केन्द्रीय भूमि जल 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

Parts of East & West Godavari District, Andhra Pradesh

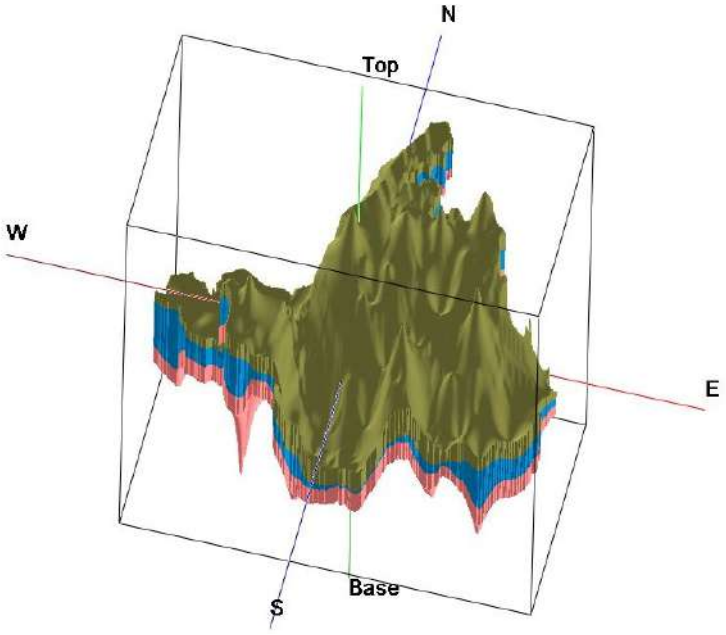
दक्षिणी क्षेत्र, हैदराबाद

Sourthern Region, Hyderabad

भारत सरकार
जल शक्ति मंत्रालय
जल संसाधन नदी विकास एवम् गंगा संरक्षण विभाग
केंद्रीय भूमि जल बोर्ड

GOVERNMENT OF INDIA
MINISTRY OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES, RD & GR

REPORT ON
AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES IN PARTS OF EAST & WEST GODAVARI DISTRICTS, ANDHRA PRADESH STATE
(AAP-2021-22)



CENTRAL GROUND WATER BOARD
APSUO, VISAKHAPATNAM
JUNE, 2022

REPORT ON
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(AAP-2021-22)

CONTRIBUTORS' PAGE

Principal Author		**Nilima Patra**
Designation	:	**Assistant Hydro geologist** CGWB, APSUO, Visakhapatnam, AP
Supervision & Guidance		
Sh. Ravi Kumar Gumma	:	Scientist-C & OIC AP State Unit Office, Visakhapatnam
Sh. J. Siddhardha Kumar	:	Regional Director, CGWB, SR, Hyderabad

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REPORT ON
AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES IN PARTS OF EAST & WEST GODAVARI DISTRICTS, ANDHRA PRADESH STATE
(AAP-2021-22)

AT A GLANCE

S.No.	Item		Particulars
1	District	:	East & West Godavari
2	Revenue Mandals	:	36
3	Villages	:	1275
4	Geographical area	:	9963 km^2
5	Mappable area for NAQUIM Studies	:	4942 km^2
6	Hilly Area	:	5021 km^2
7	Population (2021 Census)	:	
8	Location	:	Latitude: 17°15′- 18°00′ N Longitude: 81°00′ - 82°30′ E
9	Rainfall (Normal)	:	~1182 mm
10	Geomorphology	:	Structural hills, Structural valley, Pediplains, Pediment, Denudation hills, Residual hill,Flood plain
11	Major Rivers	:	Godavari
12	Land Utilization (Ha)	:	Forest occupies ~47 % of the total geographical area, remaining area is cropped, barren and waste land, Net cropped area 4018 sq.km (38% of total area).
13	Soils	:	Loamy skeletal soils and Clayey soils
14	Cropping Pattern (2019-20) (Gross Area: 4018 sq.km)	:	Crops grown are Paddy, Maize, Pulses, Greengram, Blackgram, Red gram, Foodgrain and Sugarcane, Cotton.
15	Irrigation Sources (Ha)	:	Tanks/Ponds: 22376 ha Canals: 59724 ha Other sources: 91000 ha
16	Geology	:	Banded Gneiss, Khondalite, Granite Gneiss, Chanrockite, Sandstone
17	Hydrogeological data points	:	54 number of VES data of CGWB & 14 number of wells data from SGWD.
18	Ground water yield (lps)	:	2.91
19	Water Levels: Depth to water levels (m bgl) (2011-2020)	: :	64 number of monitoring wells **Pre-monsoon:** 2 to 25 m bgl (average: 7.73 m bgl) and Majority of the water levels during this season are in the range of 5.0 to 10 m covering 82 % of the area, followed by 10.0 to 15.0 m bgl (12 %) and 2 to 5 m bgl (4 %). The water levels >10 m bgl occupy in parts of Gangavaram, Sunnampadu, Ellavaram, Kondrukota,Durgada,Tatiparthi and Kota villages. **Post-monsoon:** Majority of the water levels during

			this season are in the range of 2.0 to 5.0 m covering 50% of the area, followed by 5.0 to 10 m bgl (46%), < 2.0 m bgl (3%). The water levels > 10 m bgl occupy about 1 % of the area falling in parts of Gollaprolu, Polavaram, Y.Ramavaram mandals. Shallow water level < 2.0 m bgl occupy in parts of Jaggampet, Tallapudi, Gangavaram, Devipatnam, Rajavommangi, Prathipadu, Korukonda, Sankavaram and Gokavaram mandals. **Water table elevations** ranges from 13 – 1006 in pre monsoon period and 15 - 1019 m amsl during post monsoon periods respectively. The general ground flow is towards NE to SW part of study area.	
20	Water Level Fluctuations (May vs. November) (Decadal mean)	:	The water level fluctuations vary from 0.31 to 16.42 m with average rise of 3.27 m. The water levels rise is observed throughout the entire district and no fall in water level is recorded. Rise in water level range of 2 to 5 m covers majority of the area with 85 % followed by 0 to 2 m rise in 13% of the area. Rise of water levels > 5 m is observed in 2% of area in Ellavaram, Gudigudem, Pothavaram, Velama kotturu, Durgada, Tatiparthi Villages.	
21	Hydrochemistry	:	Total 91 data used for analysis Pre-monsoon (2019) (CGWB: 33+ SGWD: 29). Post-monsoon (2019) (CGWB: 0+ SGWD: 29).	
21.1	Electrical Conductivity (µ Siemens/cm)	:	**Pre-monsoon (2019):** Electrical conductivity varies from 130 to 4350 (avg: 1095) µ Siemens/cm. In 63 % of area EC is within 750 - 1500 µ Siemens/cm. **Post-monsoon (2019):** Electrical conductivity varies from 235 - 2350 (avg: 920) µ Siemens/cm. In 76 % of area, EC is < 750 µ Siemens/cm.	
21.2	Fluoride mg/l	:	**Pre-monsoon:** Fluoride concentration varies from 0.02 - 1.37 mg/L and found within permissible limits (1.5 mg/L). **Post-monsoon:** Fluoride concentration varies from 0.02 - 1.15 mg/L and within permissible limits (1.5 mg/L)	
21.3	Nitrate mg/l	:	**Pre-monsoon:** Nitrate concentration varies between 0.18 - 138 mg/L. In 70% of samples Nitrate concentration is beyond permissible limits of 45 mg/L	
22	Conceptualization of Aquifers	:	Weathered zone (~18 m). **Aquifer-I (~30 m).** As per well data analysis weathering depth observed: 0 to 40 m bgl.	Fractured zone (10 – 140 m) **Aquifer-II (~10-140 m).** As per well data analysis Fractured depth observed:

				08 to 140 m bgl.
23	Aquifer Characterization	:	The Weathered zone (avg. ~18 m) varies from 5 to 40 m bgl. Thickness of weathered zone is in the range of 10 - 20 m in most part of area covering ~54 % of area, > 20 m weathering thickness occurs in ~34 % of the area and shallow (<10 m) weathering occurs in rest of the area.	Fractures at the depth range of 30 to 60 m are more predominant (67 % of the area), < 30 m fractures occur in 28 % area, 60 to 100 m fractures occur in 3 % of area and deep fractures in the range of 100 – 150 m occur in 1 % area of Thatukur, Buttayagudem
24	Ground water Resources (2020) MCM	:		
24.1	Net Dynamic groundwater availability	:	**1356.74**	
24.2	Gross GW Draft	:	**337.42**	
24.3	Provision for Domestic & Industrial (2025)	:	**45.91**	
24.4	Average Stage of Ground water development (%)		**25.2**	
24.5	Net GW Availability for future irrigation	:	**1026.29**	
24.6	Categorization of mandals		Mandal wise it varies from 2 % to 66%	
25	Major Ground Water Issues Identified	:	Low yield (<1 lps) occurs in ~92 % of area. Deep water levels (> 10 m bgl) are observed during pre as well as post-monsoon season in 13 % and 1.2 % of the area respectively. Prone to water logging conditions during post monsoon periods in Rajavommangi, Sankhavaram, Kirlampudi, Jaggampeta, Gangavaram, Gokavaram, Korukonda, Devipatnam areas. Nitrate concentration in 11 mandals during pre-monsoon period is more than permissible limits. High concentration of EC (> 3000 µ Siemens/cm) in <1 % of the area is observed during pre-monsoon period.	
26	Management Strategies	:		
27	**<u>Supply and Demand side measures</u>:** Recharge Calculations (GEC, 2020)	:	1. Desiltation and maintenance of existing CD's and PT's. 2. As sustainability of bore well is low, the sprinkler and drip irrigation system with suitable cropping pattern wherever feasible may be practiced as a measure for groundwater conservation, protection and management. 3. Micro irrigation is recommended in all villages i.e 100 ha per village. Total area of 146,300 ha needs to be micro irrigated as demand side intervention	

EXECUTIVE SUMMARY

The Study area comprises of hard rock parts of East & West Godavari districts covering an area of 9963 km^2 and in which 4942 km^2 is mappable area. Administratively, the area is governed by 41 mandals with 1275 villages. The density of population in East Godavari is 477 people/ km^2 and in West Godavari is 510 people/ km^2. (2011 census). The area receives an average annual normal rainfall of 1182 mm of which SW monsoon 66% and north-east monsoon contributes 20%.

