3.3	Silty Clay with Sand mixed (Brown colour)
4	Gurrampalem	Pendurthi	83º 13' 13'' 17º 50' 04''	2.7	Silty Clay with Sand mixed (Brown colour)
5	Anandapuram	Anandapuram	83º 22' 32'' 17º 53' 21''	1.8	Silty Clay with fine Sand mixed (Brown colour)

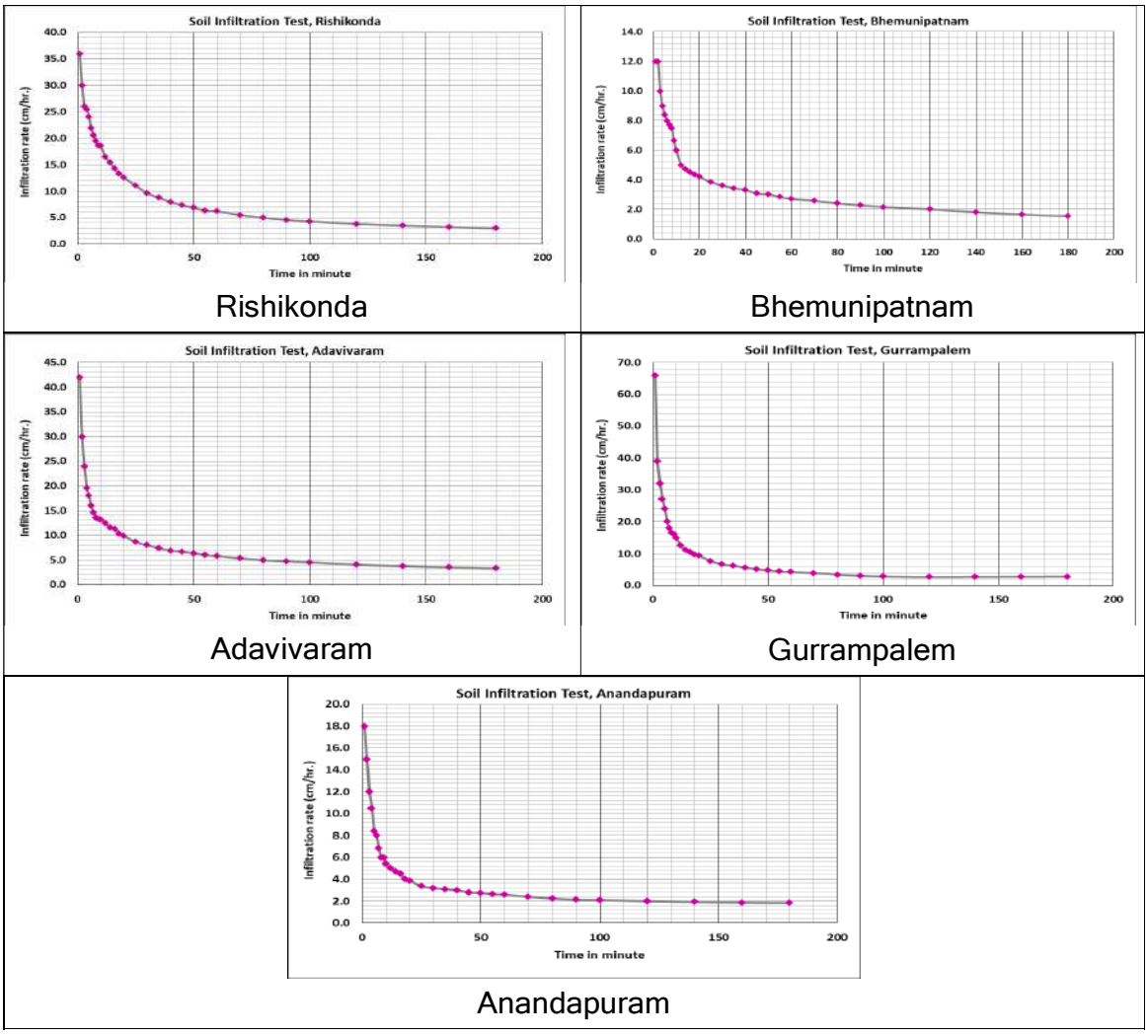
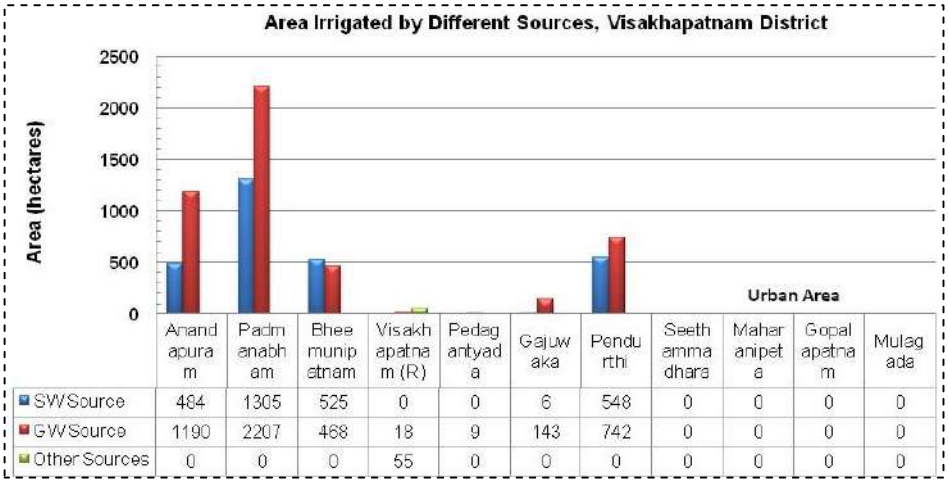


Fig - 1.9: Soil Infiltration curves in different soil types in Visakhapatnam district.

1.9 Irrigation: Agriculture is in the district is meager and only 7% area is gross irrigated area (7700 ha) rest is urbanized and others. The district irrigation covered by major to medium irrigation projects. Out of total gross irrigated area of 7700 ha, the area irrigated by surface water is 2868 ha (37%), the area Irrigated by ground water is 4777 ha (62%) and the area irrigated by other sources is 55 ha (1%). Total existing number of bore wells and dug wells in the district are 2,125 and 3075 numbers respectively. The average depth of bore wells is around 70 m bgl and the average ground water abstraction is for 3-4 hours per day. No Minor Irrigation Tanks avaible in the district for irrigation. The area irrigated by different sources is provided in Fig-1.10 and available project sources also given in Fig-1.11.



	Anandapuram	Padmanabham	Bheemunipatnam	Visakhapatnam (R)	Pedagantyada	Gajuwaka	Pendurthi	Seethammadhara	Maharanipeta	Gopalapatnam	Mulagada
SW Source	484	1305	525	0	0	6	548	0	0	0	0
GW Source	1190	2207	468	18	9	143	742	0	0	0	0
Other Sources	0	0	0	55	0	0	0	0	0	0	0

Fig - 1.10 Different sources of Irrigation in Visakhapatnam district

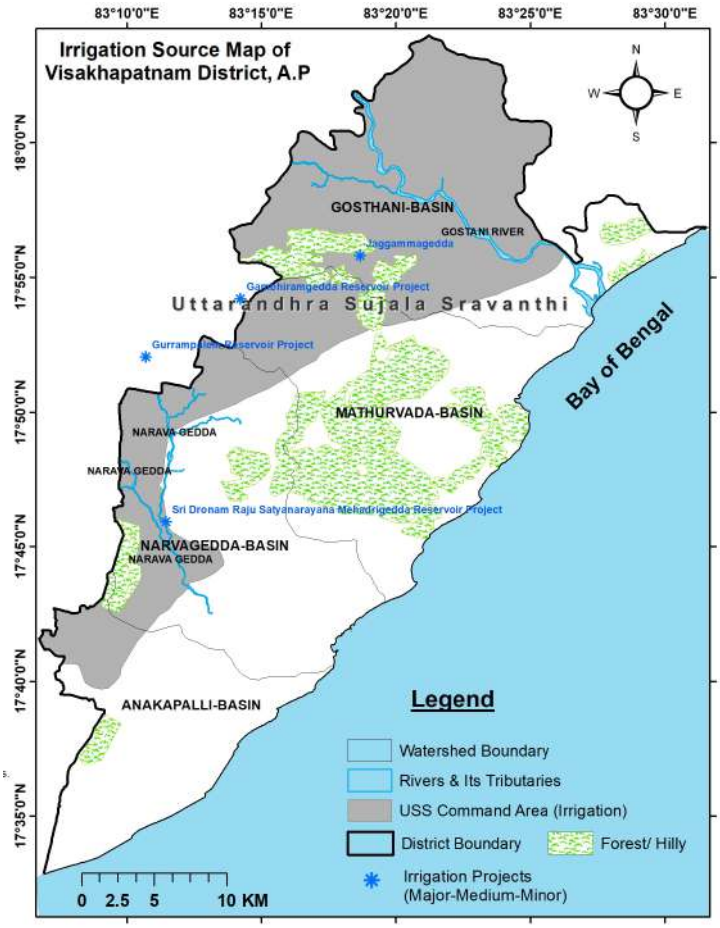


Fig.1.11: Map showing Irrigation Profile of Visakhapatnam District

Future Irrigation Scenario: The ongoing/proposed Indirasagar Polavaram Project (Left Main Canal) and Uttranadhra Sujala Sravanthi Irrigation projects have a proposed for irrigation. Jaggammagedda and Sri Dronam

Raju Satyanarayana Mehadrigedda Reservoir projects are being used for irrigation and drinking water supply projects respectively (Fig. 1.11).

1.10 Geology: The district is underlain by geological formations ranging from oldest Archaeans to Recent Alluvium. The Archaean group of rocks includes Khondalites and Charnockites of Eastern Ghat super group and Granitic gneisses of Migmatite group. The recent alluvium is prevalent along the rivers and coastal areas. The stratigraphy of Eastern Ghats Mobile Belt, lithology and basement details are shown in below Table 1.3. The geological map (rock types) of Visakhapatnam district is also show in **Fig. 1.12**. Khondalites are occupied 70% of total area and rest is Charnockite, Calc Granulites, Quartzites, Migmatites, Alluvium (clay and sand).

Table 1.3 Stratigraphy of Eastern Ghats Mobile Belt

Age	Group/ Orogeny	Lithology
950-1100 ma	Eastern Ghat Mobile Belt	Khondalite, Charnockites
	Intrusives	
2600-2800 ma	Charnockites and Granite Gneisses (Basement)	Granite / Granite Gneisses

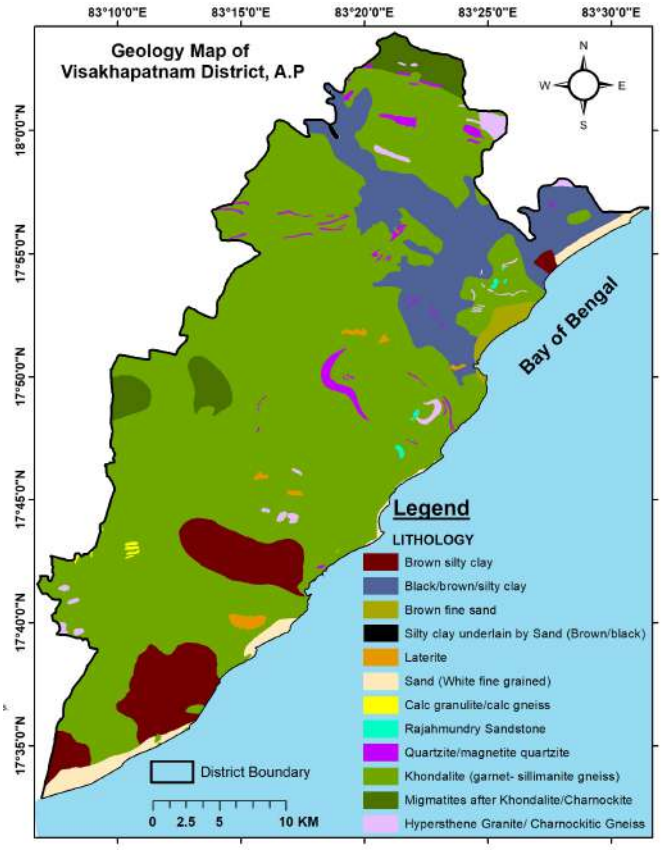


Fig.1.12: Geology of Visakhapatnam district.

2. DATA COLLECTION AND GENERATION

Collection and compilation of data for aquifer mapping studies is carried out in conformity with Expenditure Finance Committee (EFC) document of XII plan of CGWB encompassing various data generation activities **(Table-2.1)**.

Table-2.1: Brief activities showing data compilation and generations.

S.No.	Activity	Sub-activity	Task
1	Compilation of existing data/ Identification of Principal Aquifer Units and Data Gap	Compilation of Existing data on groundwater	Preparation of base map and various thematic layers, compilation of information on Hydrology, Geology, Geophysics, Hydrogeology, Geochemical etc. Creation of data base of Exploration Wells, delineation of Principal aquifers (vertical and lateral) and compilation of Aquifer wise water level and draft data etc.
		Identification of Data Gap and Analysis	Data gap in thematic layers, sub-surface information and aquifer parameters, information on hydrology, geology, geophysics, hydrogeology, geochemical, in aquifer delineation (vertical and lateral) and gap in aquifer wise water level and draft data etc.
2.	Generation of Data	Generation of geological layers (1:50,000)	Preparation of sub-surface geology, geomorphologic analysis, analysis of land use pattern.
		Surface and sub-surface geo-electrical and gravity data generation	Vertical Electrical Sounding (VES), bore-hole logging, 2-D imaging etc.
		Hydrological Parameters on groundwater recharge	Soil infiltration studies, rainfall data analysis, canal flow and recharge structures.
		Preparation of Hydrogeological map (1:50, 000 scale)	Water level monitoring, exploratory drilling, pumping tests, preparation of sub-surface hydrogeological sections.
		Generation of additional water quality parameters	Analysis of groundwater for general parameters including fluoride.
3.	Aquifer Map Preparation at Mandal/Block	Analysis of data and preparation of GIS layers and preparation	Integration of Hydrogeological, Geophysical, Geological and Hydro-chemical data.

	level (1:50,000 scale)	of aquifer maps	
4.	Aquifer Management Plan	Preparation of aquifer management plan	Information on aquifer through training to administrators, NGO's, progressive farmers and stakeholders etc. and putting in public domain.

2.1 Hydrogeology:

Hydrogeology is concerned primarily with mode of occurrence, distribution, movement and chemistry of ground water occurring in the subsurface in relation to the geological environment. The occurrence and movement of water in the subsurface is broadly governed by geological frameworks i.e., nature of rock formations including their porosity (primary and secondary) and permeability. The aquifers in the Visakhapatnam district can be broadly classified into hard formations (khondalites, charnockites, lyptonites, granitic gneisses etc.) forms the principal aquifer system in the district and soft formations (alluvium and sand stone), which forms a negligible part of the district. Ground water occurs under unconfined to semi-confined conditions in the hard formations.

Various hydrogeological investigations were carried out by Central Ground Water Board (CGWB) and State Ground Water Department (SGWD) in parts of Visakhapatnam district. As a part of ground water exploration studies, CGWB had constructed 09 numbers of exploratory wells/ observation wells/ piezometers, 11 numbers of VES surveys were conducted by CGWB and 09 wells were constructed by SGWD in Visakhapatnam district. These data from 29 wells are used to prepare aquifer maps in parts of Visakhapatnam district. All 09 numbers of wells of SGWD are below depth of 85 m bgl. The geophysical VES sounding data also used for drawing of aquifer delineation. The locations of exploratory wells of CGWB, wells of SGWD and VES points are shown in **Fig.2.1**.

The bore wells drilled in the hard formations, generally tap the weathered zone considered as potential zones and whereas fractured, fissured zones also considered as secondary potential zones for tapping of aquifers for irrigation and domestic utility. The Transmissivity ranges observed

in the weathered zones and fractured zones of hard formation ranges from ~1 to 334 m^2/day. Sandstones are exposed in the small isolated places around Nakkavanipalem and Elamanchili which are potential aquifers. Generally, in these formations, ground water occurs in both unconfined and confined conditions. The maximum depth of dug wells/ filter points in alluvium formations ranges from depth of ~4 to ~20 m bgl. Hydrogeological map of Visakhapatnam district is prepared and shown in **Fig. 2.2**.

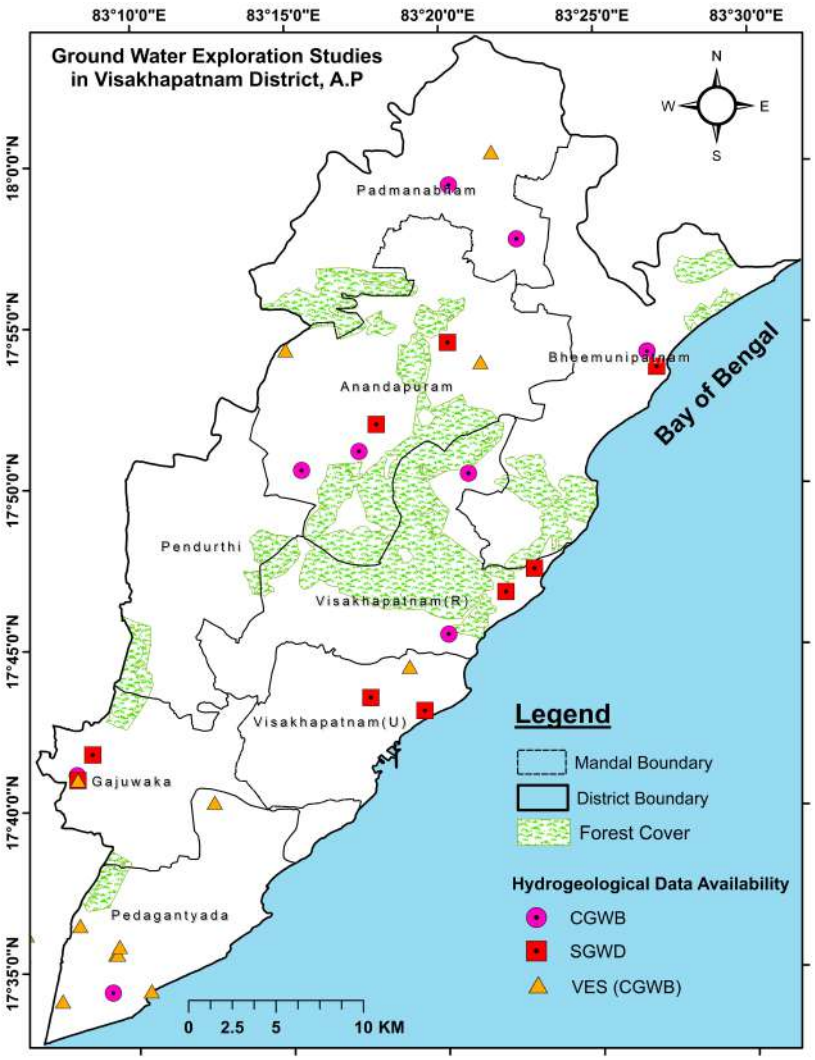


Fig. 2.1: Hydrogeological data availability in Visakhapatnam District.