The area is underlain by Khondalite (54%), Granite Gneiss (29%) and Charnockites (14%). Geomorphologically, the study area can be broadly divided into 4 distinct unit viz.; structural hills, structural valley, Pedi plains, and flood plain. The forest cover occupies ~47% of the total geographical area, remaining area is considered as plain & upland area which are mostly cropped lands. The gross cropped area (2019-20) is 401823 ha. Main crops grown are Paddy, Maize, Pulses, Greengram, Blackgram, Red gram, Food grains, Sugarcane and Cotton.

Ground water yield of hard rock formations like Khondalites, Charnockites, Granite gneiss aquifers vary from 0.21 to > 8.3 lps. Majority of fractures occur within 60 m depth and deepest fracture is encountered at 140 m bgl.

Water levels are monitored through 64 number of monitoring wells. During pre-monsoon majority of the water levels are in the range of 5.0 to 10 m covering 82 % of the area, followed by 10.0 to 15.0 m bgl (12 %) and 2 to 5 m bgl (4 %). The water levels > 10 m bgl occupy in parts of Gangavaram, Sunnampadu, Ellavaram, Kondrukota, Durgada, Tatiparthi and Kota villages. During post-monsoon, majority of the water levels are in the range of 2.0 to 5.0 m covering 50% of the area, followed by 5.0 to 10 m bgl (46%), < 2.0 m bgl (3%). The water levels > 10 m bgl occupy about 1 % of the area falling in parts of Gollaprolu, Polavaram, Y. Ramavaram mandals. Shallow water level < 2.0 m bgl occupy in parts of Jaggampet, Tallapudi, Gangavaram, Devipatnam, Rajavommangi, Prathipadu, Korukonda, Sankavaram and Gokavaram mandals.

During pre & post monsoon seasons (May and November), the water-table elevation ranges from 13 – 1006 and 15 - 1019 m amsl respectively and general ground flow is towards NE to SW part of study area. The water level fluctuations vary from 0.31 to 16.42 m with average rise of 3.27 m. The water levels rise is observed throughout the entire district and no fall in water level is recorded. Rise in water level range of 2 to 5 m covers majority of the area with 85 % followed by 0 to 2 m rise in 13% of the area. Rise of water levels > 5 m is observed only in 2% of area in Ellavaram, Gudigudem, Pothavaram, Velama kotturu, Durgada, Tatiparthi Villages.

The Electrical conductivity during pre-monsoon varies from 130 - 4350 (avg: 1095) µ Siemens/cm. In 63 % of area EC is within 750-1500 µ Siemens/cm. In 32 % area, it is <750 µ Siemens/cm, in 5 % area it is 1500-3000 µ Siemens/cm and EC above >3000 µ Siemens/cm covering < 1% area. Nitrate concentration varies between 0.18 - 138 mg/L and 70% of samples are beyond permissible limits of 45 mg/L. Fluoride concentration varies from 0.02-1.37 mg/L and all samples are within permissible limits of 1.5 mg/L. During post monsoon, the Electrical conductivity varies from 235-2350 (avg: 920) µ Siemens/cm. In 76 % of area, EC is < 750 µ Siemens/cm; in 20 % area, it is 750-1500 µ Siemens/cm; in 4 % area it is within 1500-3000 µ

Siemens/cm; Fluoride concentration all samples are below BIS permissible limits of 1.5 mg/L and varies from 0.02 -1.15 mg/L.

The aquifers of the study area can be conceptualized in to Aquifer-1, comprising of weathered, semi weathered zone and contiguous fractured zone up to 30 m and Aquifer-2, discrete fractured occurrence between the depth of 30-200 m. However, the weathered zone varies from 5 to 40 m bgl with an average thickness of 18 m. Thickness of weathered zone is in the range of 10 - 20 m in most part of area covering ~54 % of area, >20 m weathering thickness occurs in ~34 % of the area and shallow (<10 m) weathering occurs in rest of the area. The fractures in the range of 30 to 60 m depth are more predominant (67 % of the area), < 30 m fractures occur in 28 % area; 60 to 100 m fractures occur in 3 % of area and deep fractures in the range of 100 - 150m occur in 1 % area of Thatukur, Buttayagudem mandals.

The Net dynamic replenishable ground water availability as on 2020 is 1356.74 MCM, gross ground water draft is 337.42 MCM, provision for drinking and industrial use for the year 2025 is 45.91 MCM and net available balance for future irrigation use is 1026.29 MCM. The stage of ground water development varies from 2% to 66%.

The overall ground water scenario of the study area is good except localized issues like occurrence of deep-water levels (> 10 m bgl) during pre as well as post-monsoon season in 13 % and 1.2 % of the area, prone to water logging conditions during post monsoon periods in Rajavommangi, Sankhavaram, Kirlampudi, Jaggampeta, Gangavaram, Gokavaram, Korukonda, Devipatnam areas and high Nitrate concentration in 11 mandals during pre-monsoon period.

The proposed management strategies in the study area include desiltation and maintenance of existing CD’s and PT’s. adoption of drip and sprinkler irrigation as a measure for groundwater conservation and to tackle the low yield scenario of the study area. Micro irrigation is recommended in all villages i.e 100 ha per village.

NUMBER OF DATA POINTS USED FOR PREPARATION OF VARIOUS MAPS-PARTS OF EAST & WEST GODAVARI DISTRICT, ANDHRA PRADESH STATE

S. No	Data	Aquifer	Total Data Points	Source	
				CGWB	SGWD
1	Panel Diagram (3-D)			Expl: VES: 55	15
2	Hydrogeological Sections			Expl: VES: 55	15
3	Fence/panel Diagrams			Expl: VES:	
4	Depth of weathering	1 no	71	Expl: 0 VES: 46	25
5	Depth of fracturing	1 no	71	Expl: 0 VES: 46	25
6	Groundwater Potential zones	Weathered zone		Expl: VES:	
		Fractured zone		Expl: VES:	
7	Transmissivity (m^2/day)	Unconfined to Confined		Expl:	
8	Discharge (lps)	Unconfined to Confined	11	Expl: 0	11
9	Depth to Water Level Maps (2019)	Combine	128	128	
10	Water Level Fluctuation	Combine	64	64	
11	Water quality Pre-monsoon 2019 Post-monsoon 2019	Combine	**91** Pre: 62 Post:29	 33 0	 SGWD:29 SGWD:29

1. INTRODUCTION

Aquifer mapping is a process wherein a combination of geologic, geophysical, hydrologic and chemical analyses 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 rock 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 rock (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 purpose. 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 comprehensive aquifer map and to suggest suitable groundwater management plan on 1: 50,000 scale.

1.2 Scope of study: The main scope of study is summarised 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: The study area of parts of East & West Godavari districts, Andhra Pradesh having geographical area of 9963 km^2, lies between north latitude 17°15′ to 18°00′ and east longitude 81°00′ to 82°30′(**Fig.1.1**). Out of total area, majority of area is forest/hill area. Administratively the district is governed by 27 mandals of East Godavari district and 9 mandals of West Godavari District and 1275 revenue villages with a population of ~14.11 lakhs (2011 census). The area is bounded by Godavari Delta in the south, where as in the east and north east it is bounded by Visakhapatnam district and in the west by Telengana state, and north by Odisha & Chhattisgarh states. The density of population in East Godavari is 477 people/ km^2 and in West Godavari is 510 people/ km^2. (2011 census).

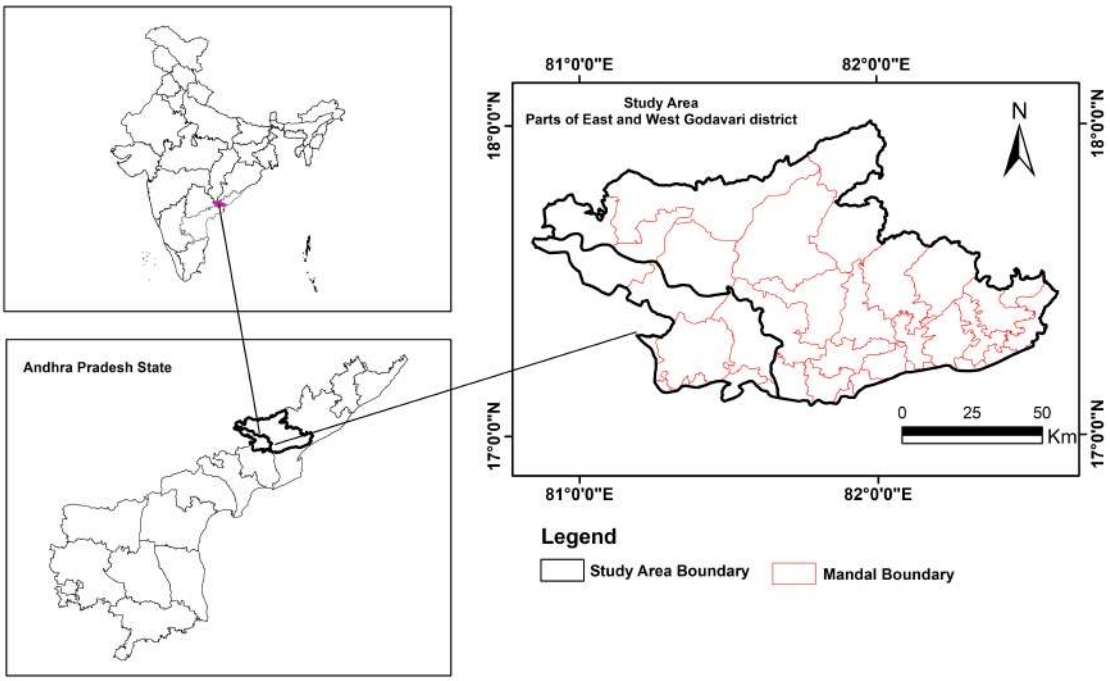


Fig.1.1: Location map of Study Area

1.4 Climate and Rainfall: The area experiences sub humid and tropical climate with summer and good seasonal rainfall. The area falls under Godavari Agro-climatic zone based on the geographical characteristics such as rainfall (1000-1200 mm), temperature, nature of soils etc. Southwest monsoon enters into the region in June and lasts until the end of September and Northeast monsoon from October to December along with occasional cyclonic storms. Summer starts in March, and reaches peak in May with average daily maximum temperature of 37.7°C and winter season starts in late November and lasts until early February with average daily minimum temperature of 19.1°C in December at Tuni IMD station. The annual normal rainfall of the area varies from 840 mm (Gollaprolu mandal) to 1503 mm

(Rajavommangi mandal) with weighted average of 1182 mm as per the data collected from DES, Andhra Pradesh. Southwest monsoon contributes 66 % (771 mm), Northeast monsoon by 20 % (231 mm) and rest 14 % by January to May months of normal annual rainfall. Mean monthly rainfall varies from 237 mm in July to 5.1 mm in December. The normal annual rainfall of Meteorological station Tuni maintained by IMD is 1154 mm with average number of annual rainy days of 61. Isohyetal map prepared using annual normal rainfall of mandals in the district collected from DES, Andhra Pradesh is shown in **Fig.1.2**. The region received annual rainfall of 1065 mm (9% below normal) and an excess rainfall of 1557 mm (32% above normal) in 2020.

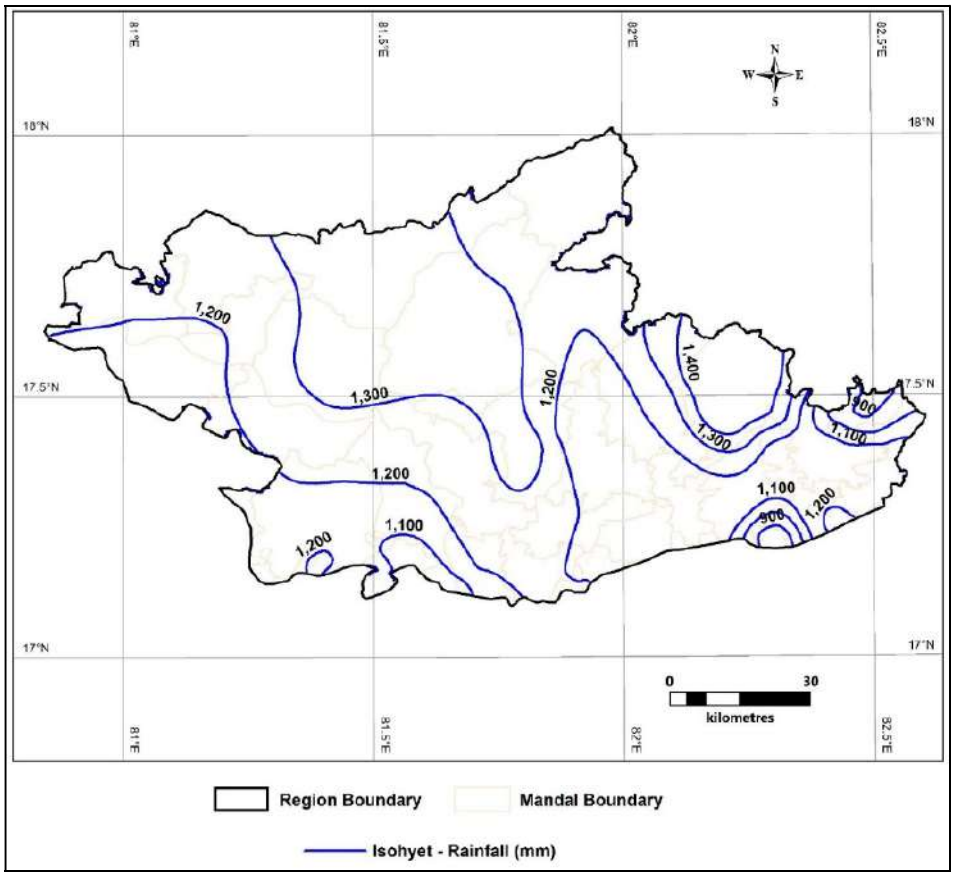
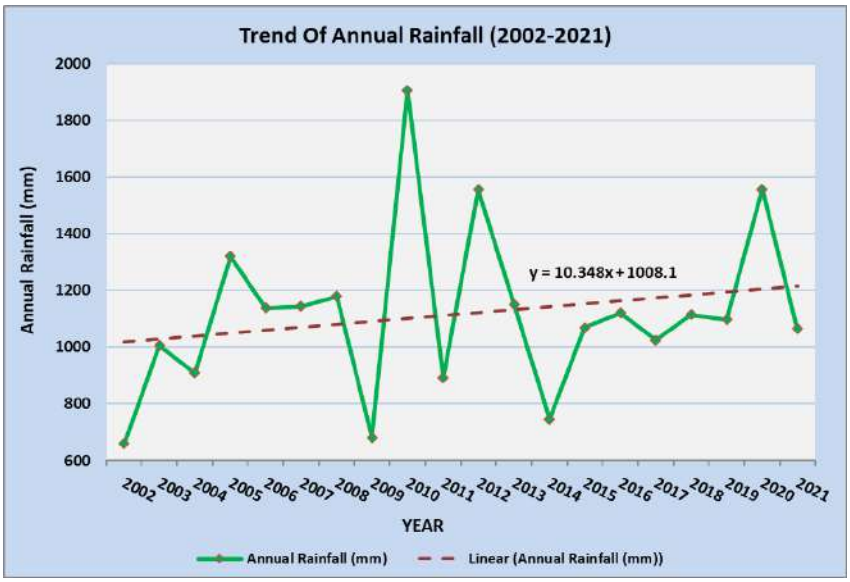


Fig.1.2: Isohyetal map of Study Area

Analysis of time series annual rainfall data of the region for 20 years (2002-2021) considering data of IMD rain gauge stations in the region shows increasing trend in annual rainfall of around 10.3 mm/yr (**Fig.1.3a**). The region received large excess rainfall (+60% & above departure from normal) in 2010, excess rainfall (+20% to +59%) in 2 years (2012 & 2020), deficient rainfall (-20% & below normal) in 6 years (2002-2004, 2009, 2011 & 2014) and normal rainfall (-19% to +19%) in the remaining 11 years. The monthly rainfall trend graph for 20 years shows increasing trend in rainfall during Southwest monsoon months especially for July (6.3 mm/yr) and decreasing trend for October (-3.7 mm/yr) (**Fig.1.3b**).



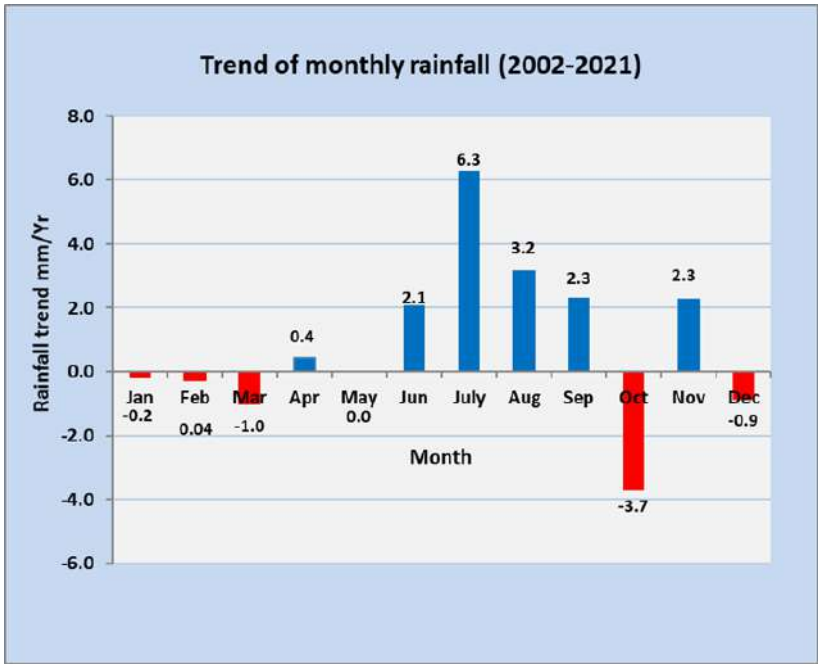


Fig. 1.3a and Fig. 1.3b

1.5 Geomorphological Set up: Geomorphologically the district can be broadly divided into 4 distinct units viz.; structural hills, structural valley, pediplains, and flood plain. The majority parts of study area are occupied by Structural hills and all are composed of charnockites and Khondalites. The pediplains comprise pediment, residual hills. The flood plains are developed along Godavari River course. The other landforms observed are plateau denudation hills, channel fill, etc. **(Fig.1.4.)**