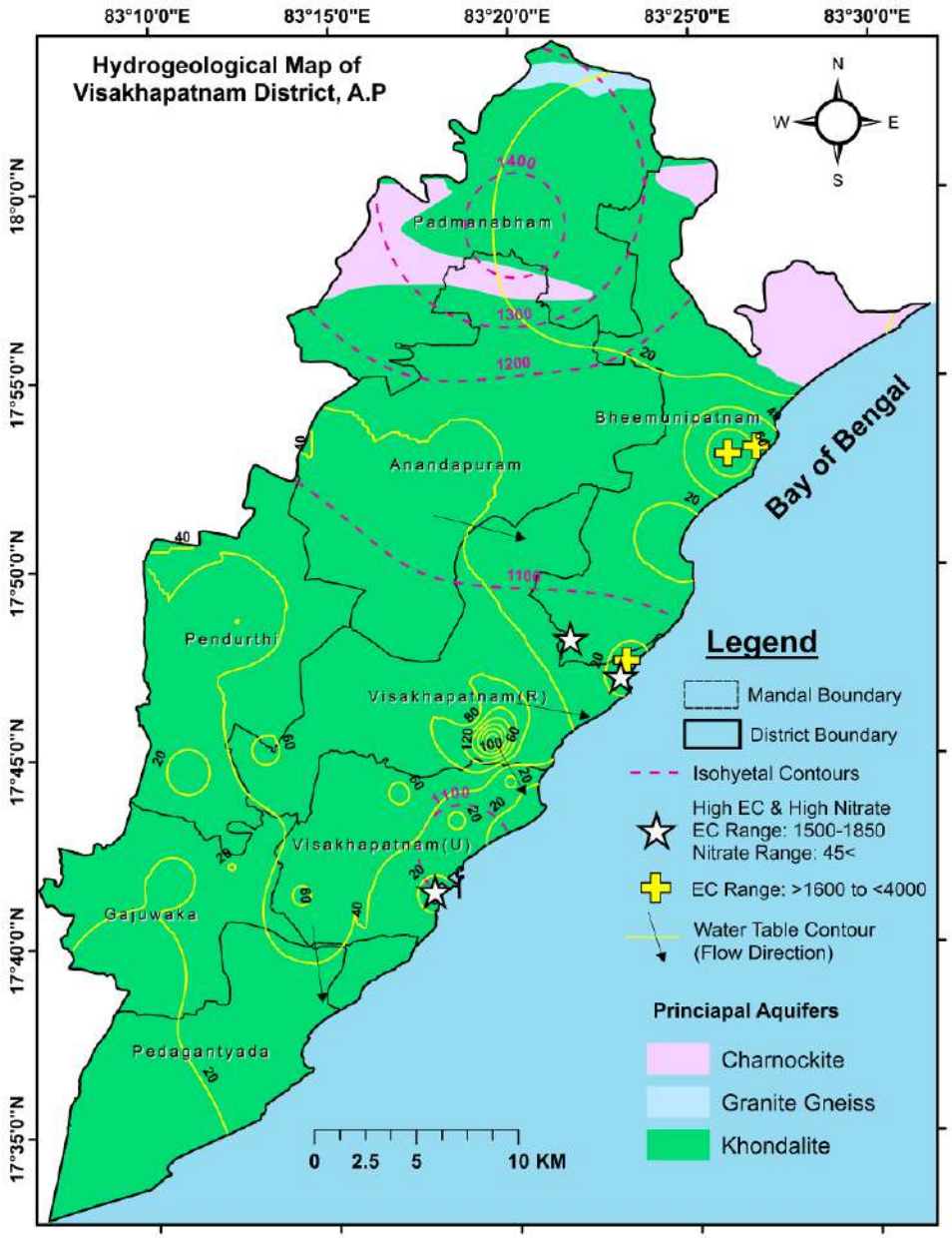


Fig-2.2: Hydrogeological map of Visakhapatnam district.

2.1.1 Ground Water occurrences and movement: Ground water occurs in unconfined conditions and also in semi-confined/confined conditions. The ground water flows from the weathered zone into the fracture zone in hard rock area, where as in alluvial/soft rock formations the ground water flows follows simply reciprocate to topography. The main aquifers constitute the weathered zone at the top, followed by a discrete anisotropic fractured/fissured zone at the bottom, generally extending down to 200 m

depth. At present, ground water extraction is mainly through boreholes of approximately ~15 to ~60 m depth.

2.1.2 Ground Water Yield: Ground water yield vary from <1 to <2.1 lps. Wells located in the command area have higher yield (approx 1-3.5 lps) and sustain for more hours of pumping when compared to non-command area where yields are relatively low with sustainability for 2-4 hrs (**Fig.2.3).**

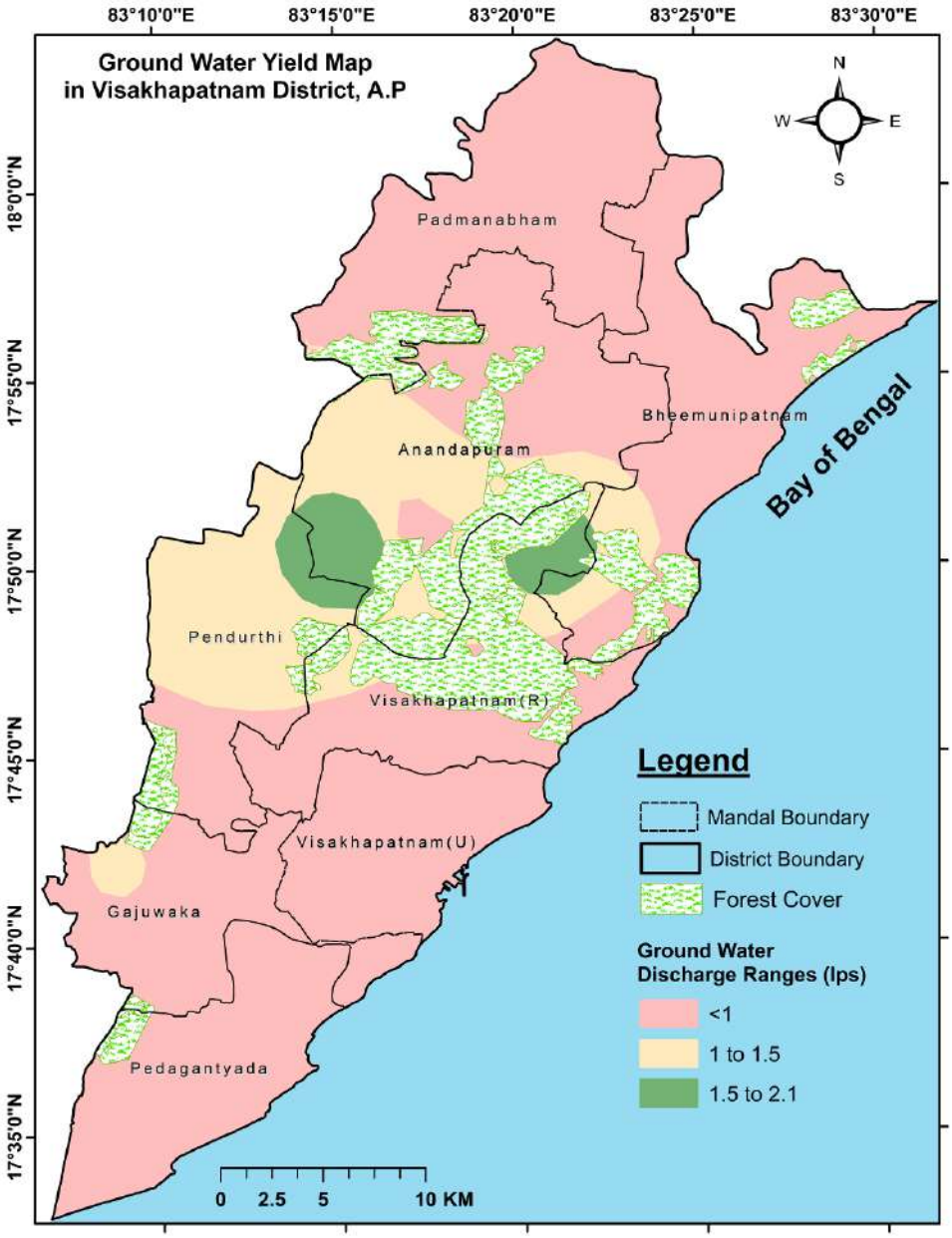


Fig. 2.3: Ground water yield potential map in Visakhapatnam district

2.2 Water Levels: Ground water levels are monitored from 33 numbers of hydrograph network stations in which 12 monitoring stations by CGWB and 21 wells by SGWD. The water level data of 10-year average (2010 to 2019) were used for preparation of depth to water level maps for pre-monsoon and post-monsoon seasons

2.2.1 Depth to Water Levels (DTWL): The average DTWL of 10 years (2010 to 2019) for pre-monsoon and post-monsoon were analyzed. The avg. DTWL varies from 1.04 to 22.08 meter below ground level (m bgl) (average: 11.56 m bgl) and 0.27 - 12.08 m bgl (average: 6.17 m bgl) during pre and post-monsoon seasons respectively.

Pre-monsoon season: Majority of the water levels during this season are in the range of 5-10 m covering 92% of the area, followed by 10-20 m bgl (5%) and <5 m bgl (3%) (**Fig.2.4**). Deep water levels here between 10-20 m.bgl occupy 5% of the area in small parts of Padmanabham, Bhemunipatnam and Visakhapatnam Urban mandals.

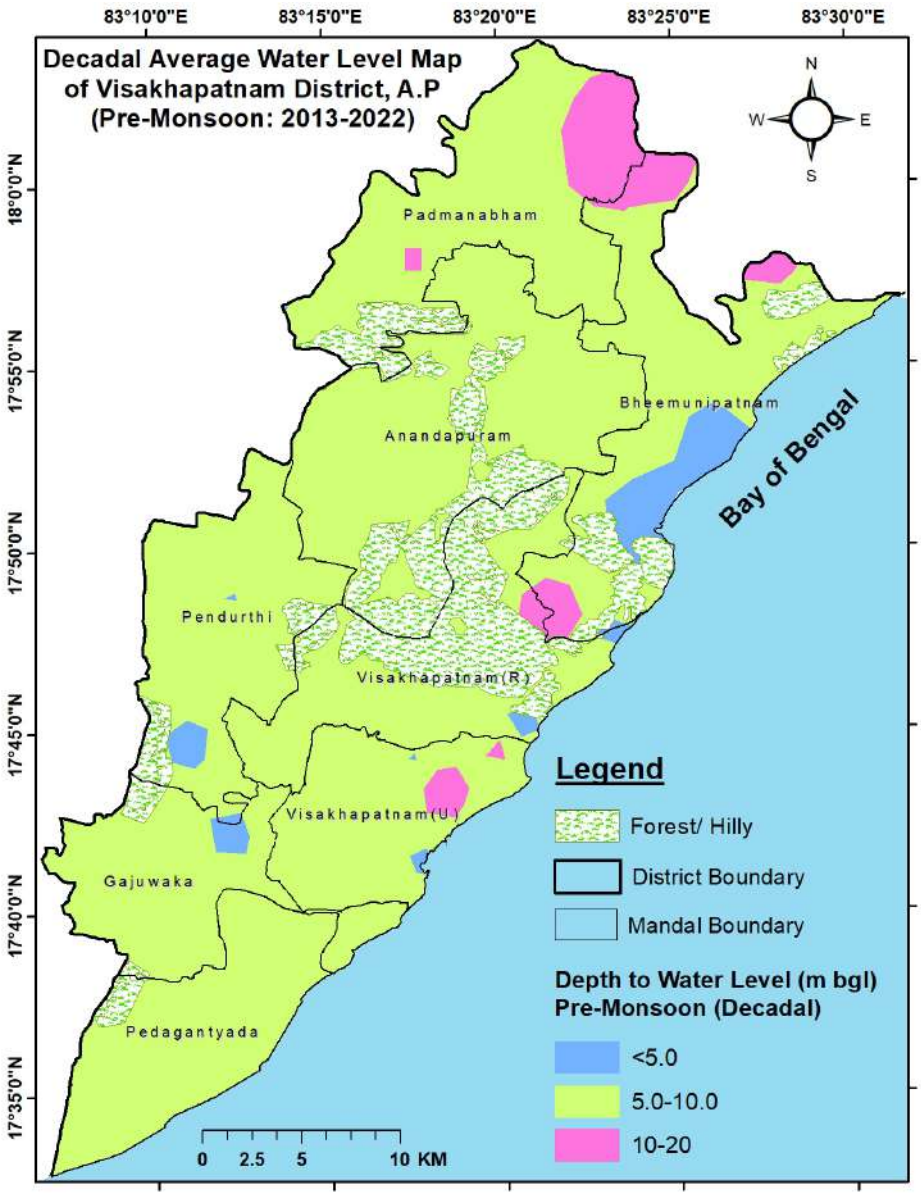


Fig.2.4: Depth to water level map, Pre-monsoon (Decadal)

Post-monsoon season: Majority of the water levels during this season are in the range of <5 m covering 53% of the area, followed by 5-10 m bgl (46%) and 10-20 m bgl (1%). Deep water levels in the range of <20 m bgl occupy about 1% of the area falling mostly in parts of Padmanabham mandal (**Fig.2.5**). Shallow water level <5 m.bgl occupy 53% of the area in Pedagantyada, Gajuwada and small parts of Visakhapatnam urban & Rural areas, Pendurthi, Anandapuram, Padmanabham and Bhemunipatnam mandals.

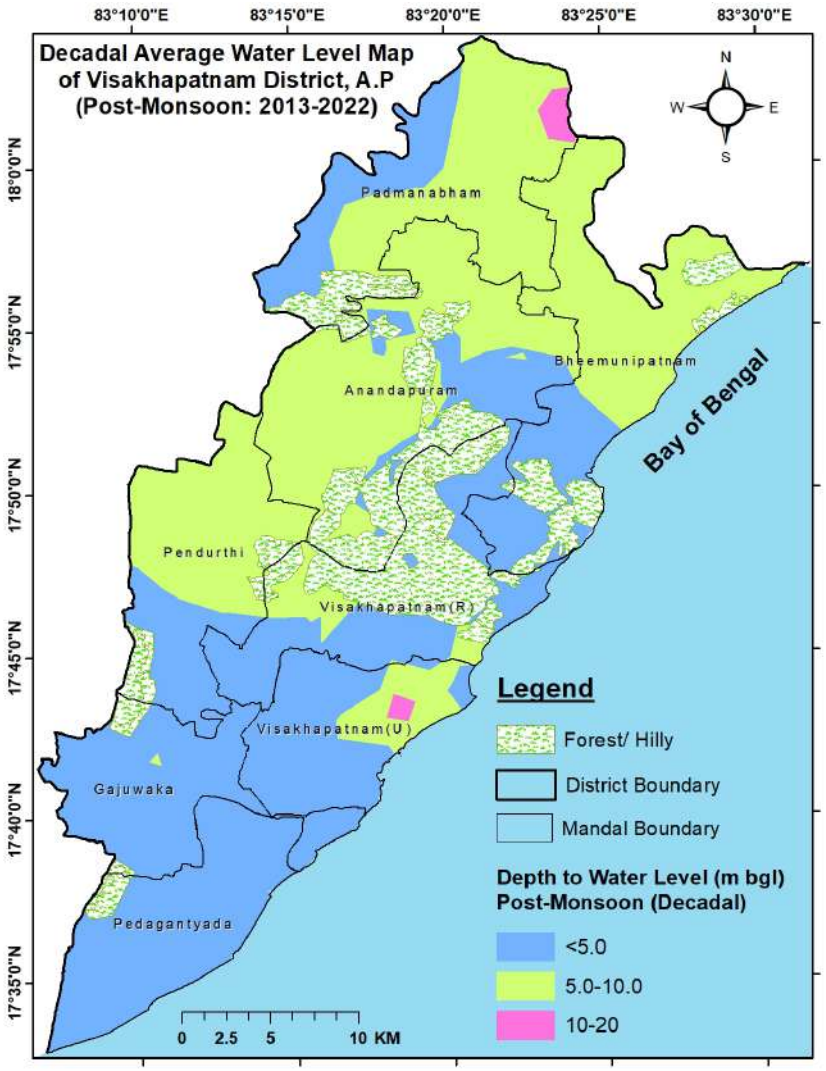


Fig. 2.5: Depth to water level map, Post-monsoon (Decadal)

2.2.2 Water Level Fluctuations (May vs. November): The water level fluctuations vary from -7.86 to 11.11 m with average rise of 3.48 m (**Fig.2.6**). 91% (30 nos) of the wells show rise in water level and 9% (3 nos) of wells show falling in water level. Fall in water level is recorded only in 3% of the area, whereas rise in water levels is observed throughout the district covering 97% of area. Rise in water level range of 2 to 5 m occurs in majority of the area (63%) followed by 0 to 2 m rise in 28% area, 5 to 10 m rise in 6% area and >10 m in <1% area. Rise of water levels >10 m is observed only in only Visakhapatnam rural mandal. Falls of water levels <-5 m is observed in Bhemunipatnam, Pendurthi and Visakhapatnam rural mandals.