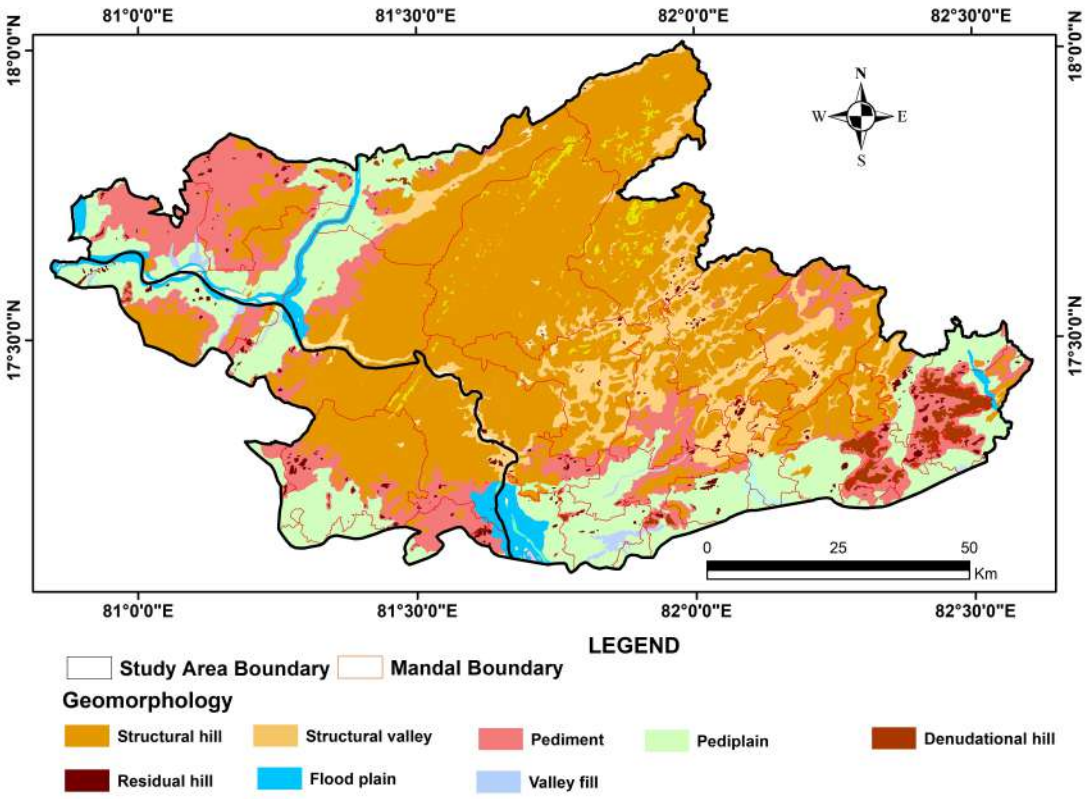


Fig.1.4: Geomorphology of Study Area.

1.6 Drainage and Structures:

The area is drained by Godavari River and separates the study area into two districts i.e East Godavari & West Godavari and flows NW to SE directions. Lineaments trend along E-W, NE-SW and NW-SE directions. Map depicting drainage, water bodies, lineaments and watershed boundaries is presented in Fig.1.5.

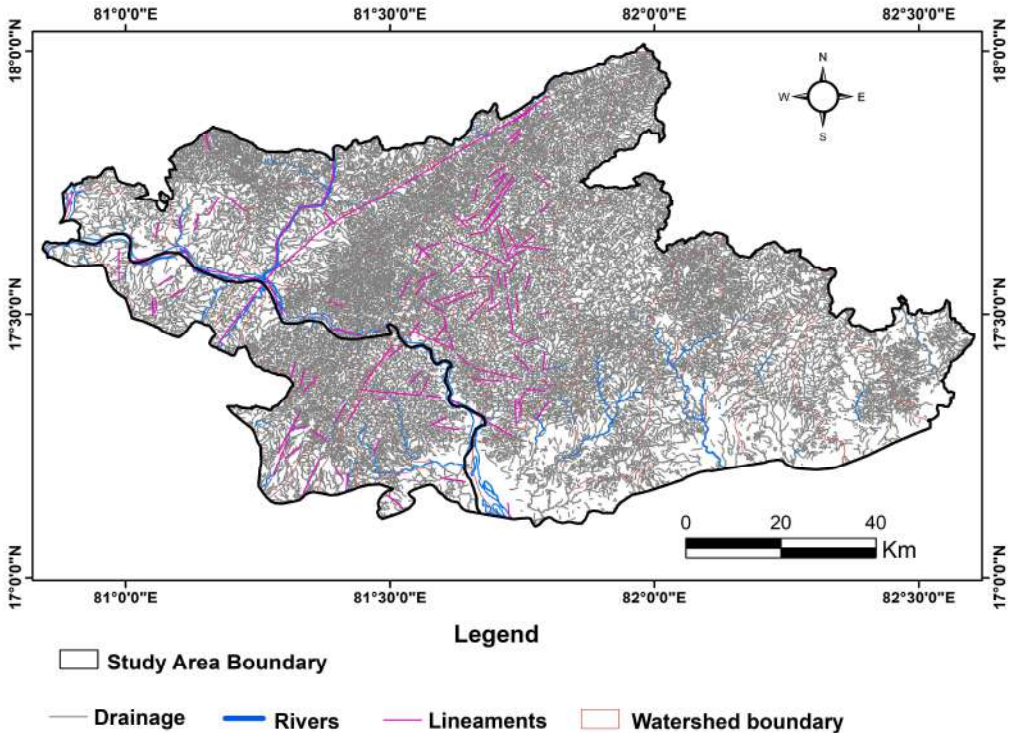


Fig.1.5: Drainage, lineaments and watershed boundaries of study area

1.7 Land use, Irrigation & Cropping Pattern:

Forest occupies ~47 % of the total geographical study area, Kharif & Rabi (double-cropped) is 13%, kharif land is 11% and wasteland is 19%. Total cropped area is 377567 ha, forest occupies 402803 ha and Gross irrigated area is 173178 ha. During Kharif & Rabi season main crops grown are Paddy, Maize, Pulses, Green gram, Black gram, Red gram, Food grain Sugarcane and Cotton. Land use and land cover map of the district is depicted in Fig. 1.6. Land use pattern and area irrigated by different sources in the area are presented as Fig. 1.6a & 1.6b.

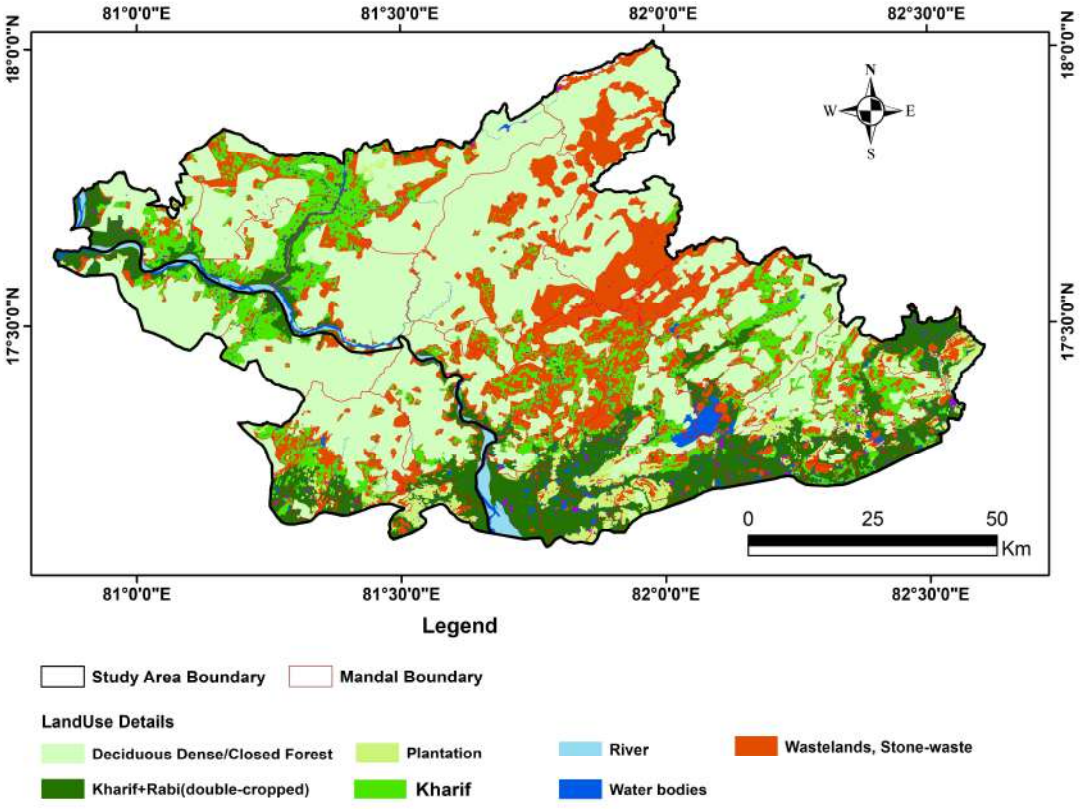


Fig.1.6: Land use and land cover of study area.

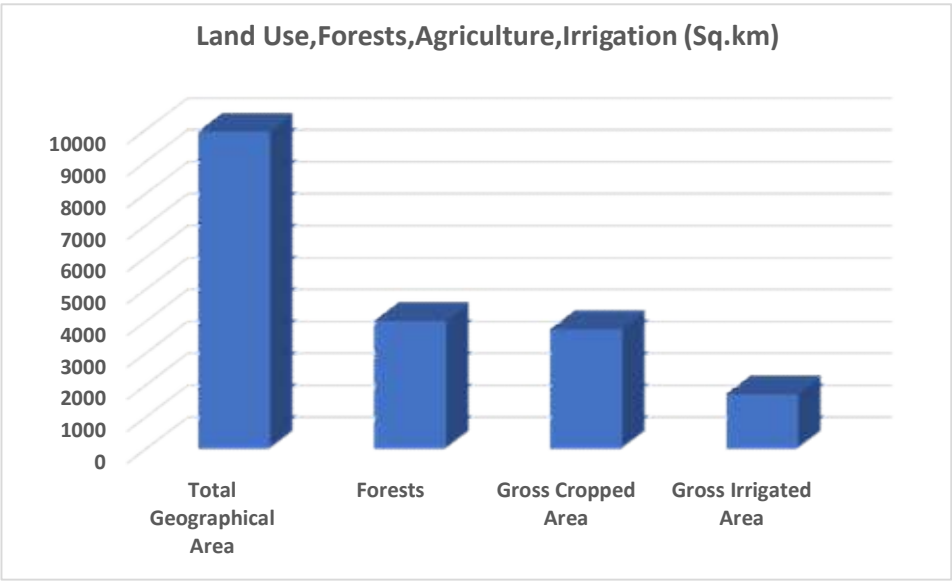


Fig.1.6a: Land use pattern

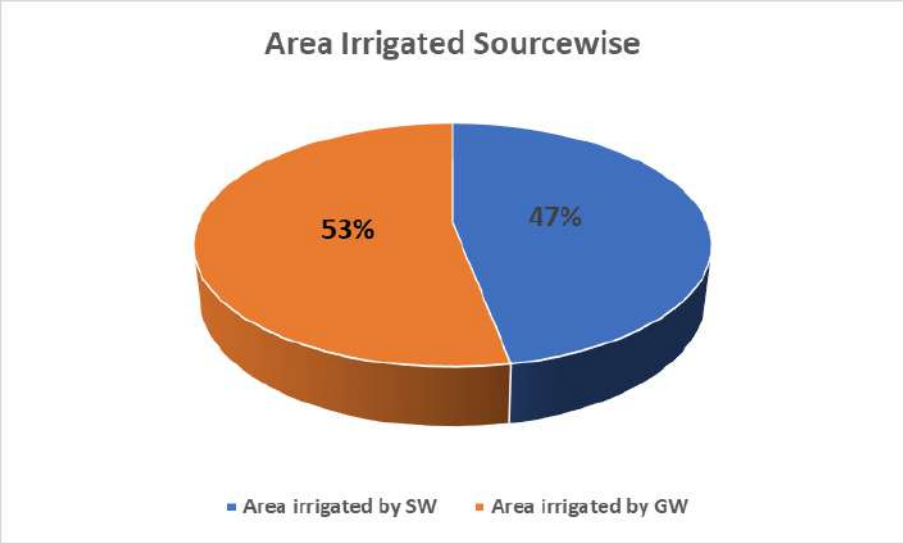


Fig.1.6b: Area Irrigated by Different Sources

1.8 Soils: The area is mainly occupied by Clayey soils (62%) (Moderately deep clayey soil with medium available water content (AWC),well drained & Shallow gravelly clay with low available water content (AWC), well drained), Loamy Soil (36%) (Which are shallow to deep with medium to low available water content (AWC) & well drained) and rock land (2%) (**Fig.1.7**).

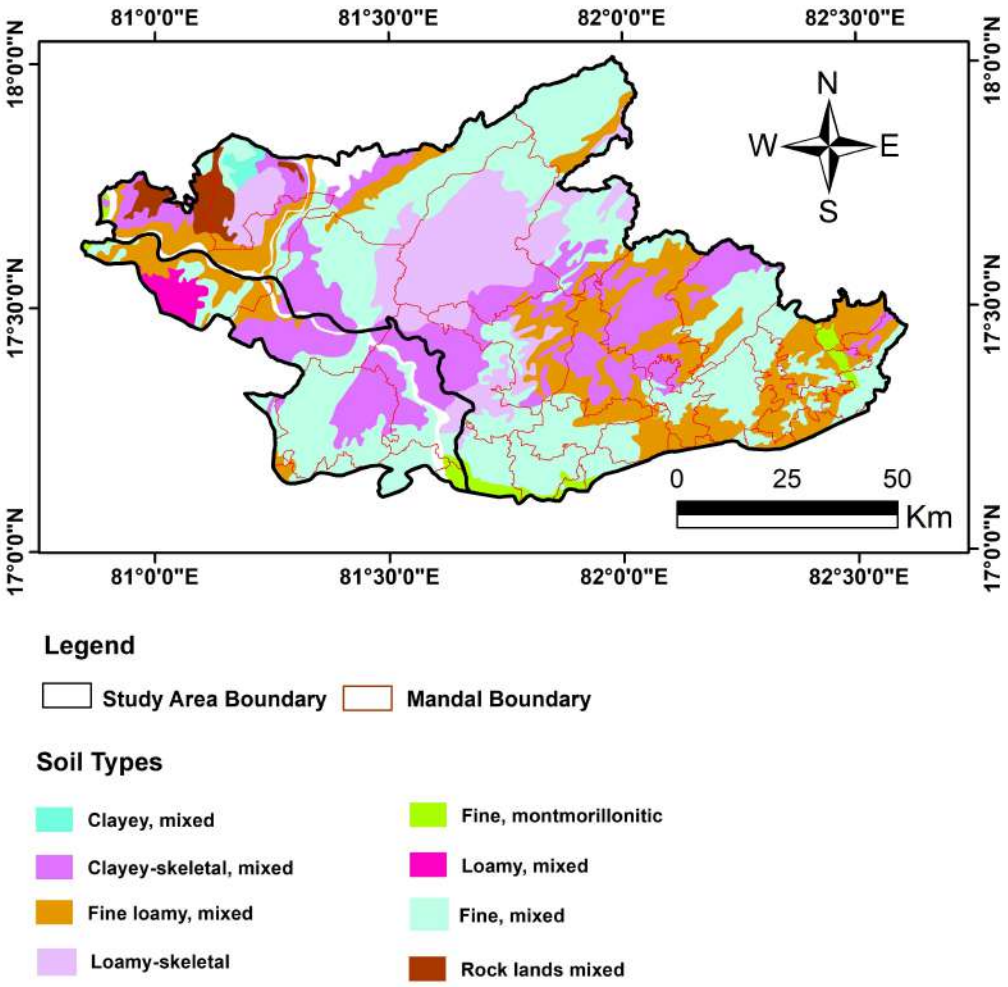


Fig.1.7: Soil map of Study area

1.9 Prevailing Water Conservation/Recharge practices: Govt. of Andhra Pradesh had constructed 2230 no. of percolation tanks, 298 no. of Check dams, 2260 no. of Farm ponds under PMKSY-Watershed & MGNREGS. The details are presented as Fig 1.8a & Fig 1.8b.

1.10 Geology: The study area is underlain by various geological formations, namely Khondalite (54%), Granite gneiss (29%), Charnockites (14%), Alluvium (2%) and Sandstone (1%). The Khondalite group include feldspar-Quartz-Biotitic-Gneiss, Feldspar-Quartz-gneiss, garnet-sillimanite gneiss and Garnetiferous gneiss. The Charnockite group include pyroxene granulite (basic charnockite) and charnockite (acid/intermediate). Alluvium comprising clay sands and gravels occur along Godavari River.