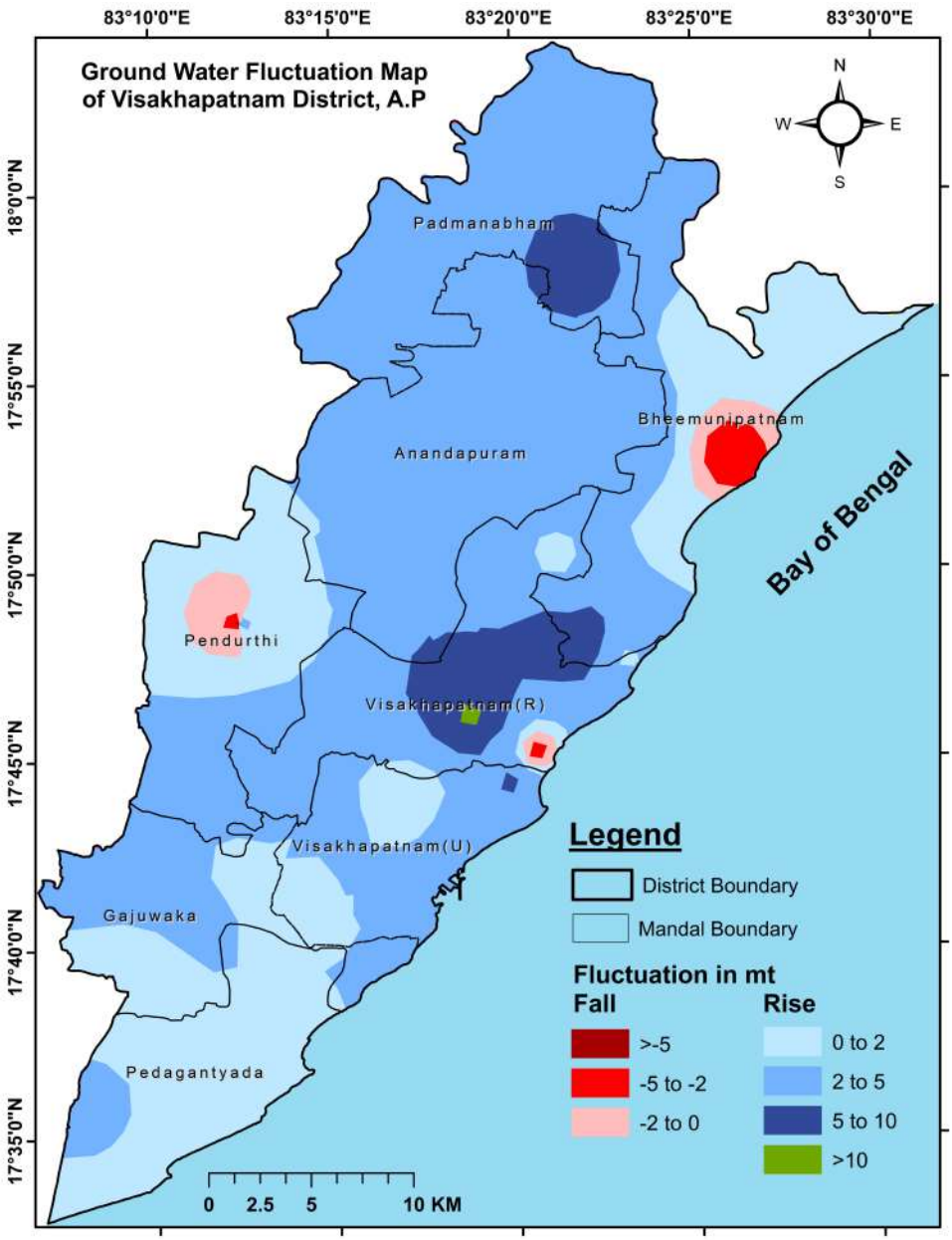


Fig.2.6: Water Level Fluctuations (Nov with respect to May).

2.2.3 Water Table Elevations: The water-table elevation ranges from 4.52 to 171 during pre monsoon and 5.90 to 176 meter above mean sea level (m amsl) during post monsoon seasons. The general ground flow is towards NW to SE in the southern parts, south east part of the district (98% of area) (**Fig.2.7)**.

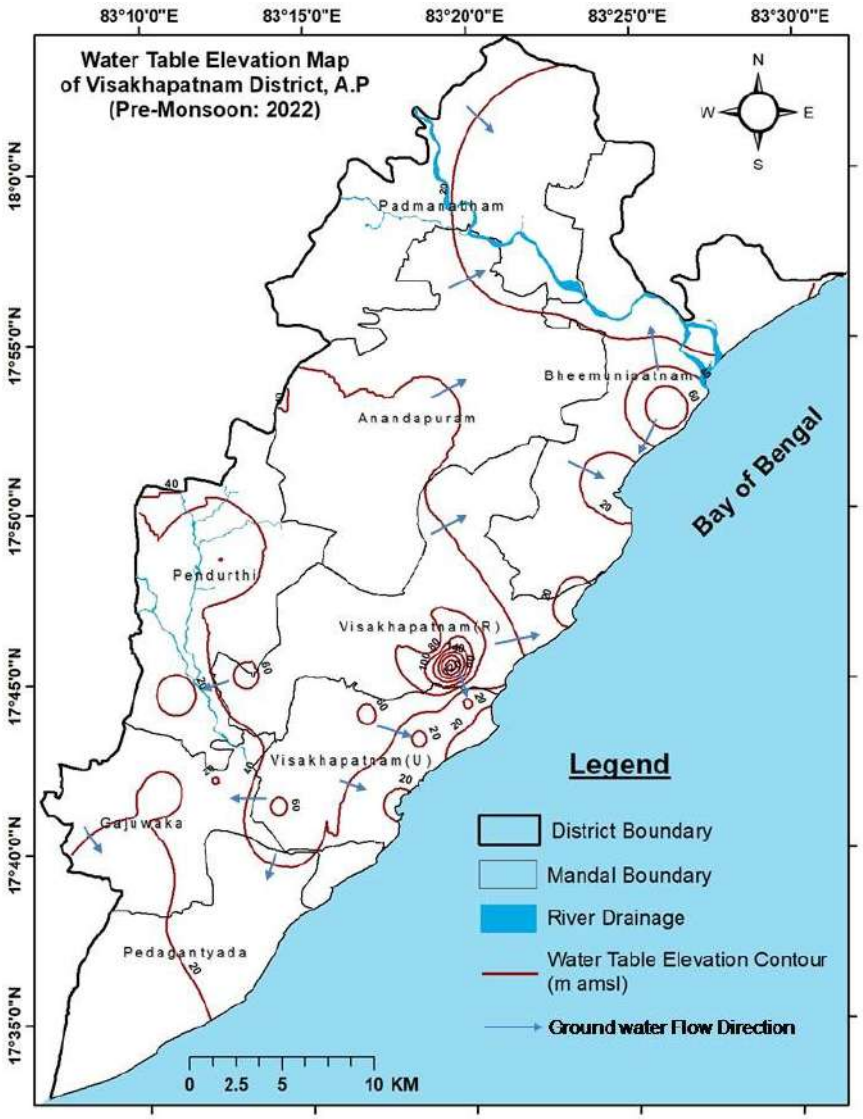


Fig.2.7: Water table elevations (m amsl) during pre monsoon season

2.2.4 Long term water level trends: The long term ground water trend analysis for the last 10 years (2013-2022) is analyzed from 12 hydrograph stations of CGWB. It is observed that during pre-monsoon season 07 wells shows falling trend (0-1 m: 07 wells) (max fall: -0.47 m/yr) and 05 wells shows rising trend (0-1 m: 05 wells) (max rise: 0.64 m/yr). During post-monsoon season 12 wells show falling trend (0-1 m: 07 wells) (maximum fall: -0.42 m/Yr) and 05 wells shows rising trends (0-1 m: 05 wells) (max rise: 0.65 m/yr). The spatial distribution of ground water level trend map is drawn and shown in **Fig 2.8.**

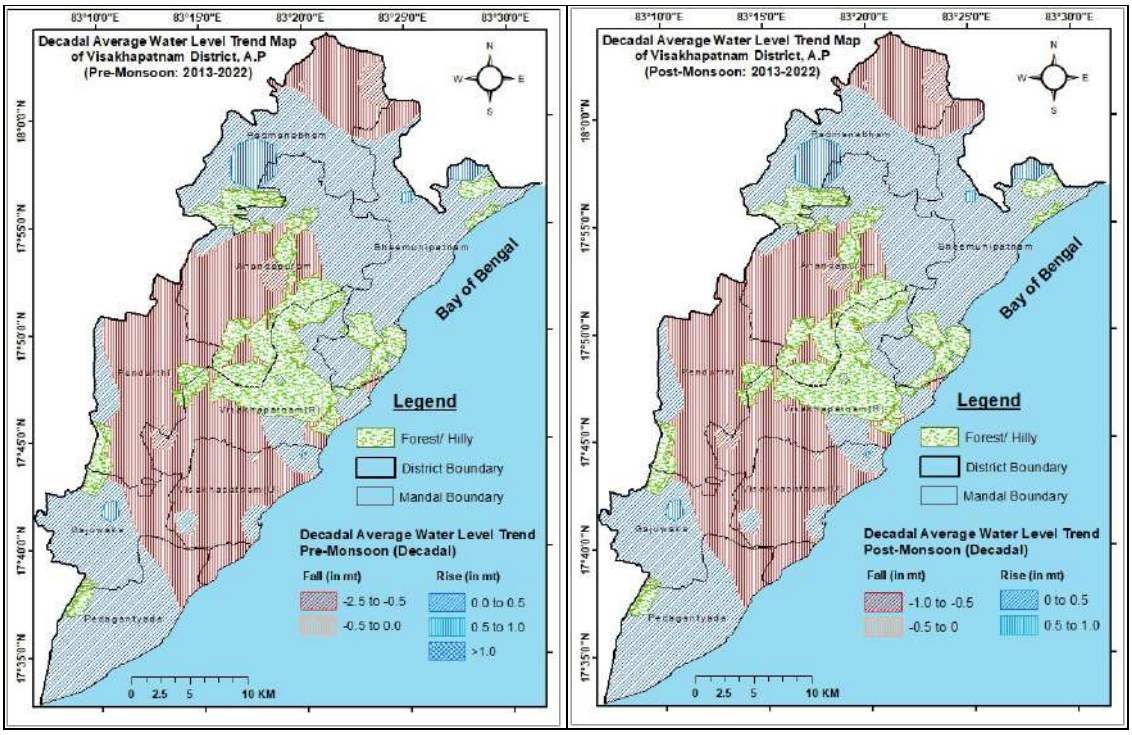


Fig. 2.8: Long-term water level (Pre & Post monsoon) trends

2.4 Geophysical Studies:

Vertical Electrical Soundings (VES) were carried out in 11 locations over the entire district of Visakhapatnam district. Attempt on factor analysis of VES data at each location marked probable occurrence of fractured aquifer in compact rocks. Borehole lithology and comparison of aquifer zone depths mapped from exploratory drilling by CGWB are matching more or less similar to the depth zones delineated by Factor analysis as well the shallow and middle level aquifer bearing formation dimensions.

Resistivity is in the range of 2 to 15181 ohm (Ω) m for the weathered and fractured granite with an inferred depth of 2 - 140 m, whereas resistivity is in the range of 2 to 15181 Ω m for massive granite with maximum thickness of 50 m to 200 m. The resistivity for the weathered and fractured Khondalite ranges from <2.3 to 90 ohm (Ω) m, while it is in the range of and 106 - 625 Ωm for massive Khondalite with maximum thickness of 90 m to 200 m. Charnockite formations are generally shows high resistivity values more than 500 Ωm. The resistivity of shear zone aquifers is very low 12 to 30 Ωm.

2.5 Hydro-chemical Studies:

To understand chemical nature of groundwater, 71 ground water sample data is utilized from ground water monitoring wells of CGWB and SGWD wells (Pre-monsoon: 42 wells and post-monsoon: 29 wells) during the pre-monsoon and post-monsoon seasons of 2019 respectively. The Parameters were analyzed are pH, EC (in µS/cm at 25° C), TH, Ca, Mg, Na, K, CO_3, HCO_3, Cl, SO_4, NO_3 and F.

2.5.1 Pre-monsoon: (Total 42 samples were analyzed (CGWB: 26, SGWD: 16**)**

Groundwater from the area is mildly alkaline to alkaline in nature with pH in the range of 6.56-9.22 (Avg: 8.32). Electrical conductivity varies from 232-8200 µ Siemens/cm@25°C (Avg: 1502 µ Siemens/cm@25°C)**.** In 90% of area EC is within 2000 µ Siemens/cm, in 5% area is 2000-3000 µ Siemens/cm and in 5% area is **>**3000 µ Siemens/cm (**Fig.2.9).** Nitrate concentration varies from 0.05-162.00 mg/L in 81% of samples are within permissible limits of BIS and rest 19% is beyond permissible limit of 45 mg/L (**Fig.2.10**). Fluoride concentration varies from 0.14-2.71 mg/L (**Fig 2.11**) and 93% of samples are within permissible limits of BIS and rest 7% is beyond permissible limit of 1.5 mg/L. High fluoride concentration is observed mostly in the stations of Bhimunipatnam, Gajuwaka and Visakhapatanm urban of mandals of the district.

2.5.2 Post-monsoon: (Total 29 samples were analyzed (SGWD: 29)

Groundwater from the area is mildly alkaline to alkaline in nature with pH in the range of 7.4 - 8.94 (Avg: 8.34). Electrical conductivity varies from 502 - 5610 µ Siemens/cm@25°C (Avg: 1605 µ Siemens/cm@25°C)**.** In 87% of area EC is within 2000 µ Siemens/cm, in 8% area is 2000-3000 µ Siemens/cm and in 5% area is **>**3000 µ Siemens/cm (**Fig.2.12).** Nitrate concentration varies from 0.11-24.19 mg/L in all samples is within permissible limits of 45 mg/L (**Fig.2.13**). Fluoride concentration varies from 0.06-2.57 mg/L (**Fig 2.14**) and 93% of samples are within permissible limits of BIS and rest is beyond permissible limit of 1.5 mg/L. High fluoride concentration is observed in Gajuvaka and Pedagantyada mandals of the district.

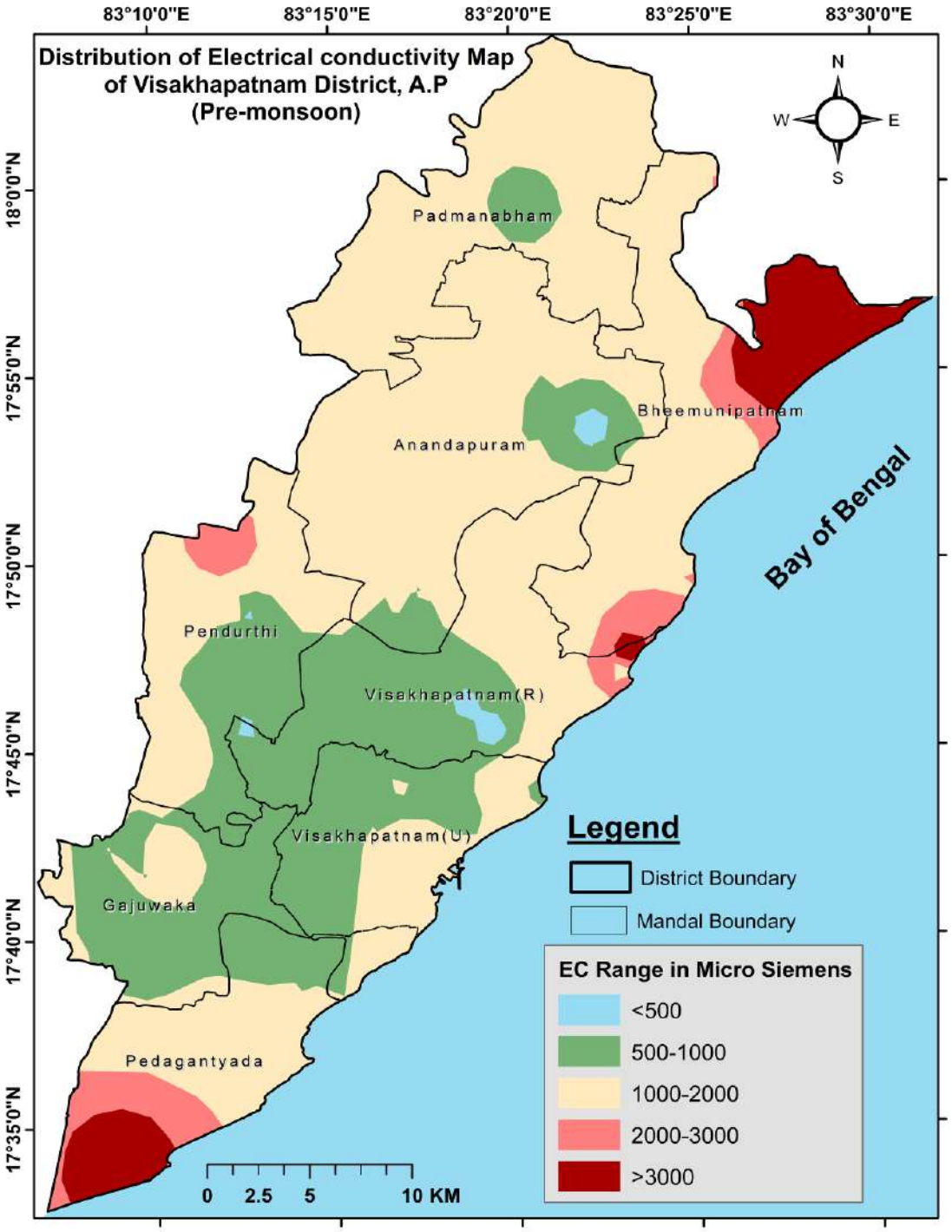


Fig. 2.9: Distribution of Electrical conductivity (Pre-monsoon).

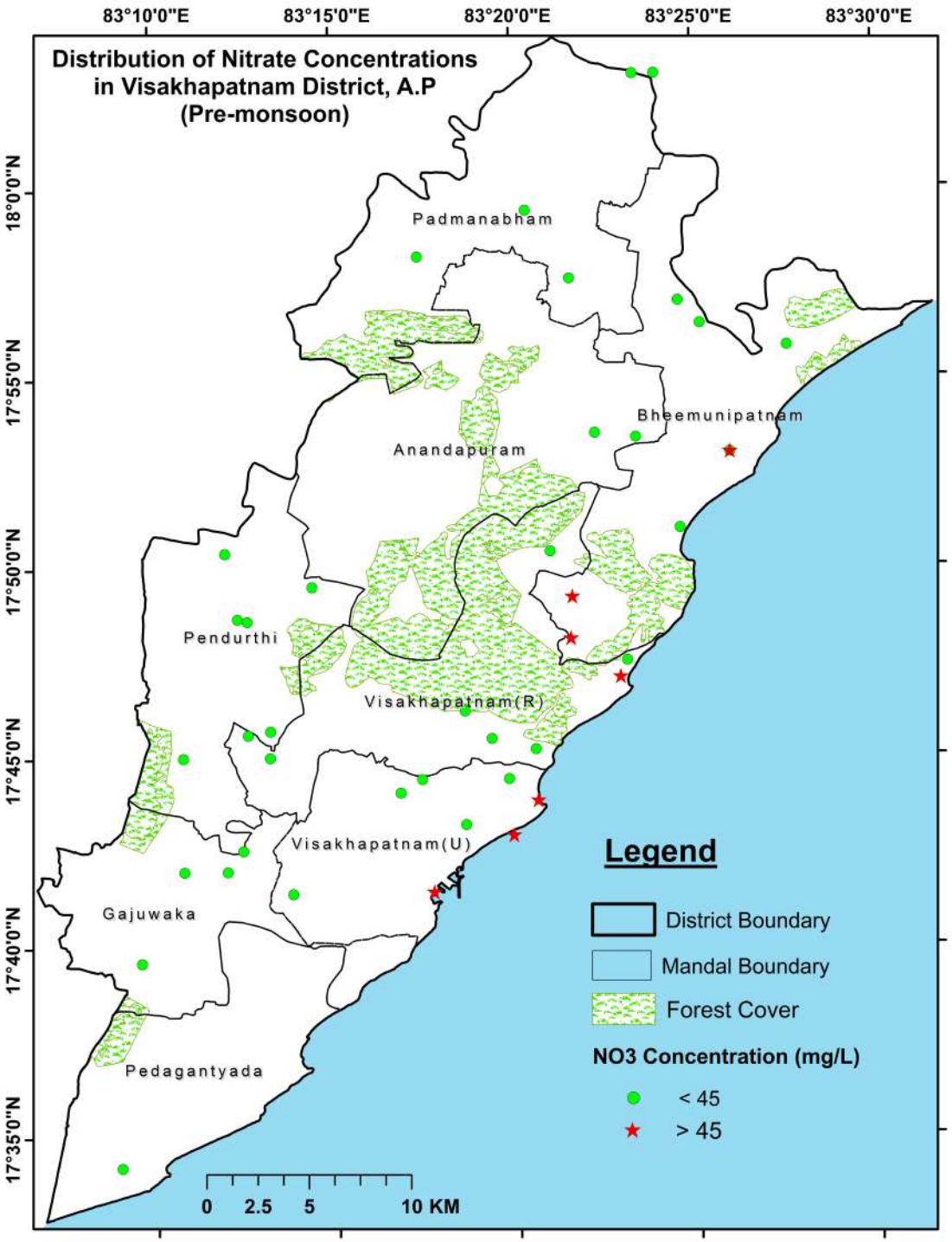


Fig.2.10: Distribution of Nitrate concentrations (Pre-monsoon).

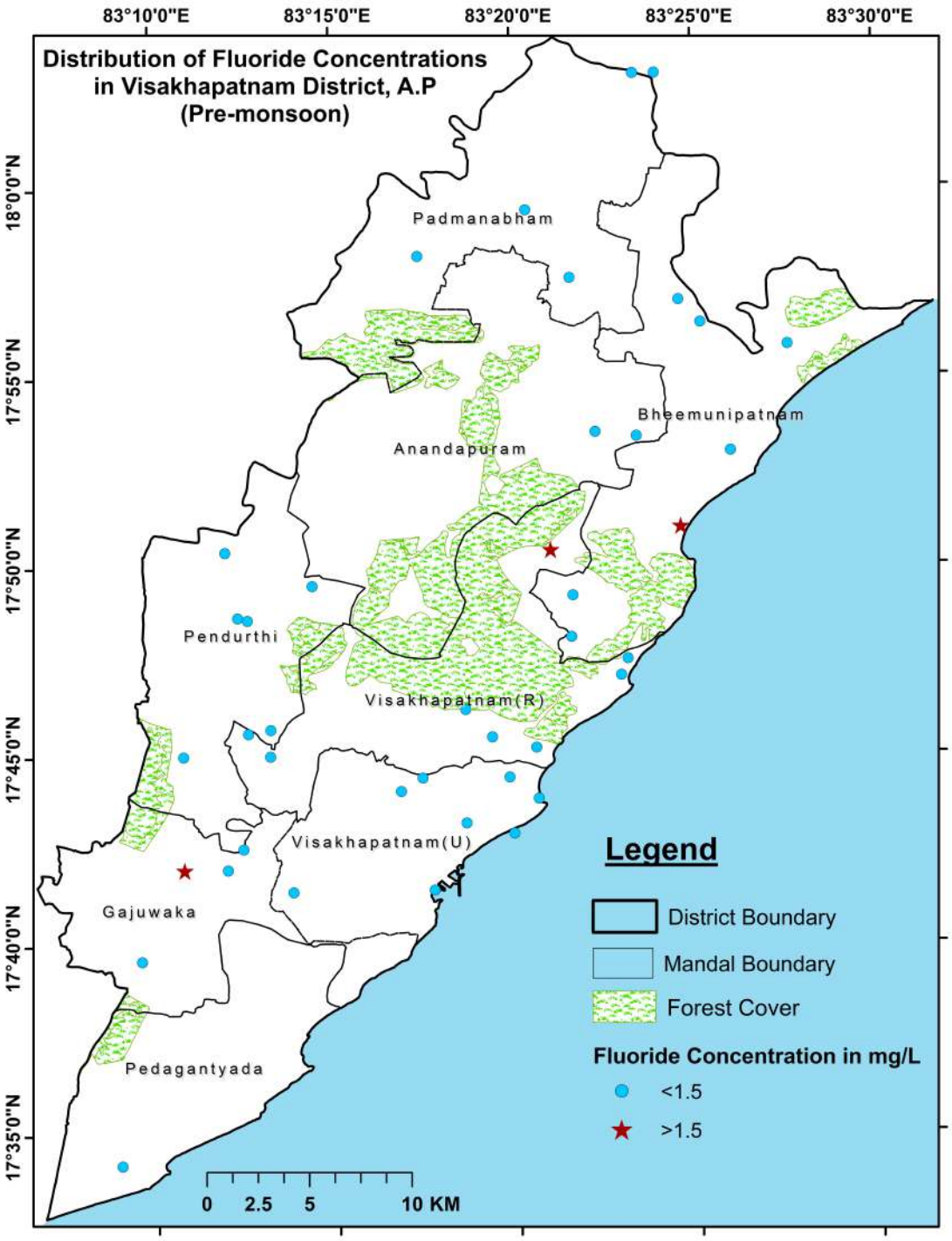


Fig.2.11: Distribution of Fluoride concentrations (Pre-monsoon).

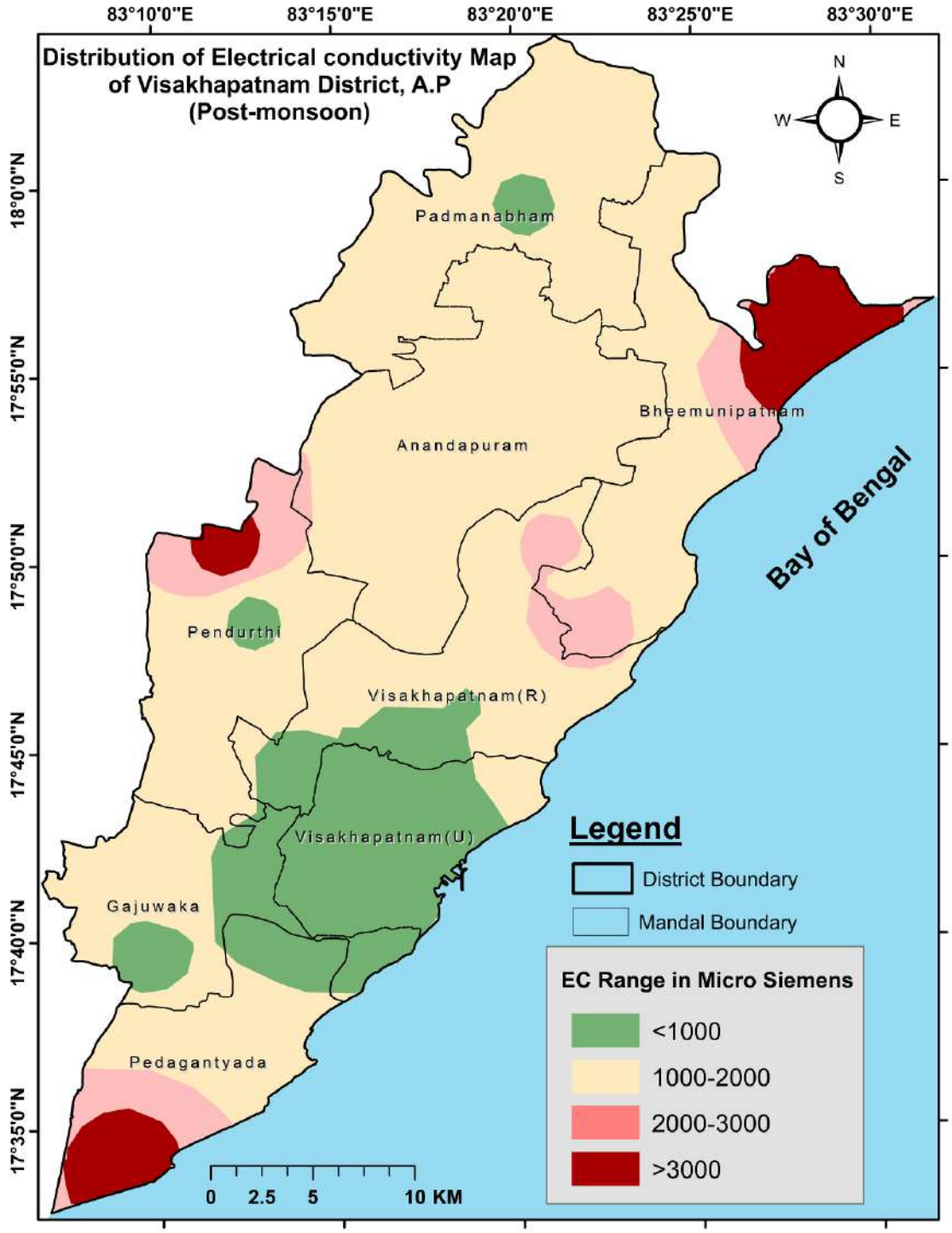


Fig. 2.12: Distribution of Electrical conductivity (Post-monsoon).

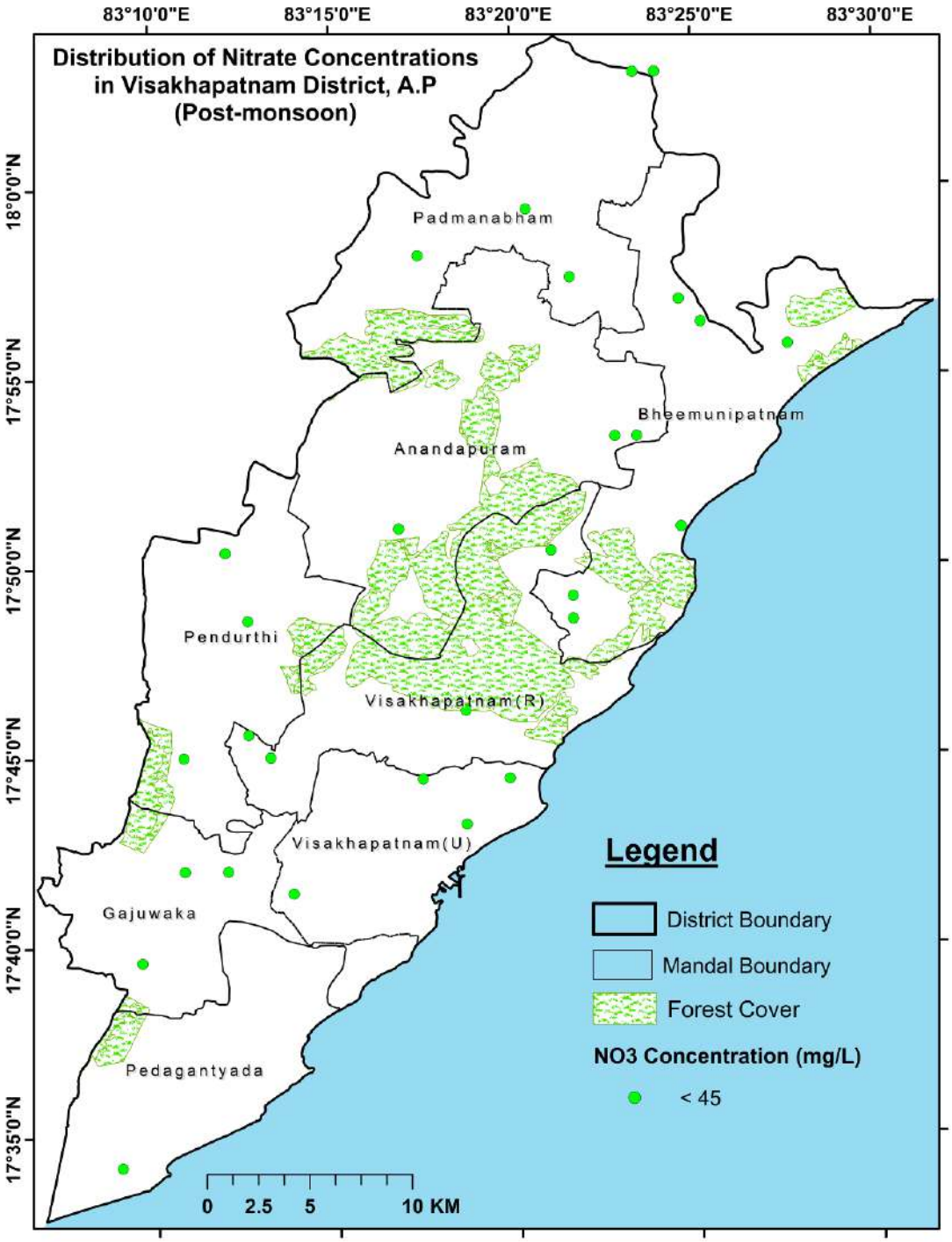


Fig.2.13: Distribution of Nitrate concentrations (Post-monsoon).

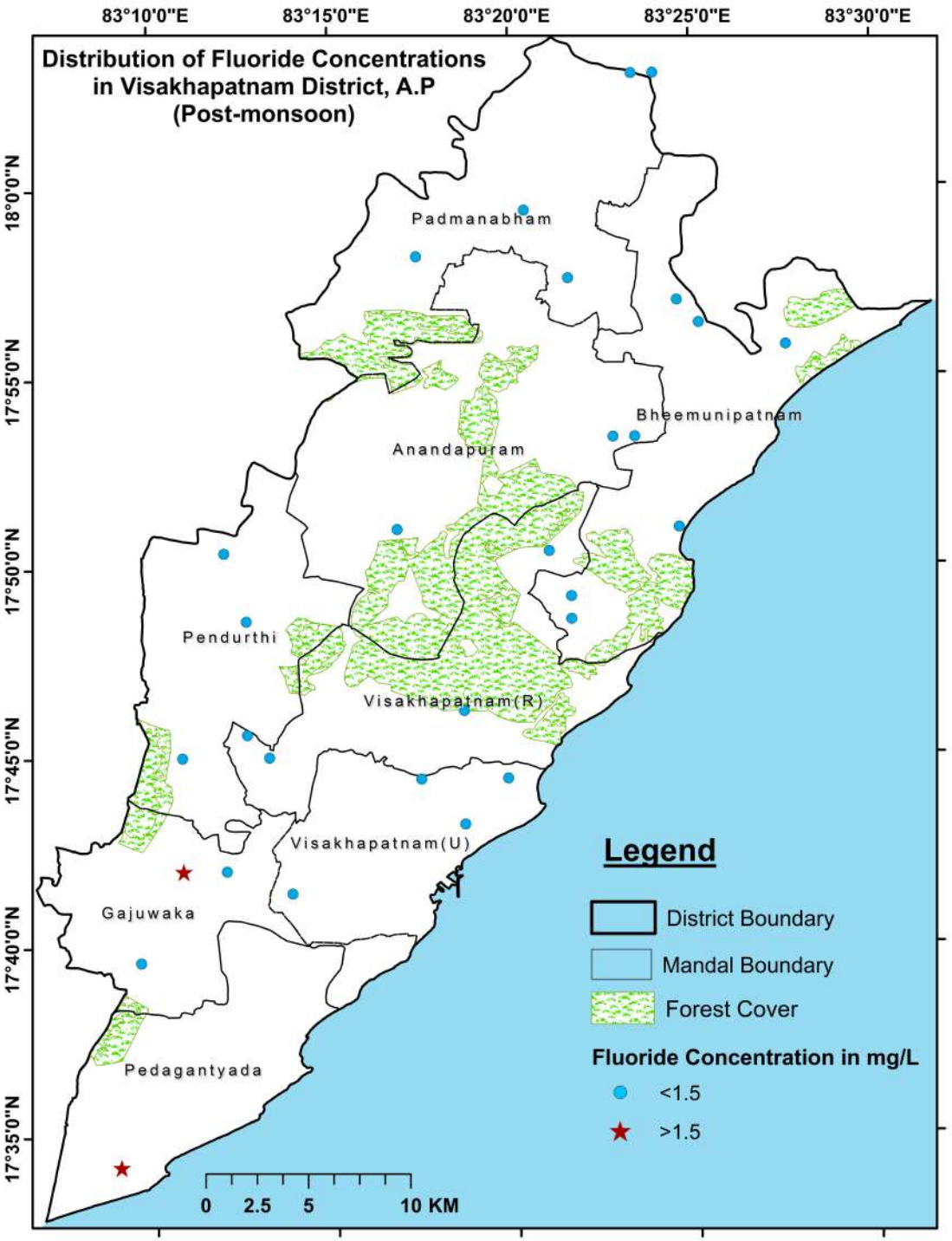


Fig.2.14: Distribution of Fluoride concentrations (Post-monsoon).