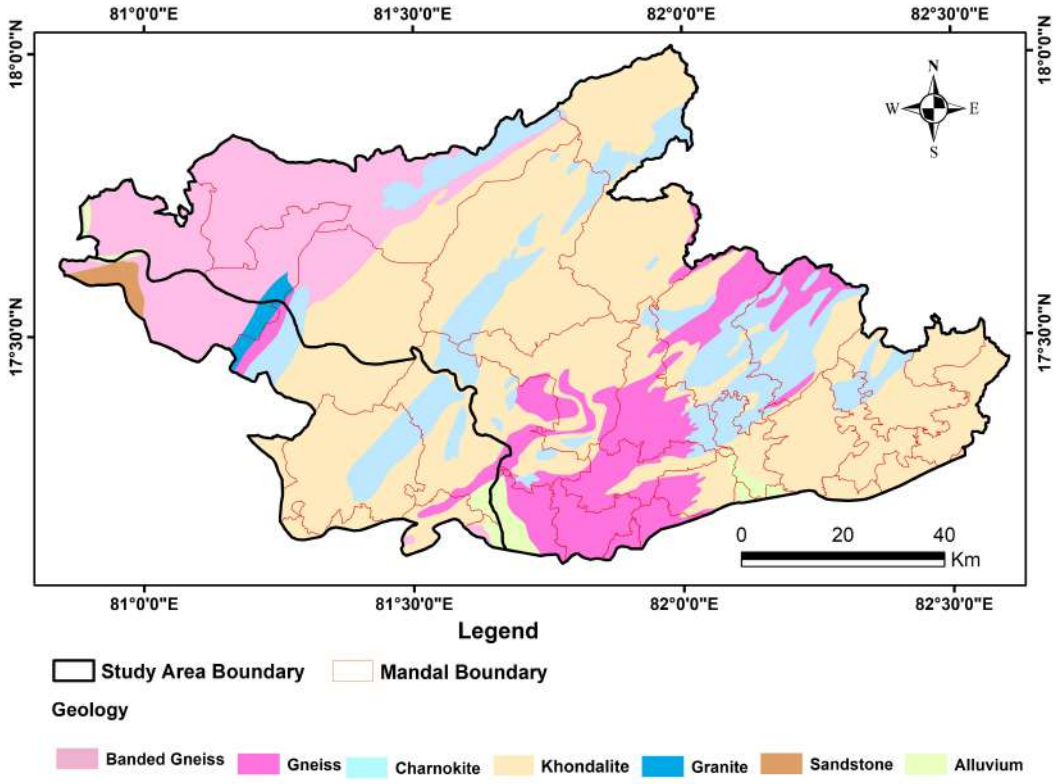


Fig.1.9: Geology of Study area

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	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 (1:50,000 scale)	Analysis of data and preparation of GIS layers and preparation of aquifer maps	Integration of Hydrogeological, Geophysical, Geological and Hydro-chemical data.
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 Hydrogeological Studies

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 principal aquifer in the area is Banded gneisses, Charnockites and khondalites. The occurrence and movement of ground water in these rocks is controlled by the degree of interconnection of secondary pores/voids developed by fracturing and weathering. Based on hydrogeological data points, hydrogeological map is prepared.

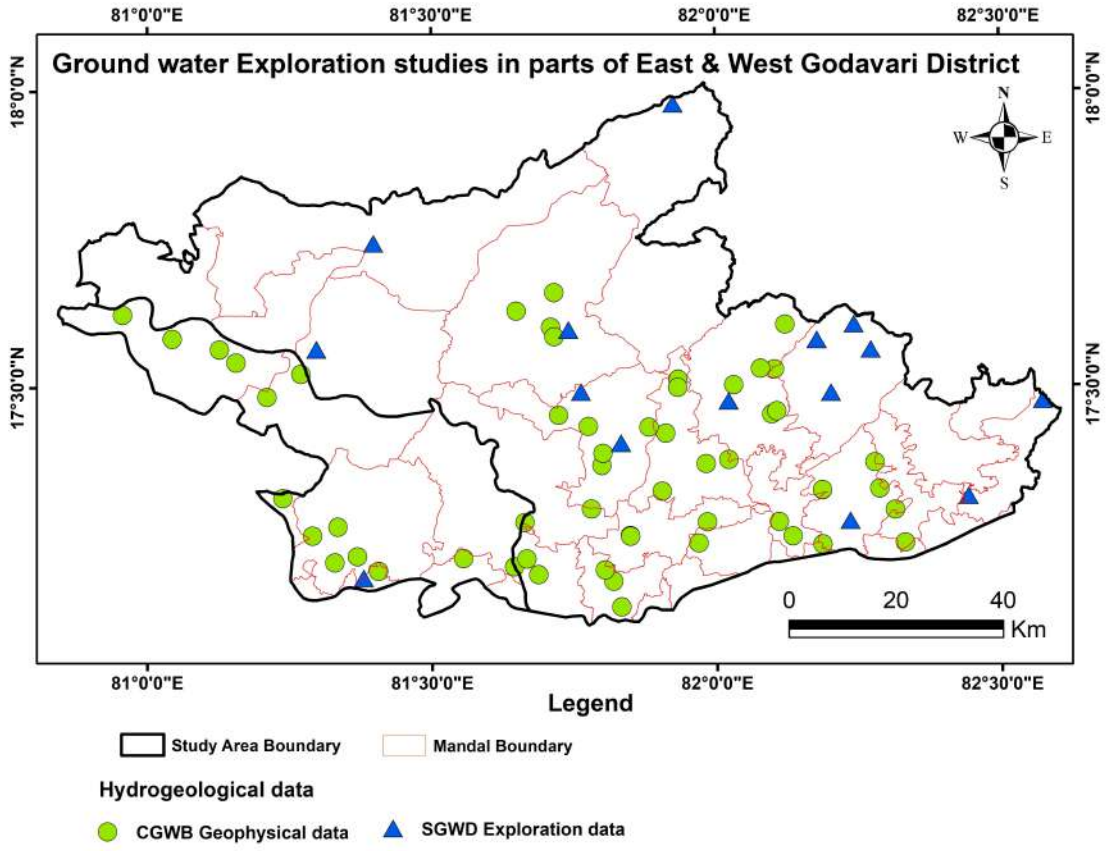


Fig. 2.1: Hydrogeological data availability.

2.1.1 Ground water occurrences and movement:

Ground water occurs under unconfined and semi-confined/confined conditions and flows downward from the weathered zone into the fracture zone. 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 140 m depth. At some location like Thatukur, Buttayagudem, deep fractures occur in the range of 100-140 m. The discharge in the exploratory wells vary from 0.21 to as high as 8.3 lps. The hydrogeological map of the area is presented in **Fig. 2.2.**

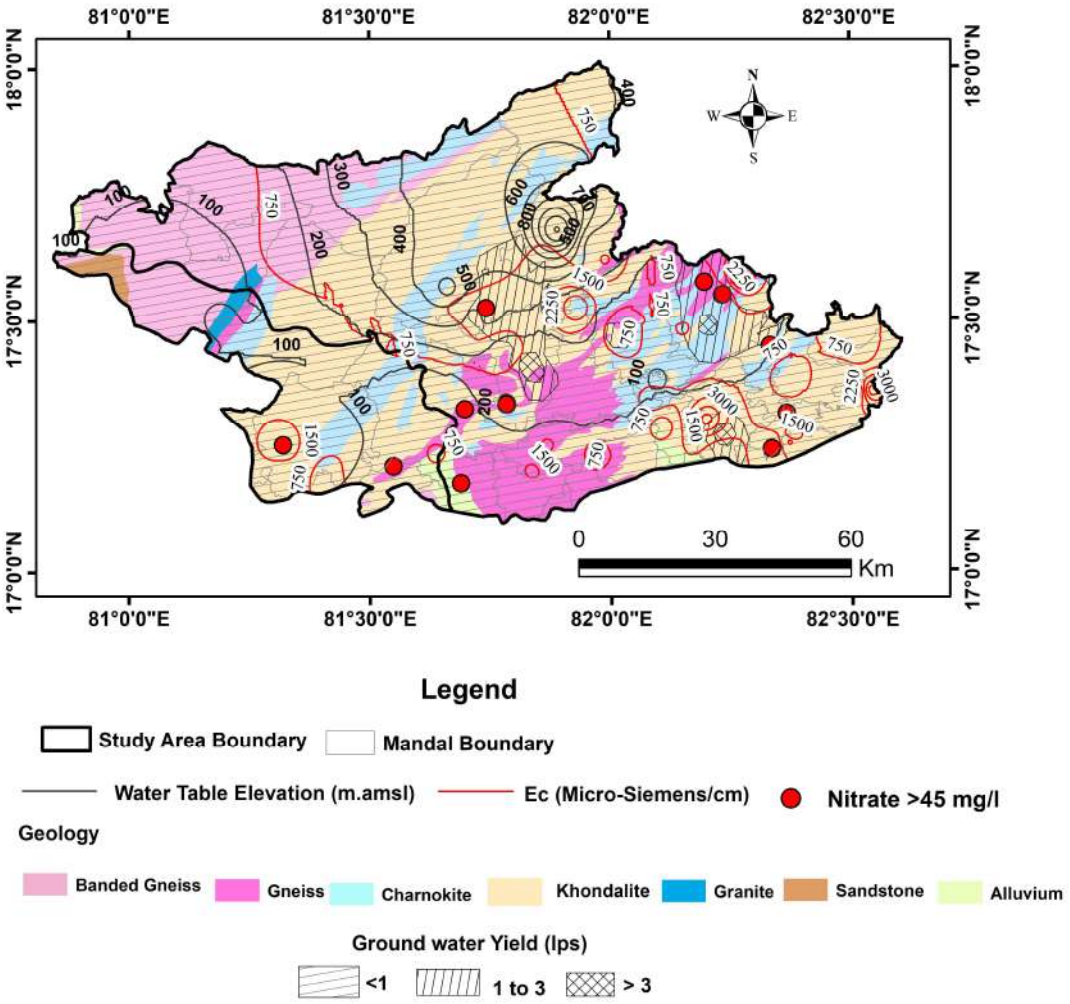


Fig.2.2: Hydrogeological map of Study Area.