3. DATA INTEGRATION, INTERPRETATION AND AQUIFER MAPPING

Conceptualization of 3-D hydrogeological model was generated by interpreting and integration of 31 number of data points (CGWB: 11, SGWD: 09 and VES: 11) for conceptualization of Aquifers disposition. The well data points are calibrated for elevations from SRTM data and finally, the optimised lithological information were used to generate 3-D maps and hydrogeological concepts i.e lithological models, panel/fence diagrams and 2-D cross-sections by using the RockWorks-17 software for Visakhapatnam district **(Fig.3.1 & 3.2)**.

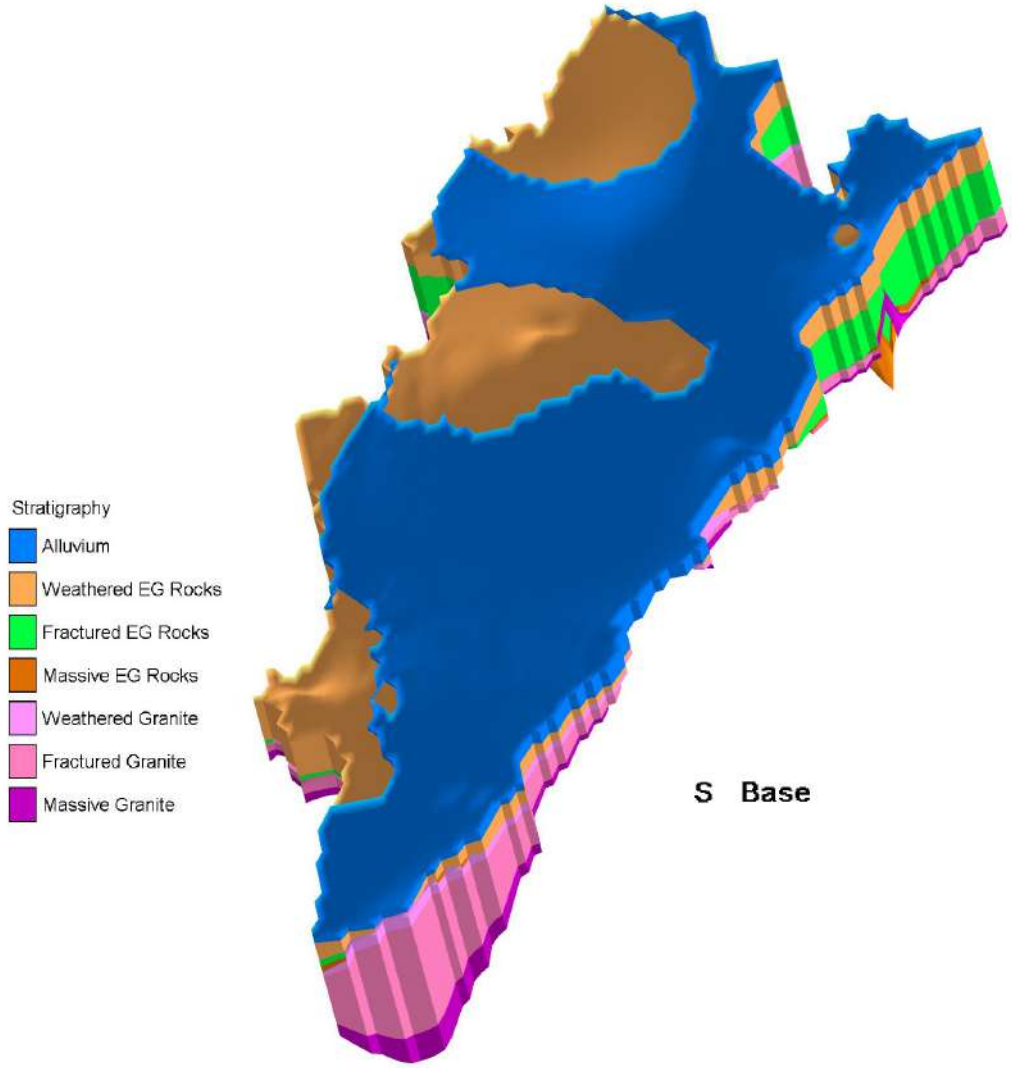


Fig.-3.1: 3-D Stratigraphic models of Visakhapatnam district.

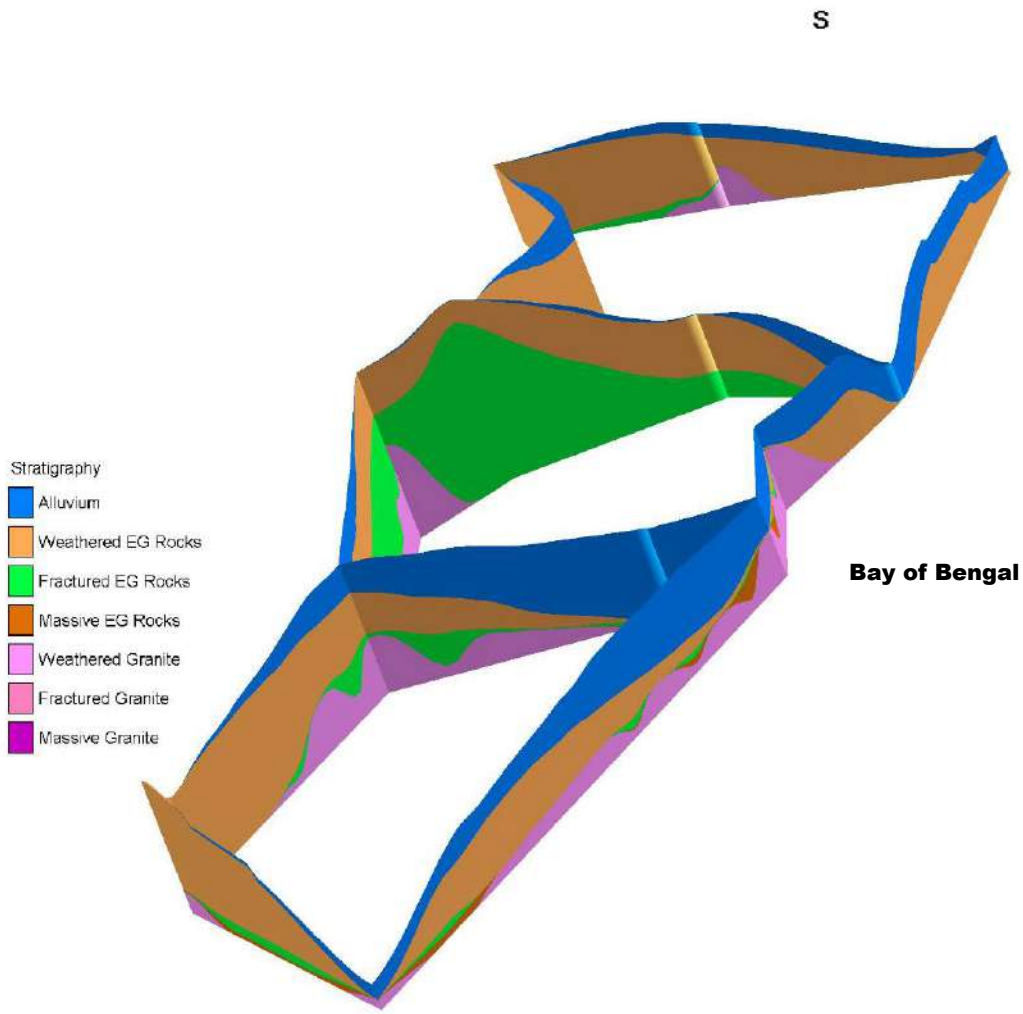


Fig.-3.2: 3-D stratigraphic fence diagrams of Visakhapatnam district.

3.1 Conceptualization of aquifer system in 3D

The rock types of Khondalite, lyptonites, quartzites in litho-units are categorized in to Eastern group of rocks and which all are underlined by basement Granite gneiss. Weathered zone is considered up to the maximum depth of weathering and first fracture encountered (below weathered depth) generally down to ~27 m average depth and the fractured zone (fractured granite) is considered up to the depth of deepest fracture below weathered zone (~27-200 m).

3.2 Hydrogeological Sections

Hydrogeological sections are prepared in NW-SE, SW-NE and W-E direction (**Fig. 3.3**) for hilly-valley areas and plain areas of Visakhapatnam district.

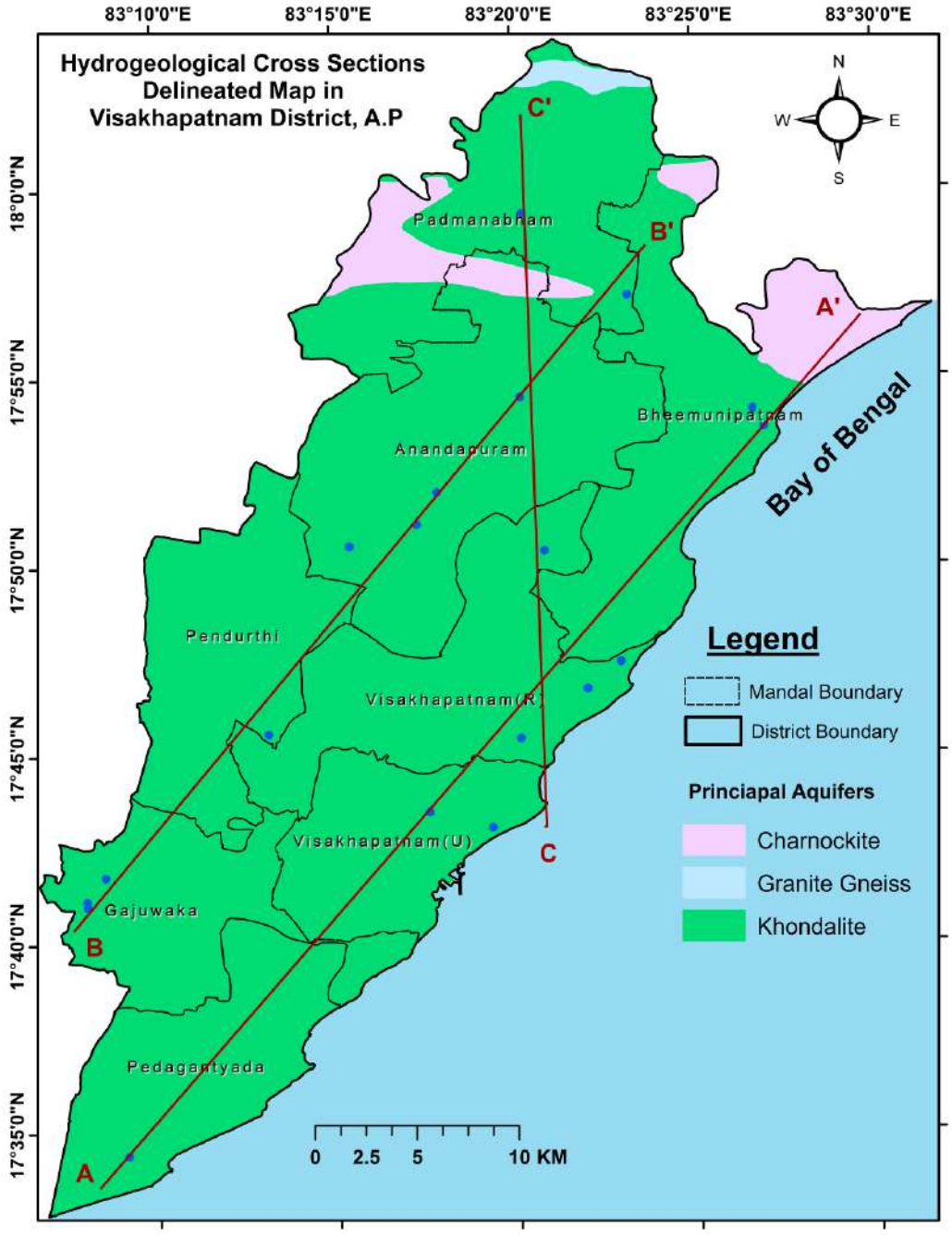


Fig.-3.3: Map showing orientation of hydro-geological Sections.

3.2.1 North-East and South-West Section (towards Land side B-B'): The section is drawn along the NE-SW direction towards opposite direction from coast covering a distance of ~53 kms (**Fig.3.4a**). It depicts thin weathered zones and fractured zones in south western and north eastern parts in Eastern Ghat rock types (Khondalite and Charnockite formations) and underlain by Granites which forms the basement. Along this direction, it is observed that Eastern Ghat rock types are underlain by basement rock is limited depth (approx 145 m). Fractured formations are also observed limited fractured zones in hilly areas along the direction.

3.2.2 North-East and South-West Section (towards Sea side A-A'): The section is drawn along the NE-SW parts covering distance of ~51 kms (**Fig.3.4b**). It depicts thin weathered zones overlaid Alluvium and thick fractured zones in north eastern parts of this direction in Eastern Ghat rock types (Khondalite and Charnockite formations) and underlain by Granites which forms the basement towards south western direction. Along the direction, it is observed that Eastern Ghat rock types are more dominant rock formations towards NE direction and granite gneisses are predominant exposures found in SW part of direction. Fractured formations are more dominant extensions in NE direction (Eastern Ghat group of rocks) as compare to SW part (basement). Alluvium is extended to 51 km area with average depth of 4 to 15m depth.

3.2.3 North-South Section (C-C'): The section drawn horizontally along the North-South direction covering distance of ~31 kms (**Fig.3.4c**), depicts alluvium is partially covered in small pockets of beach areas i.e eastern part and also basement exposures also observed in eastern part and northern part (away from coast) of direction at deep depths. Thick weathered zones and fracture zones are observed more towards northern side from in all along the direction.

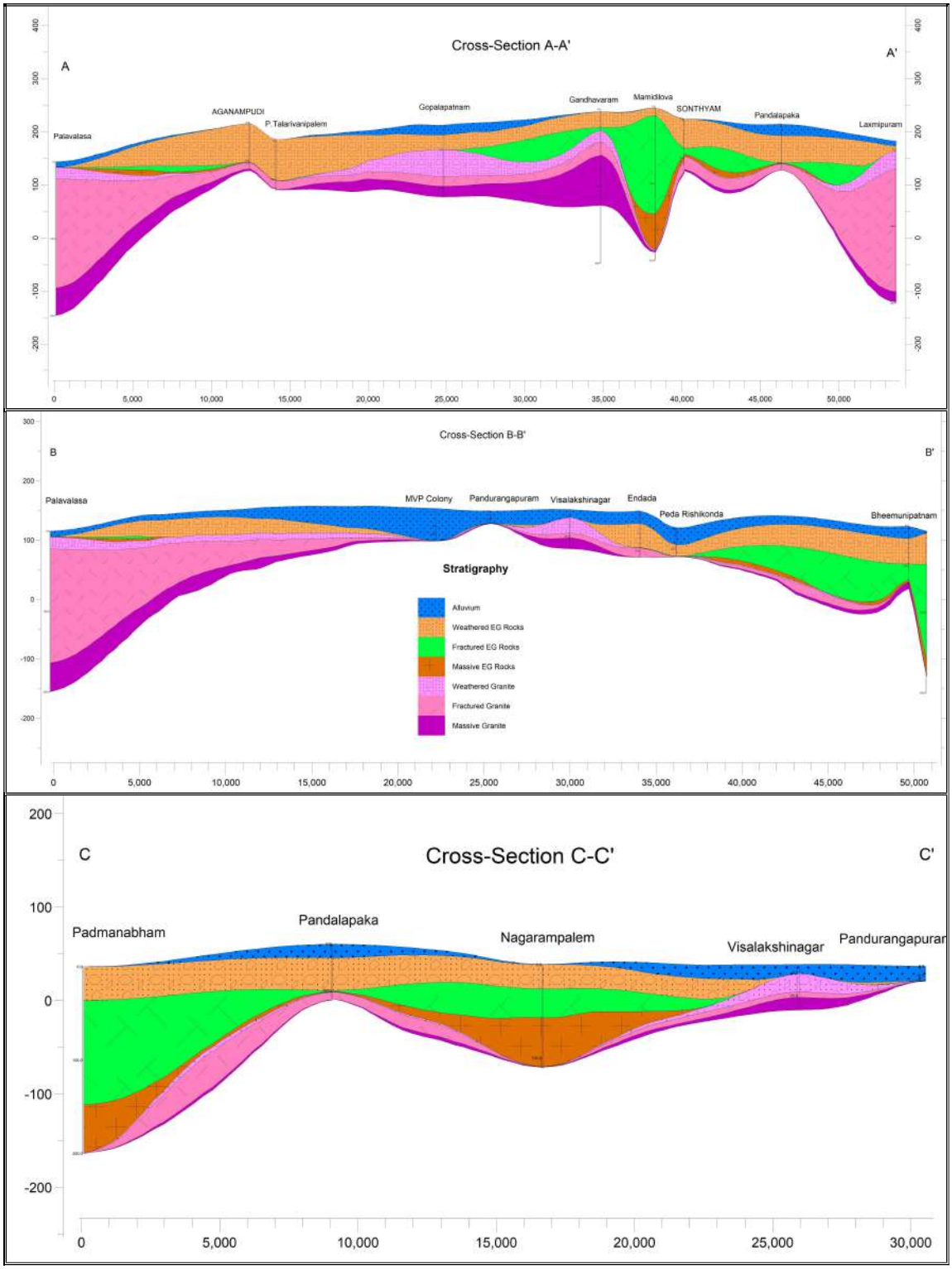


Fig.3.4 (a-c): Hydrogeological profiles in different directions of Visakhapatnam district.