2.1.2 Exploratory Drilling: SGWD drilled 15 no's bore wells, 02 wells were drilled in granite gneiss area and 13 wells were drilled in khondalitic area. Data analysed from SGWD wells indicates, depth of well ranges 21 - 60 m. The deepest fracture was encountered at 51 m. bgl at Kindra, Rajavommangi mandal.

2.1.3 Ground water Yield: Ground water yield of granitic aquifers varies varies from 0.21 to 8.3 lps (avg: 2.91 lps). (**Fig.2.3)**

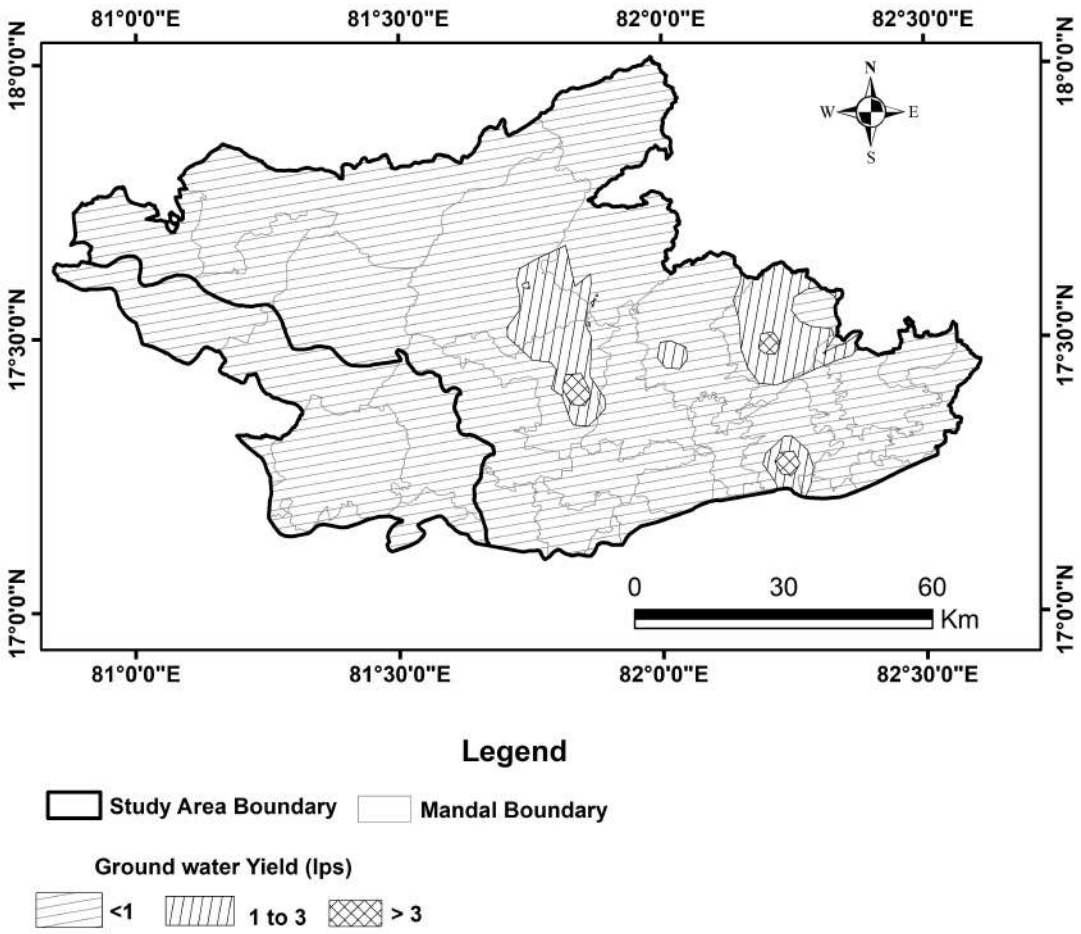


Fig.2.3: Ground water yield potential map of Study Area.

2.2 Water Levels: The ground water regime was studied for pre-monsoon and post-monsoon from 63 wells which are being monitored by CGWB and State Ground Water & Water Audit department. The data sets were used for preparing maps of pre-monsoon depth to water level, post monsoon depth to water level and water-level fluctuation.

2.2.1 Water Table Elevations: During pre & post monsoon seasons (May and November), the water-table elevation ranges from 13 – 1006 m amsl and 15 - 1019 m amsl respectively and general ground flow is towards NE to SW part of study area. (**Fig.2.4**)

2.2.2 Depth to Water Levels (DTWL): The average DTWL of 10 years (2011 to 2020) for pre-monsoon and post-monsoon were analysed, the avg. DTWL varies from 2.28 to 25.16 m bgl (average: 7.54 m bgl) and 1.09 to 13.85 m bgl (average: 4.40 m bgl) during pre-monsoon and post-monsoon seasons respectively.

Pre-monsoon season: Majority of the water levels during this season are in the range of 5 to 10 m covering 82 % of the area, followed by 10 to 15 m bgl (12 %) and 2 to 5 m bgl (4 %). The water levels > 10 m.bgl occupy in parts of Gangavaram, Sunnampadu, Ellavaram, Kondrukota, Durgada, Tatiparthi and Kota villages. (**Fig.2.5**)

Post-monsoon season: Majority of the water levels during this season are in the range of 2 to 5 m covering 50% of the area, followed by 5 to 10 m bgl (46%), < 2.0 m bgl (3%). The water levels > 10 m bgl occupy about 1 % of the area falling in parts of Gollaprolu, Polavaram, Y. Ramavaram mandals. Shallow water levels < 2.0 m bgl occupy in parts of Jaggampet, Tallapudi, Gangavaram, Devipatnam, Rajavommangi, Prathipadu, Korukonda, Sankavaram and Gokavaram mandals. (**Fig.2.6**)

2.2.3 Water Level Fluctuations (May vs. November): The water level fluctuations vary from 0.31 to 16.42 m with average rise of 3.27 m (**Fig.2.7**). The water levels rise is observed throughout the entire district and no fall in water level is recorded. Rise in water level range of 2 to 5 m covers majority of the area (85 %) followed by 0 to 2 m rise in 13% of the area. Rise of water levels > 5 m is observed in 2% of area in Ellavaram, Gudigudem, Pothavaram,Velama kotturu, Durgada, Tatiparthi Villages.

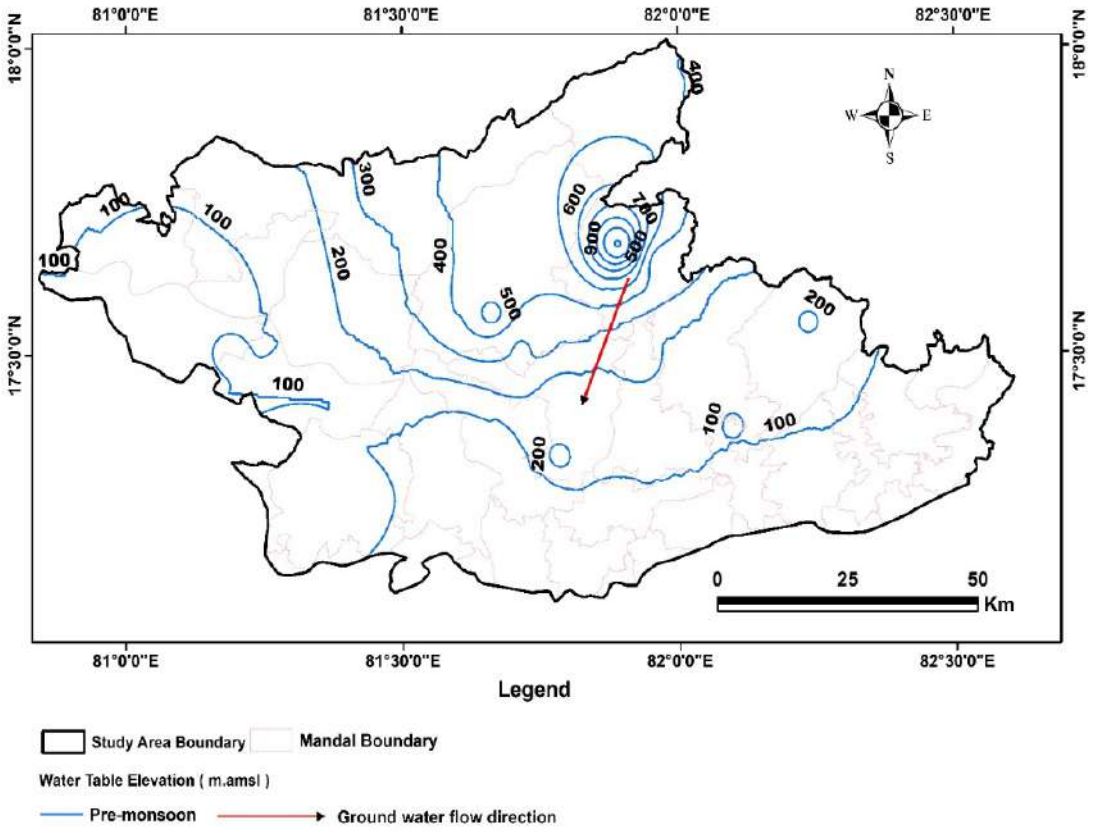


Fig.2.4: Water table elevations (m amsl) during pre-monsoon seasons.