3.3 Aquifer Characterization

3.3.1 Weathered Zone: The average depth of occurrence of weathering is of ~31 m bgl which varies in different formations from meager to ~20 mbgl in Granitic formations, meager to 37 m in Charnockite, upto ~54 m in Khondalite. Spatial distribution of weathering depth zone map is given in **Fig.3.5**. Thickness of weathered zone is in the range of 20 - 40 m occurs in most part of area (81%). Shallow weathered zones i.e < 10 m occurs in 1% of the area, 10-20 m in 9% area and deep weathered zone (**>**40 m to max. 54 m depth zone) occurs in rest of the area (9%). The graphical presentation for weathered zones in mappable area is shown in **Fig.3.6**.

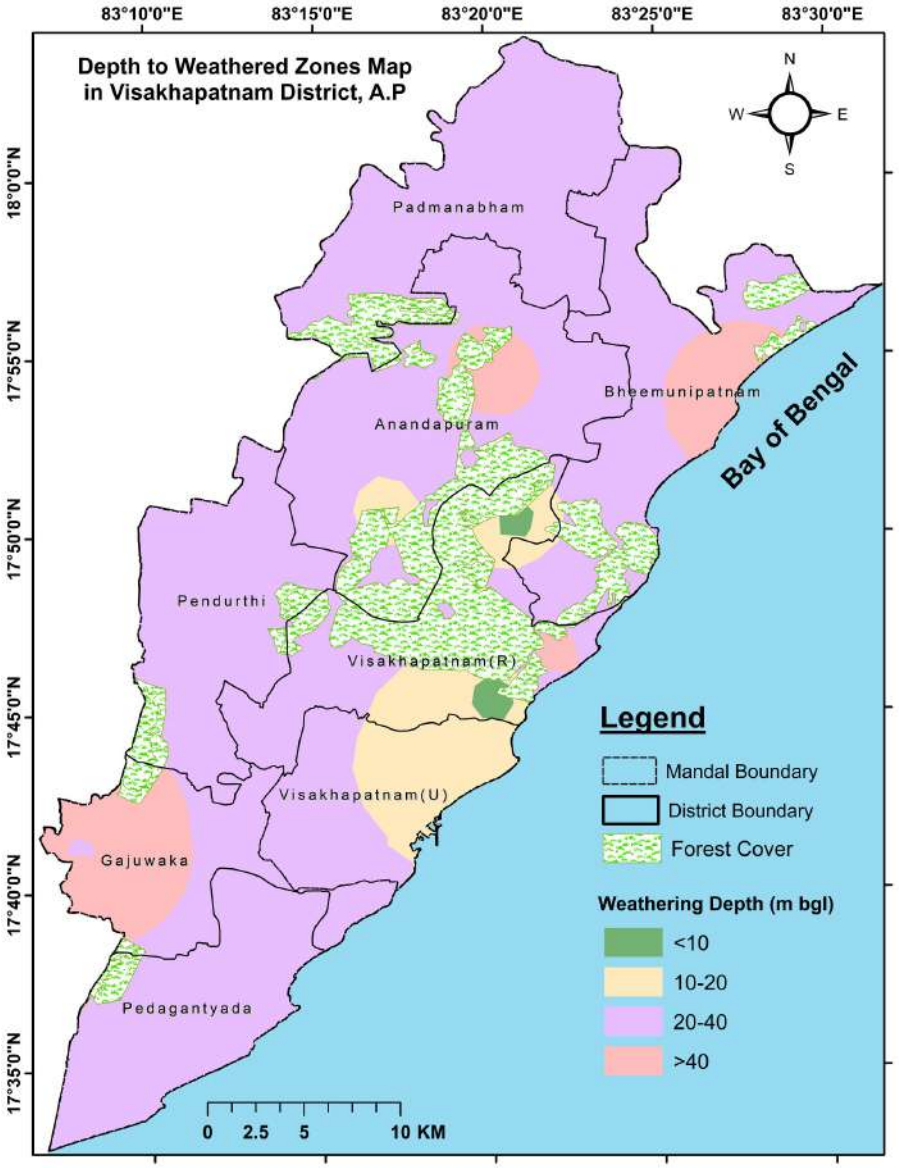


Fig.3.5: Thickness of Weathered zones in Visakhapatnam district.

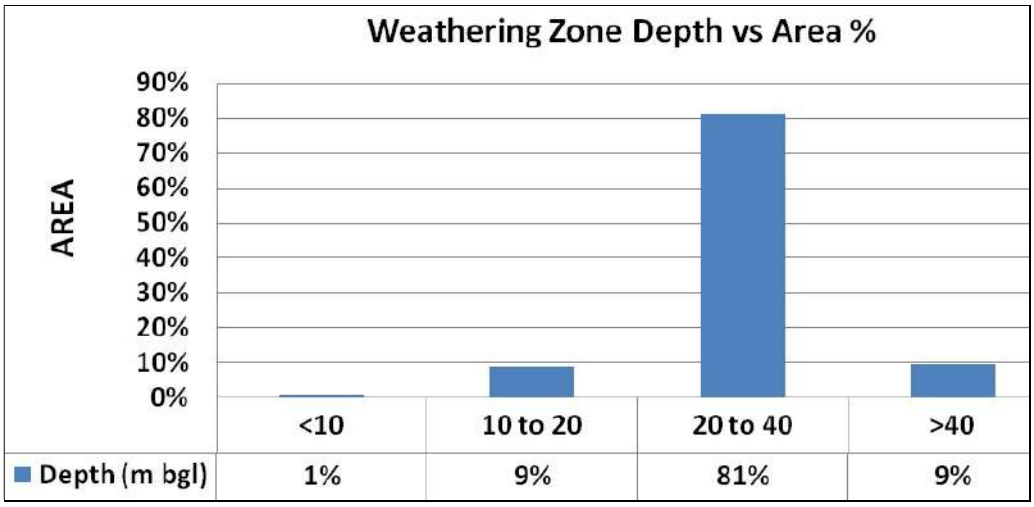


Fig.3.6: Depth wise weathered zone distribution details in Visakhapatnam district.

3.3.2 Fractured zone: Ground water is extracted mainly through bore wells of beyond the depth of ~24 m from each fractured zones of the hard rocks. Based on CGWB, VES data and SGWD drilling data analysis, it is inferred that fractures depth starts from ~24 to 200 m bgl. The fracture zones at the depth range of 50-100m is more predominant (59% of the area), followed by 100-150 m depth (23% of the area), <50m depth (11% of the area) and rest 7%, the fractures are within >150 m depth.

Groundwater yield of fractured granites / gneisses varies from 0.3 to 2 lps (Avg: 0.8lps). Wells located in the command area have higher yield (1-2 lps) and sustains more hours of pumping as compared to non-command area where yields are relatively low and sustains for 2-3 hrs. Storativity of the fracture zones varies from 3.2×10^{-6} to 1.92×10^{-2}. The graphical presentation for fracture zones in formation wise is explained and shown in **Fig.3.7** and the distribution of depth wise occurrence of fractures shown in **Fig.3.8.**

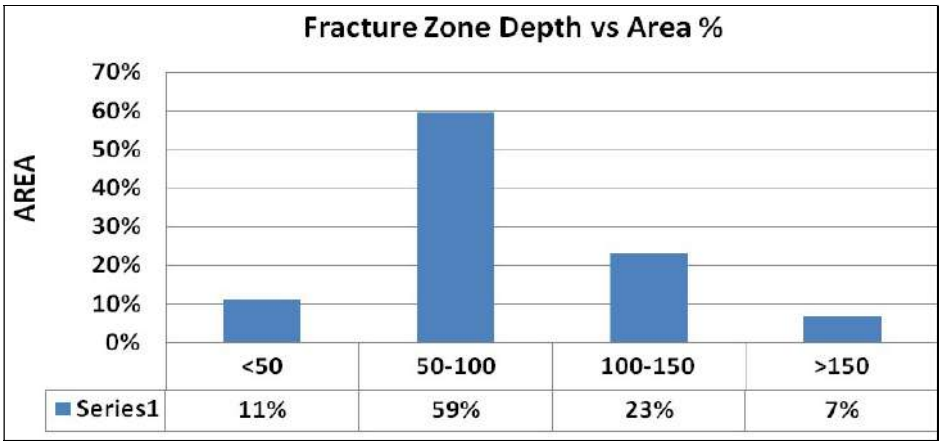


Fig.-3.7: Depth wise fracture zones details in Visakhapatnam district.

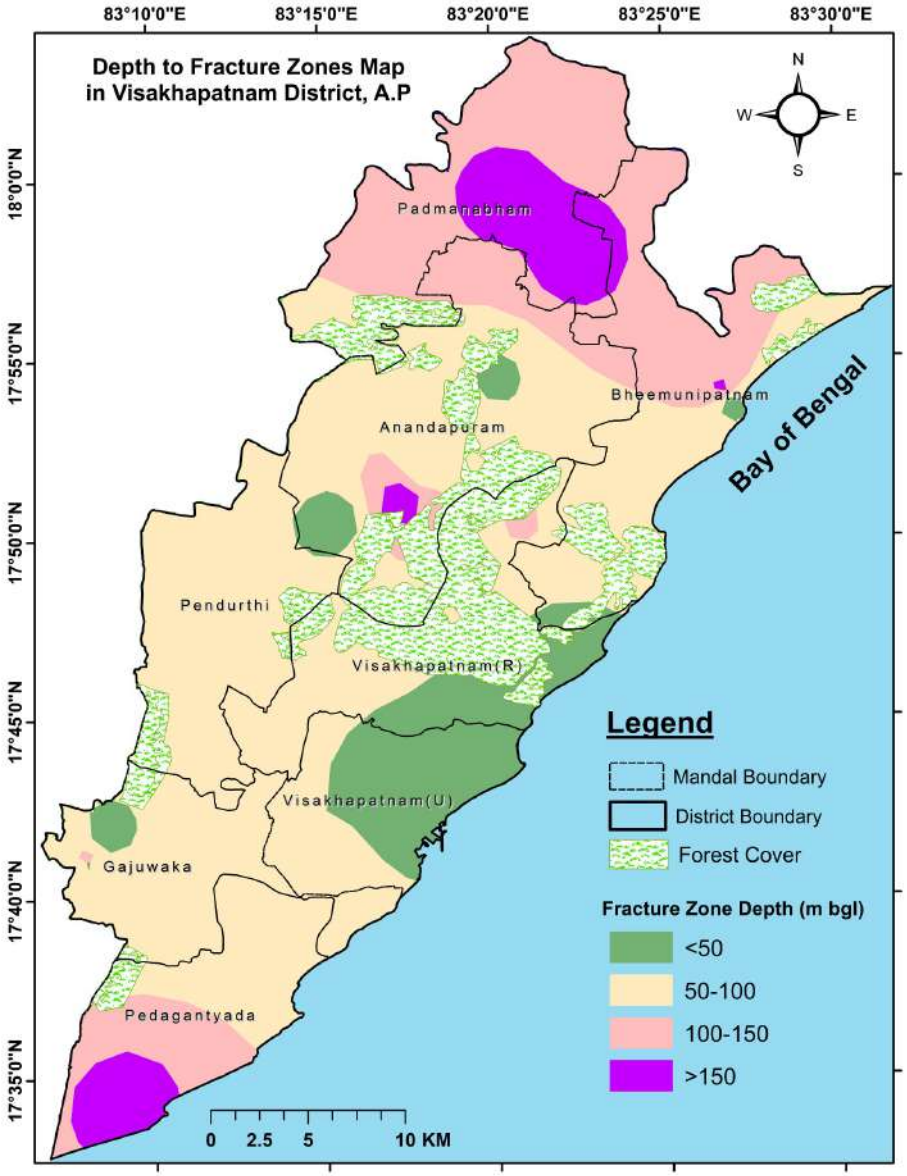


Fig.-3.8: Depth of occurrence of Fractured zones

4. GROUND WATER RESOURCES (2022)

In hard rocks, for practical purpose it is very difficult to compute zone wise (aquifer wise) ground water resources, because the weathered zone (WZ) and fractured zone (FZ) are inter-connected with fractures/joints and fractured zone gets recharged through weathered zone. The resources are estimated considering is as a single aquifer system. The dynamic ground water resources are computed as per the guidelines laid down in GEC methodology.

The Summarized command/ non-command area and mandal wise resources are given in **Table-4.1**. As per GWRA - 2022, the annual extractable ground water resources are 135 MCM, gross ground water draft for all uses 59 MCM, net annual ground water provision for drinking, industrial and irrigation use for the year 2025 is 42 MCM. All 11 mandals are categorized as Safe in the district. The Mandal wise stage of ground water development (SOD) varies from 36% (Anandapuram mandal) to 62% (Pendurthi mandal) with average of SOD is 49% for Visakhapatnam district. The maps showing categorization of mandals and utilizable ground water resource are prepared and shown in **Fig. 4.1 a, b & c**.

Ground Water Recharge: The Annual Ground Water Recharge varies from 4.27 MCM (Pendurthi Mandal) to 65.03 MCM (GVMC Mandals). The Gross Annual Ground Water Recharge in the district is 135 MCM. The net available recharge after leaving natural discharge from monsoon period varies from 0.21 MCM (Pendurthi Mandal) to 3.25 MCM (GVMC Mandals). The net available recharge in the district is 129 MCM.

Ground Water Draft: The ground water draft from irrigation and Domestic /Industrial sources is presented in Table: 4.1. The Existing Gross Ground Water Draft for all uses varies from 2.50 MCM (Pendurthi) to 29.47 MCM (GVMC mandals). The Gross Ground Water Draft for All uses in the district is 59.11 MCM.

Stage of Ground Water Development: The stage of ground water development in Visakhapatnam district varies from 36% to 62% and all assessment (mandals) units have been categorized as Safe (Fig 4.1b) as per

Ground Water Resources Assessment - 2022. The overall stage of groundwater development of Visakhapatnam district is 49%.

Table-4.1: Computed Dynamic ground water resources in Visakhapatnam district.

Parameters	Total Resources (2022)
As per GEC 2017 & 2020	MCM
Dynamic (Net GWR Availability)	**135.40**
• Ground Water recharge from rainfall	74.80
• Ground Water recharge from other sources	60.59
• Environmental Flows	
Gross GW Draft	**59.11**
• Irrigation	25.91
• Domestic and Industrial use	33.20
Provision for Drinking and Industrial use for the year 2025	41.84
Net GW availability for future use	62.27
Stage of GW development (%)	49%

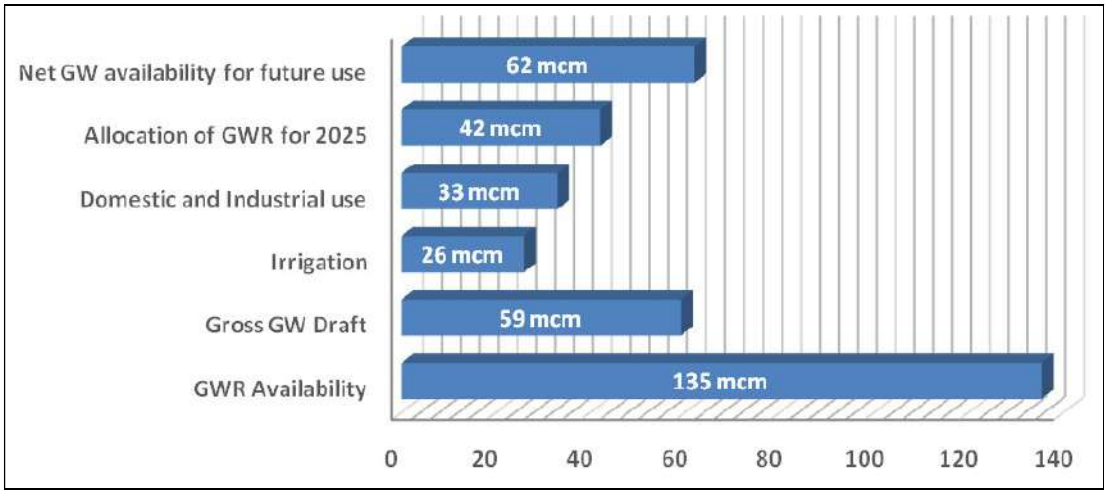


Fig.4.1 a: Graphical presentation of Dynamic ground water resources in Visakhapatnam district (GEC 2020).

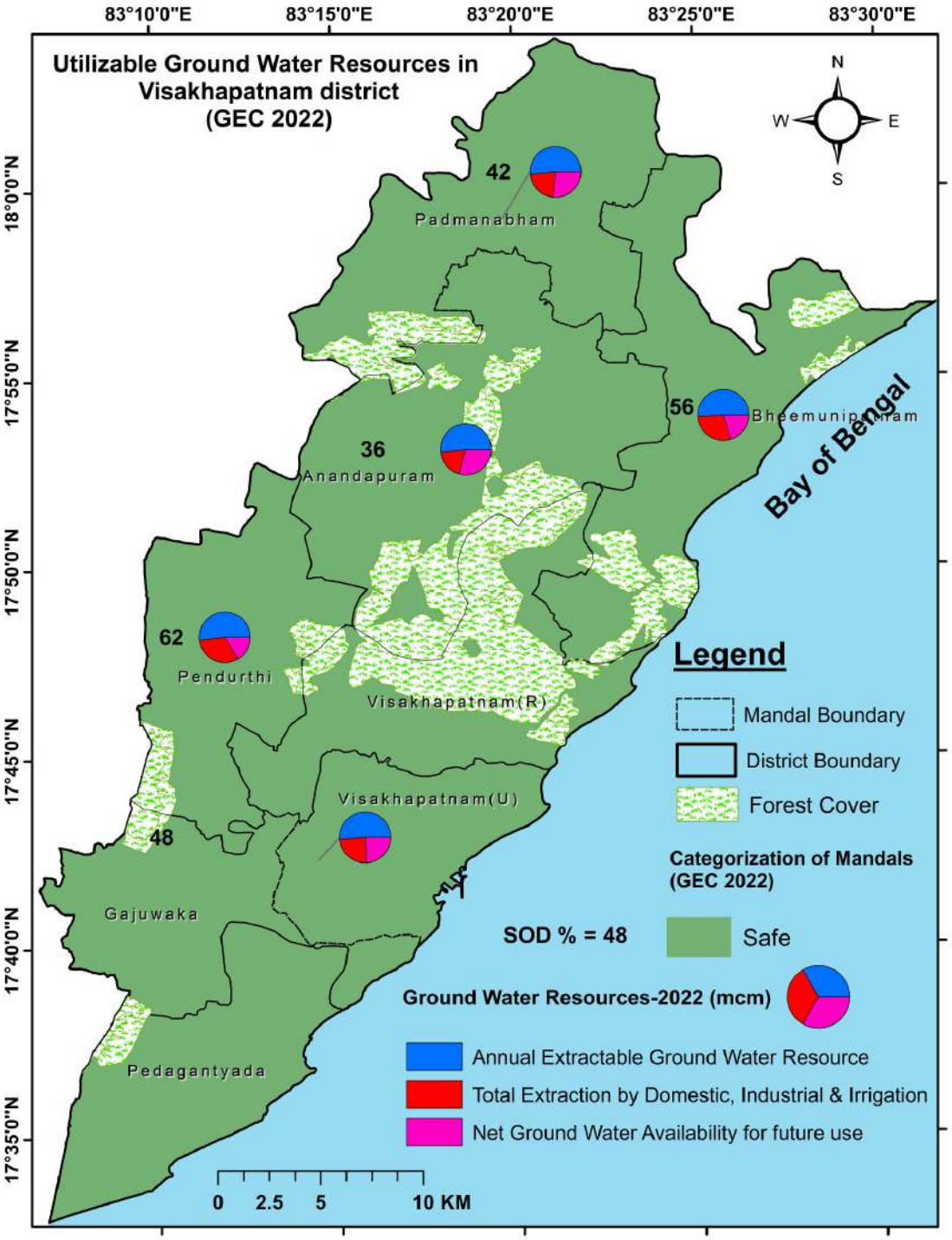


Fig.4.1 b: Categorization of mandals (GEC 2020) in Visakhapatnam district.

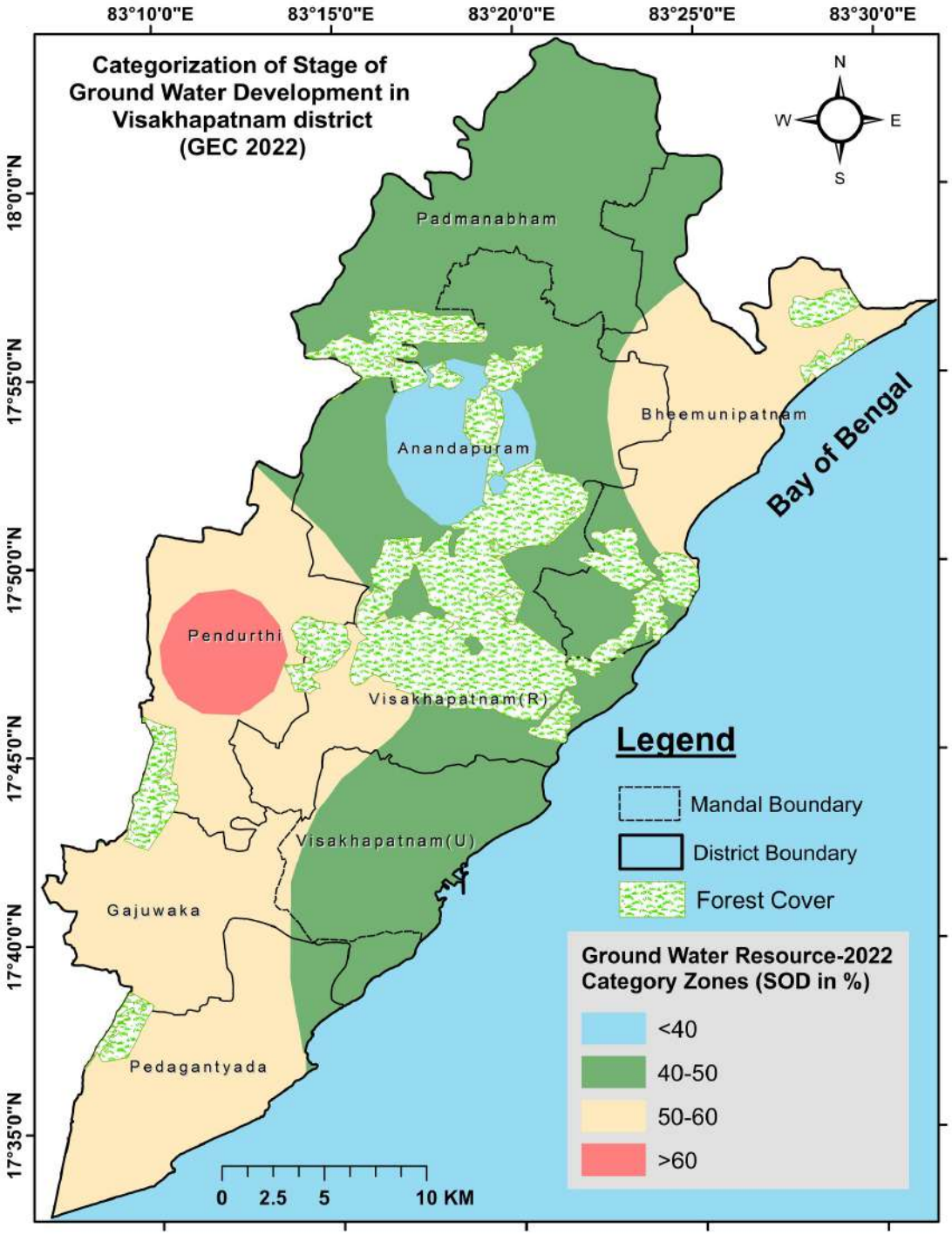


Fig.4.1 c: Utilizable ground water resources in Visakhapatnam district.

5.0 VISAKHAPATNAM URBAN WATER SUPPLY

The Greater Visakhapatnam Municipal Corporation (GVMC) with an area of 624 Sq km, comprises of Visakhapatnam Municipal Corporation, Gajuwaka Municipality and 32 villages. It forms large residential and industrial base with major industries such as the Visakhapatnam Steel Plant, Bharat Heavy Plate and Vessels and the Hindustan Zinc etc. The GVMC is the responsible body for water supply.

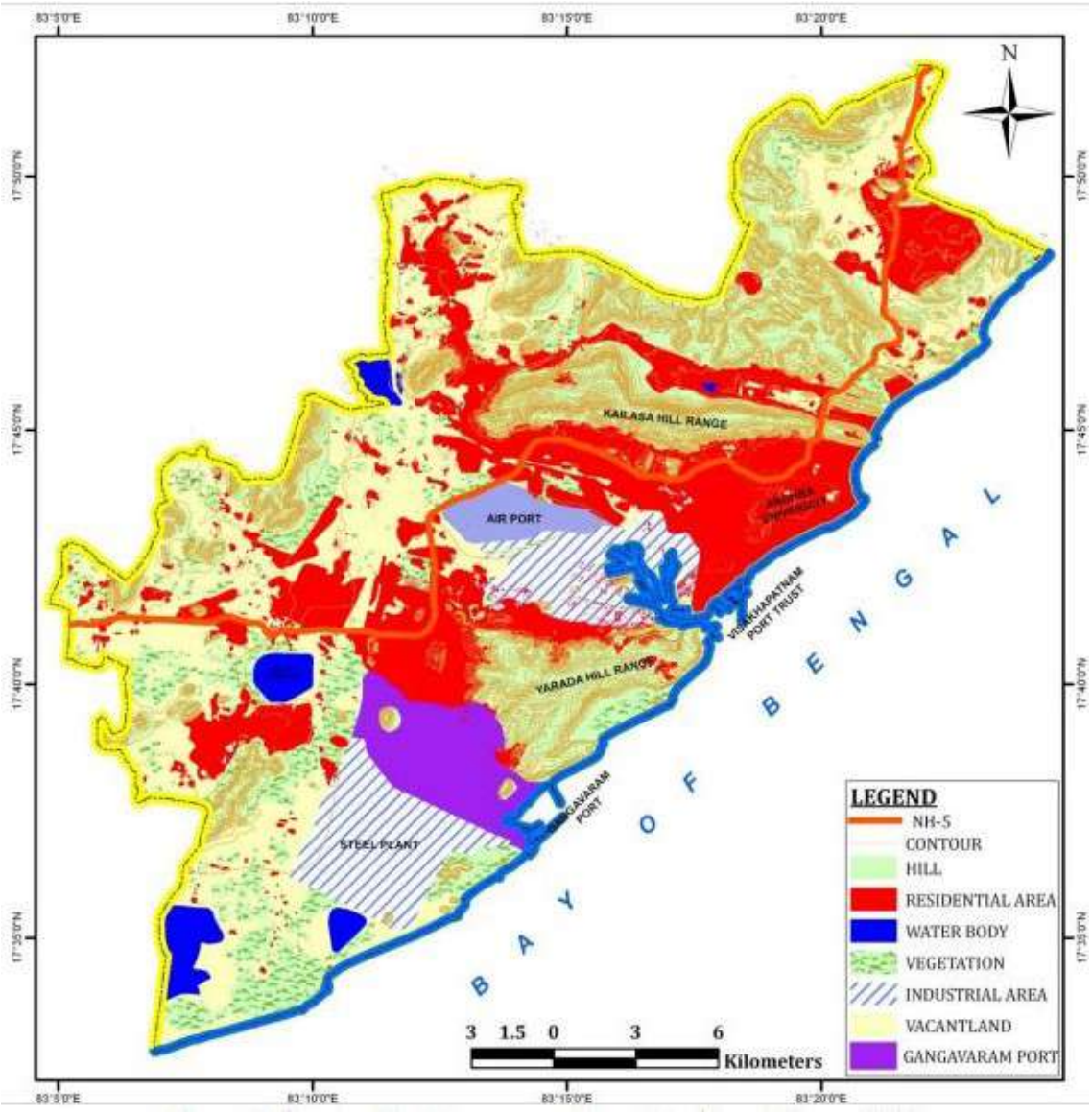


Fig-5.1: Map showing Visakhapatnam Urban Area

5.1 Surface Water Availability:

The GVMC is supplying drinking water to the GVMC area from the followoing reservoirs.

Table 5.1: Sources of Surface Water Supply to GVMC area

S. No.	Name of Reservoir	Distance from GVMC (Km)	Quantity drawn in MLD
1	Godavari/Yeleru reservoir	190	182 to 204
2	Raiwada reservoirs	56	72.5
3	Gosthani river surface	25	20.5
4	Thatipudi reservoir	60	45.0
5	Meghadrigadda reservoir	GVMC	41.0
6	Mudasarlova reservoir	GVMC	4.5
7	Gambheeram reservoir	GVMC	2.7
8	Anakapalli sarada river	GVMC	6.0
9	Bheemili (Samayyavalasa Nagarampalem)	GVMC	5.8
		Total	**380 MLD**

Out of 380 MLD of raw water is available from all sources; GVMC is able to drawn 345.5 MLD due to shortage of water from Raiwada reservoir and Gostani River.

5.2 Ground Water Availability in GVMC Mandals:

As per Dynamic Ground Water Resources estimation (2022), the total ground water resources are estimated as 406 MCM at GVMC and surrounding all zones. The dynamic ground water resources are 61.78 MCM and in-storage water resources estimated as 344.14 MCM. The stage of groundwater development for Greater Visakhapatnam Municipal Corporation is 48% and categorized in Safe mandal. The details are as follows (refer Table 5.2).

Table 5.2: Particulars of ground water resources availability in GVMC Visakhapatnam (GEC, 2022)

Total Area of GVMC & surrounding all zones Visakhapatnam (Sq.km)	Methods used	Dynamic GW Resources (GEC, 2022) (M.Cu.m)	In-storage (M.Cu.m)	Total Resources (M.Cu.m)
624.20	RIF and GWF	61.78	344.14	401.55

Aquifer		Particulars	MCM
Unconfined Aquifer* (Hard rock)	:	Dynamic Resources (Annual Extractable Ground Water Resources)	61.78
	:	Ground Water extraction for all uses	29.47
	:	Annual allocation for Domestic and Industrial Uses	32.36
	:	Stage of Ground Water Development and Category	48% (Safe)
Confined Aquifer (Hard rock)	:	In-storage ground water resources	344.14

***SY for Un-Confined Aquifer: 1.5 to 3%**

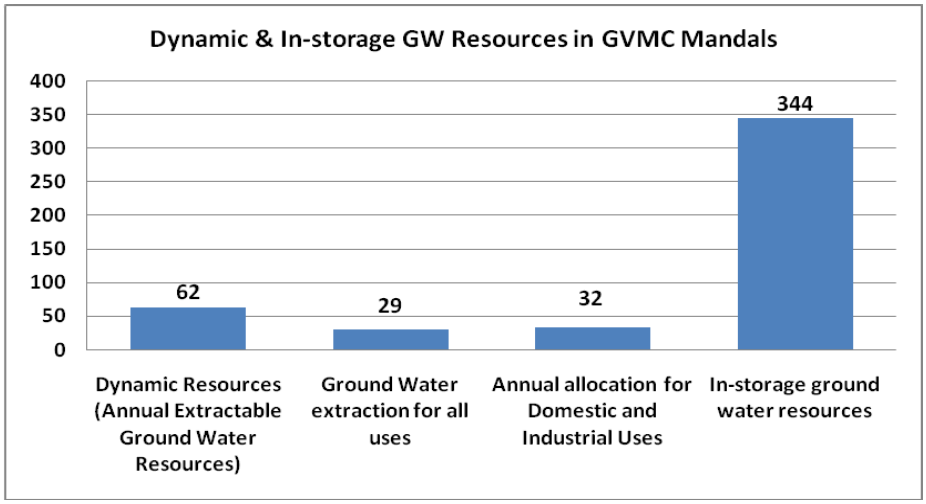


Fig - 5.2 Graphical representation of Ground water Resources of GVMC area

5.3 Total Water Demand for Deficit in GVMC:

The total demand projected by GVMC Visakhapatnam Urban and its surroundings for the Year 2020 is 490 MLD (180 MCM/year), 828 MLD (302 MCM/Year) for the Year 2031 and 1014.02 (393 MCM/Year) for the Year 2041 (Table-5.3 and Fig-5.3).

Table 5.3: Water Demand vs Supply and deficit in present and future perception for GVMC.

S. No.	Year	Population	Quantity @135 LPCD (in MLD)	Bulk demand (MCM)	Losses @15% (MCM)	Clear Water Demand (MLD)	Present Supply (in MLD)	Deficit (in MLD)
1	2023	23,48,655	315	115	20	490	391	99
2	2031	36,80,000	496	219	114	828	391	-437
3	2041	49,20,000	664	264	150	1078	391	-687

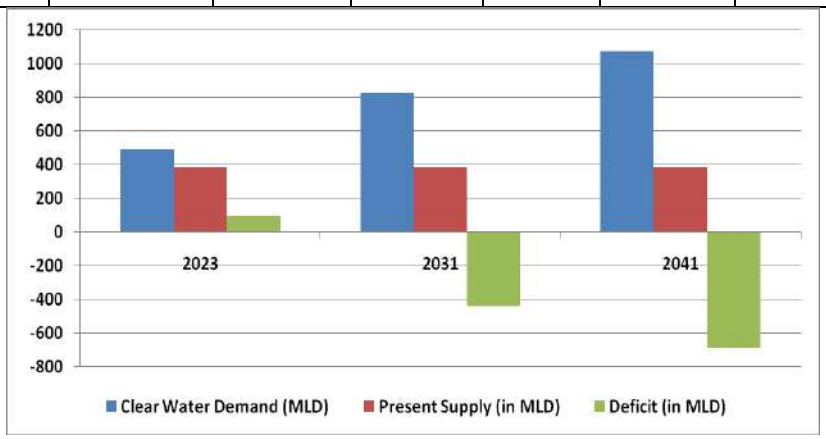


Fig-5.3: Graphical representation of water supply status in GVMC area

5.4 Proposed Plans for Water Supply in GVMC area:

The present and future water demands can't be meted out from ground water in GVMC area. Ground Water can only be supplementing the water supply during lean periods and majority of the water requirements need to be meted out from surface water sources. The GVMC had submitted proposals for improvement of water supply in GVMC area through interconnections to trunk main and lying of distribution pipe lines of about 245 kms and service reservoirs for mitigating the water supply in peripheral areas and hill areas. Also, upon completion of from Polavaram reservoir, the allocated 12 TMC of water supply, the demands of water for both domestic and industrial needs of Visakhapatnam can be meted out.

In addition, for sustainable ground water development and management, there is a need for artificial recharge and roof top rainwater harvesting for ground water recharge in the urban areas.

6. GROUND WATER RELATED ISSUES

Overall, the Visakhapatnam district, the ground water regime scenario is good except a few locations where quantity and quality issues identified. Over the years, there is no significant change in water levels in the district and water levels are showing a significant rising trend as well as declining trend. However, which need to be managed through suitable artificial recharge and water conservation practices. Water logging does not exist in the canal command and irrigated areas of the district.

In terms of ground water quality, geogenic and anthropogenic contamination in the district is noticed at few mandals. High concentration of Nitrate, more than permissible limits in the district during pre-monsoon can be attributed to urban sewerage disposal, improper drainage system and excess use of fertilizers. There is no contamination by nitrate concentration during post monsoon season due to dilution. High concentration of Fluoride is observed in some places. Though the district has a coast line of 132 km, no sea water intrusion/ ingress is reported and observed. Heavy metal pollution of ground water exists in the Mindi - Chukkavanipalem industrial area due to the industrial effluents.

- Low yield (<1 lps) occurs in 76% of area in the district. This is mainly attributed to hard rock aquifers, absence of primary porosity, negligible development of secondary porosity, discrete occurrence of fractures etc.
- Deep water levels in the range of 10-20 m bgl occupy about 4% of the area falling mostly in parts of Padmanabham, Bhimunipatnam and Visakhapatnam (U) mandals.
- Water-logging is observed in and around Bhimunipatnam, Visakhapatnam urban village coastal areas with areas of ~10 to 15 sq.km during post-monsoon seasons.
- High concentration of Fluoride min 0.14 to max 2.71 mg/L during pre-monsoon season is found in groundwater at Gajuwaka, Bhemili, and Visakhapatnam Rural mandals. Higher concentration of fluoride in ground water is attributed due to source rock i.e Granite Gneiss and Khondalite, rock water interaction where acid-soluble fluoride bearing

minerals (fluorite, fluoro-apatite) gets dissolved under alkaline conditions. Higher residence time of ground water in deeper aquifer may also cause.

- High nitrate (**>** 45 mg/L) is observed in 8 locations of 3 mandals i.e Visakhapatnam Urban, Rural and Bhimilipatnam mandals during pre-monsoon in range of 47 mg/L to 162 mg/L. Higher concentration of Nitrate is mainly attributed to unscientific sewage disposal of untreated effluents in urban and rural areas. High use of fertilizers in rural areas.
- Industrial corridor in Visakhapatnam urban and rural surrounding mandals, high concentration of trace metals found in ground water in a few samples due to industrial contamination.
- The high concentration of EC (**>** 3000 micro-seimens/cm) in 5% area is **>**3000 µ Siemens/cm of the area is observed during pre-monsoon and post-monsoon seasons respectively.
- As per the fresh-saline water interface drawn along and across the coast shows, no saline water interface with the depth range of 300 m. There is no saline water intrusion in the district. However, few pockets there are salinity issues owing to marine depositional conditions.

7. MANAGEMENT STRATEGIES

The lacking of assured irrigation facilities in the rural areas, the demand and gap in water supply in urban areas, the dependency of ground water is increasing day by day. The ground water development in hard rock aquifer system may led to a steady fall in water levels, pose sustainability issues which may pose challenges to food and drinking water security in future. The occurrence of fractures in hard rock aquifers are very limited in extent, as the compression in the rock reduces the opening of fractures at depth and the majority of fractures occur within 50-100m depth (59%). Though the general ground water scenario of the district is good, the uneven groundwater availability and its utilization indicates for requirement of integrated water resource management and sustainable practices for maintaining sustainable ground water scenario in the district.

Management plan

The study suggests notable measures for sustainable groundwater management, which involves a combination of various measures given below.

1. Supply side measures
2. Demand side measures
3. Regulatory measures & Institutional measures

7.1 Supply side measures:

7.1.1 Artificial Recharge structures:

In the district 5 MCM of recharge potential volume is varialble in the aquifers. This can be utilized for implementing artificial recharge structures. Govt. of AP under IWMP and MNREGS constructed a total of 124 Check dams and 06 percolation tanks in the district. The details of ARS have been provided in the figure 7.1 and table 7.1.

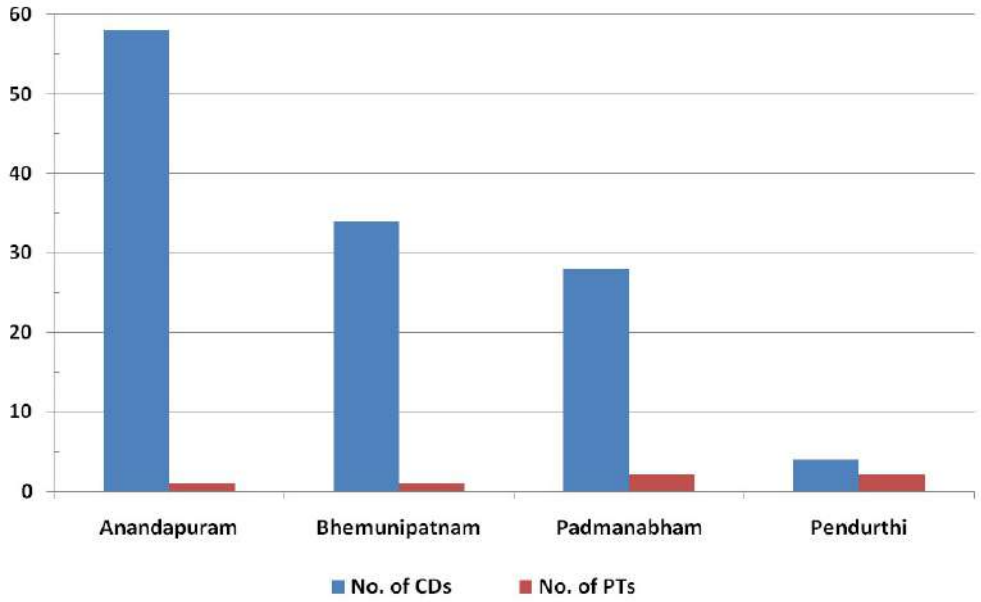


Fig- 7.1 Graphical representation of Existing ARS

Division	No. of CDs	No. of PTs
Anandapuram	58	01
Bhemunipatnam	34	01
Padmanabham	28	02
Pendurthi	04	02
Total	**124**	**06**

Table-7.1: No. of existing ARS and WCS

It is recommended for desiltation of all existing artificial recharge structures and water conservation structures for effective utilization of existing structures and storage created through these structures. In addition, there is a feasible area for artificial recharge existed around are of 314 sq.km, in which there is a scope for construction of 354 artificial recharge structures (**110 CDs** and **244 PTs**) can be proposed, which can be taken up as per requirement in the districts (Fig-7.2). With this 12 MCM of ground water can be recharged (Table 7.2).

Geographical Area(sq.km)	Area identified for AR (sq.km)	**Volume of Unsaturated Zones (MCM)**	**Volm of Surface water Required (MCM)**	**Volume of Surplus Runoff (MCM)**	Feasible CDs	Feasible PTs	Total	Existing CDs	Existing PTs	Proposed CDs	Proposed PTs	No. of ARS/sq.km
992	314	**5**	**6**	**12**	234	250	484	124	6	110*	244*	0.65
**Village wise calculations done and considered 100% surplus runoff*												

Table 7.2: Feasible for Artificial Recharge structures at village wise calculations and summary details

Existing geo-tagged water harvesting structures (ARS), feasible are details, proposed check dam, percolation tank details and urban area, industrial area details for artificial recharge are shown in mandal wise in the Fig-7.2.

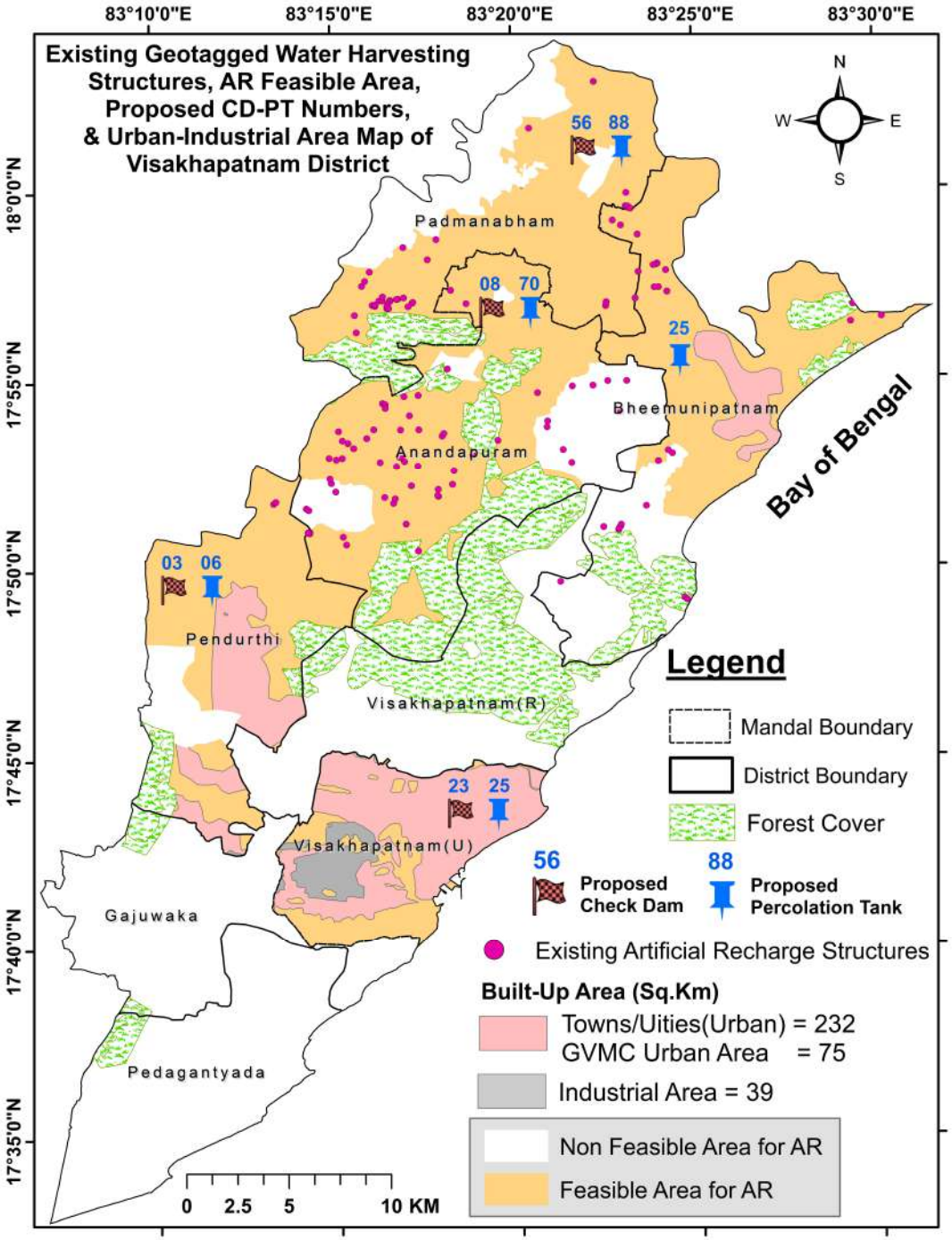


Fig- 7.2 Map showing existing and proposed AR Structures in Visakhapatnam district

Total Urban and Industrial area is 232 sq.km to be had used for rain water harvesting in Visakhapatnam district. There is 201 mcm water savings can be done, If considered a 100% area for recharge or harvesting mechanism. 130mcm, 100mcm, 50mcm water saving may be achieved if the vicinity considers at 75%, 50% and 25% respectively. The information of Urban/Town and Industrial area wise calculations is given in table and figure (Table 7.3 & Fig. 7.3).

In Total Visakhapatnam District	Volume@ 100% Area (mcm)	Volume@ 75% Area (mcm)	Volume @50% Area (mcm)	Volume@ 25% Area (mcm)	Total Area Covered (Sq.Km)
Town/ City (Urban)	167	125	83	42	192.8
Industrial	34	25	17	8	39.4
Total Savings: (mcm)	201	150	100	50	232.1

Table 7.3: Urban/ Town Area utilizable for Rain water Harvesting Mechanism for saving of water in Visakhapatnam District

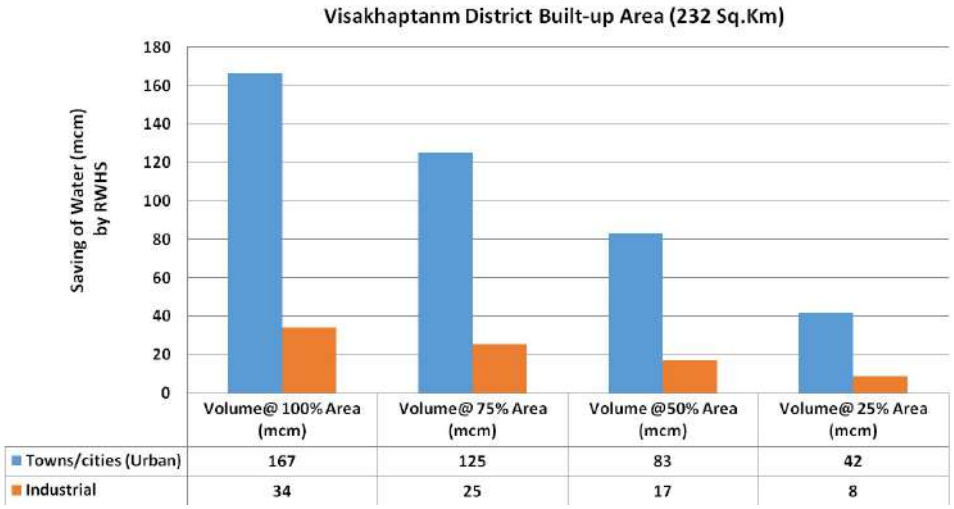
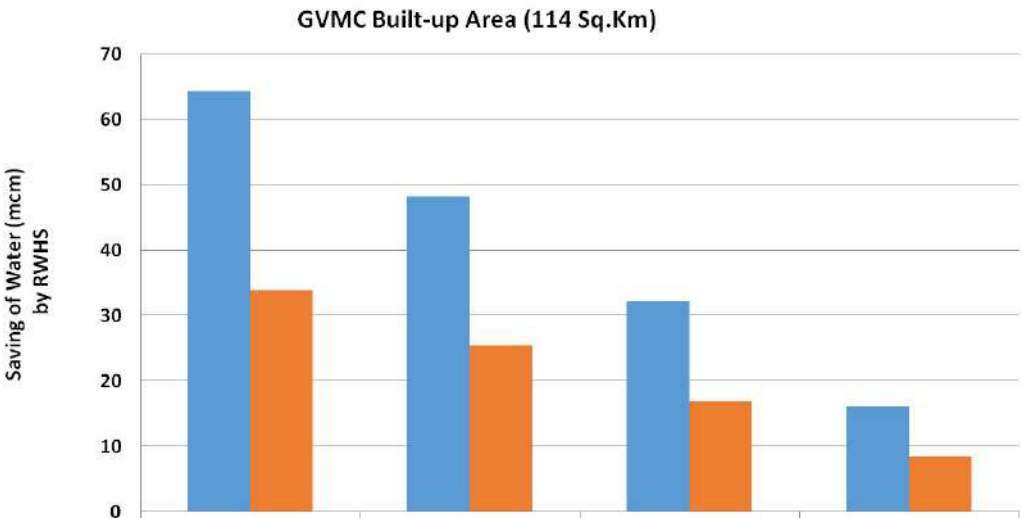


Fig- 7.3 Graphical representation of Water saving vs area selected for Rain water harvesting mechanism in Urban/Town and Industrial area

In Visakhapatnam district, GVMC & VRDMA urban/town and Industrial area only considered for rain water harvesting mechanism, the total area is available 144sq.km. There is 98 mcm water savings can be done, if considered a 100% area for recharge or harvesting mechanism. 74mcm, 49mcm, 25mcm water saving may be achieved if the vicinity considers at 75%, 50% and 25% respectively. The information of Urban/Town and Industrial area wise calculations is given in table and figure (Table 7.4 & Fig. 7.4).

In GVMC Area	Volume@ 100% Area (mcm)	Volume@ 75% Area (mcm)	Volume @50% Area (mcm)	Volume@ 25% Area (mcm)	Total Area Covered (Sq.Km)
Town/ City (Urban)	64	48	32	16	**74.6**
Industrial	34	25	17	8	**39.4**
Total Savings: (mcm)	**98**	**74**	**49**	**25**	**114**

Table 7.4: Urban/ Town Area utilizable for Rain water Harvesting Mechanism for saving of water in GVMC & VMRDA area in Visakhapatnam District



	Volume@ 100% Area (mcm)	Volume@ 75% Area (mcm)	Volume @50% Area (mcm)	Volume@ 25% Area (mcm)
Towns/cities (Urban)	64	48	32	16
Industrial	34	25	17	8

Fig- 7.4 Graphical representation of Water saving vs area selected for Rain water harvesting mechanism **in GVMC & VMRDA area**

While calculating the requirement of no. of artificial recharge structures in each village, the recharge potential if aquifer is estimated by multiplying the area with specific yield and unsaturated thickness (post-monsoon water levels below 5 m bgl). Potential surface run off is estimated by following standard procedures. 20% run off yield is considered as uncommitted yield for recommending artificial recharge structures.

- Roof top rainwater harvesting structures should be made mandatory for all Government buildings and all Apartments and infrastructures in urban areas (as per norms of CGWA, 2021).

7.1.2 Water Conservation Measures (WCM) (Farm Ponds):

The farm ponds are the ideal water conservation structures, which are constructed in the low-lying areas of the farm. The Govt. of Andhra Pradesh had constructed around 1425 no. of farm ponds, other structures 1136 no. found in this district. It is recommended for desilting of existing farm ponds. Further, it is recommended to construct 1580 farm ponds (20 in each village in 79 villages).

7.2 Demand side measures:

The yield of bore well is <1.0 lps identified in 738 sq.km in Hard rock (Eastern Ghat) area of the district. As sustainability of bore well is low, the sprinkler and drip irrigation system with suitable cropping pattern is recommended in where recharge potential is more than the total run off and surplus run off availability. Particularly, in parts of uplands of the district, as a measure for groundwater conservation, protection and management is needed.

7.3 Other measures

- Existing ARS like percolation tanks and check dams and dried dug wells can be de-silted involving people's participation through the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS). This will also help in sustainable management of groundwater resources.
- As a mandatory measure, every groundwater user should harvest and recharge rainwater through artificial recharge structures in proportionate to the extraction. This mechanism will be helped in rejuvenating ground water vulnerability zones into fresh water zones.
- A Participatory Groundwater Management (PGWM) approach in sharing of groundwater and monitoring resources on a constant basis along with effective implementation of the existing 'Water, Land and Trees Act' of 2002 (WALTA-2002) are the other measures suggested. Subsidy/ incentives on cost involved in sharing of groundwater may be given to the concerned farmers.
- In urban and rural areas, the sewerage line should be constructed to arrest leaching of nitrate into ground water system. GVMC must adopt proper treatment of sewerage water treatment plants by installing STPs in urban area before it reaches to ocean (otherwise which will a create major damage in ocean bio-diversity).

- Implementation Polavaram canal towards drinking water supply for Visakhapatnam urban and rural areas, which will be helped in minimizing ground water abstraction rate in urban areas.
- In urban and rural area, the sewerage line should be constructed to arrest leaching to nitrate.

With the above interventions, the likely benefit would be the net recharge/ conservation of 213 MCM (12 mcm from Artificial Recharge structures@20% Uncommited runoff and 201 mcm by rain water harvesting mechanism) of ground water in the district.

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