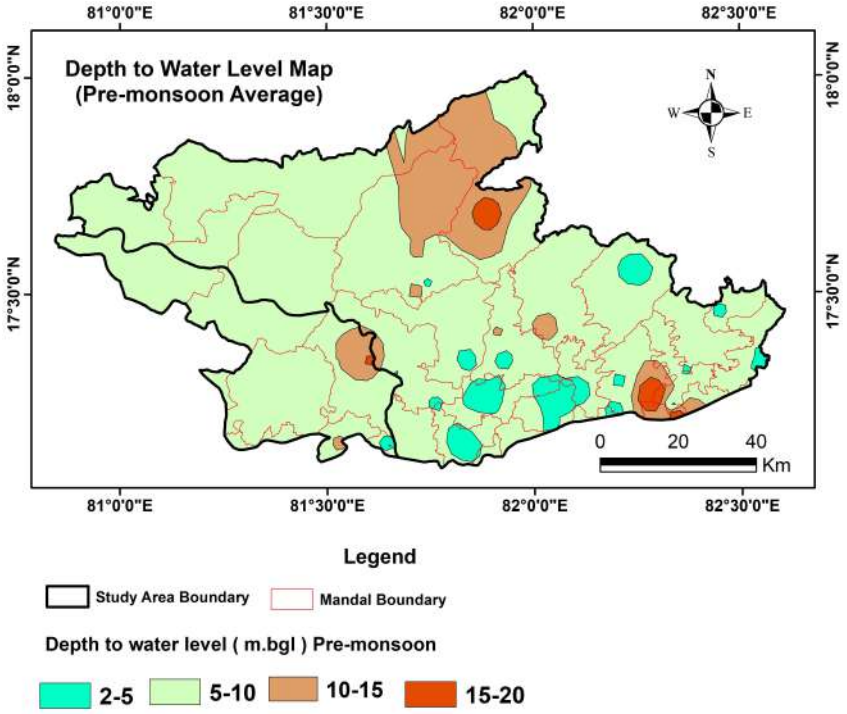


Fig.2.5: Depth to water levels Pre-monsoon (Average).

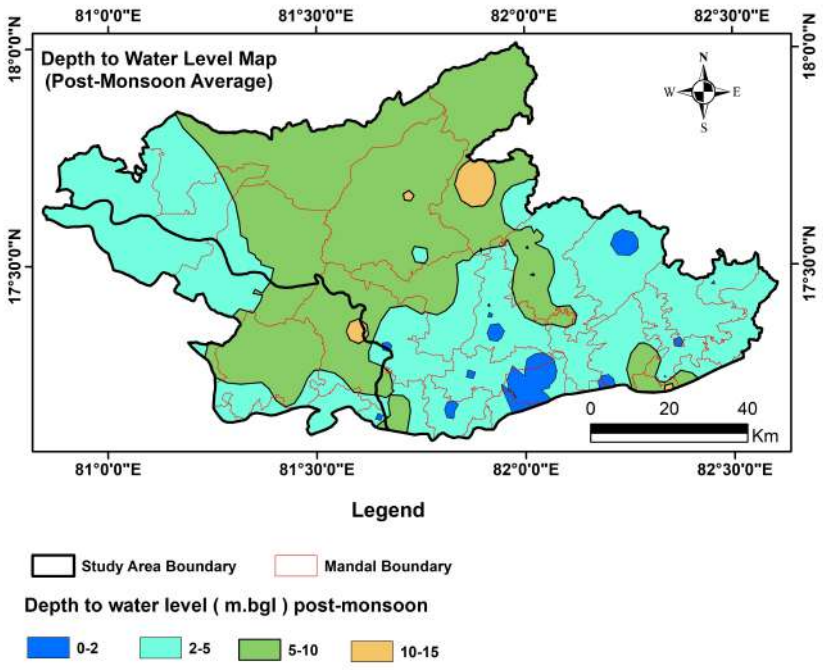


Fig.2.6: Depth to water levels Post-monsoon (Average).

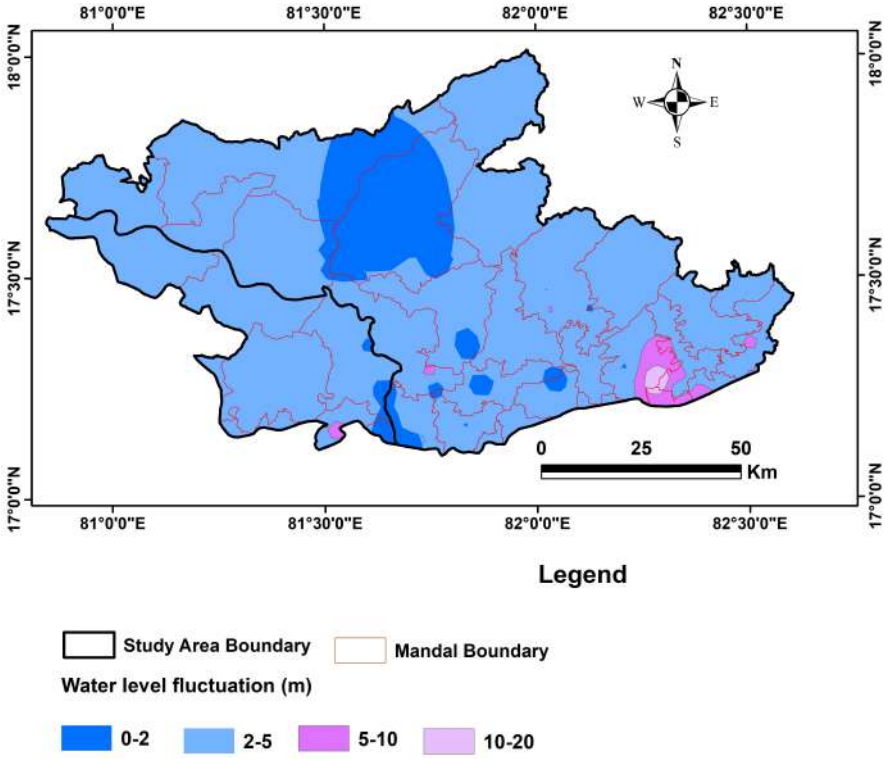


Fig.2.7: Water Level Fluctuations (m) (Nov with respect to May).

2.3 Geophysical Studies

Vertical Electrical Sounding (VES) were carried out in 55 locations across the study area and able to demarcate weathered and semi-weathered, fracture zone and basement of Khondalite and Charnockite.

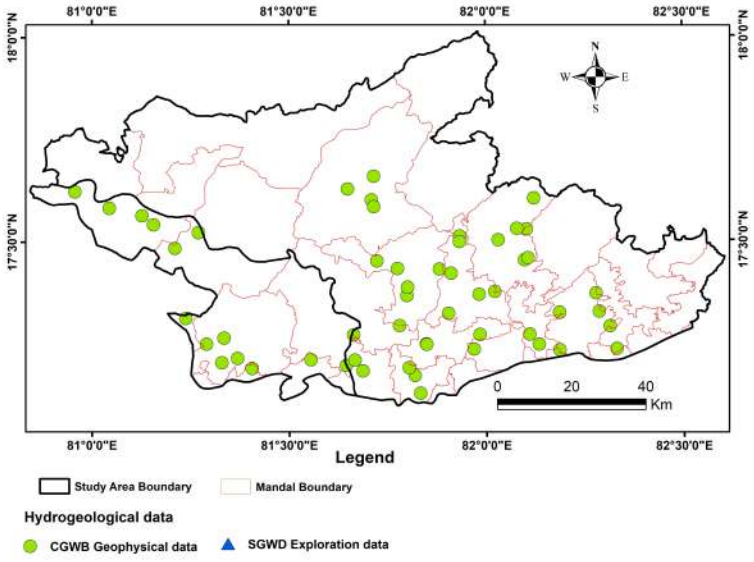


Fig.2.8: VES locations

2.4 Hydro chemical Studies

To understand chemical nature of groundwater, 91 water samples data is utilized from ground water monitoring wells of CGWB and SGWD wells (Pre-monsoon:62 and post-monsoon:29) during the pre-monsoon season of 2019 and post-monsoon season of 2019. Parameters namely pH, EC (in µS/cm at 25° C), TH, Ca, Mg, Na, K, CO_3, HCO_3, Cl, SO_4, NO_3 and F were analyzed.

2.4.1 Pre-monsoon: Electrical conductivity varies from 130-4350 (avg: 1095) µ Siemens/cm**.** In 63 % of area EC is within 750-1500 µ Siemens/cm; in 32 % area, it is <750 µ Siemens/cm; in 5 % area it is 1500-3000 µ Siemens/cm; and EC above >3000 µ Siemens/cm covering < 1% area. (**Fig.2.9).** Nitrate concentration in all samples varies between 0.18 - 138 mg/L. Nitrate concentration in 70% of samples is beyond permissible limits of 45 mg/L (**Fig.2.10**). Fluoride concentration varies from 0.02-1.37 mg/L and all samples falling under permissible limits of 1.5 mg/L. (**Fig 2.11**)

2.4.2 Post-monsoon: Electrical conductivity varies from 235-2350 (avg: 920) µ Siemens/cm. In 76 % of area, EC is < 750 µ Siemens/cm; in 20 % area, it is 750-1500 µ Siemens/cm; in 4 % area it is within 1500-3000 µ Siemens/cm; **Fig.2.12.** Fluoride concentration all samples is below BIS permissible limits of 1.5 mg/L and varies from 0.02 -1.15 mg/L (**Fig 2.13**)

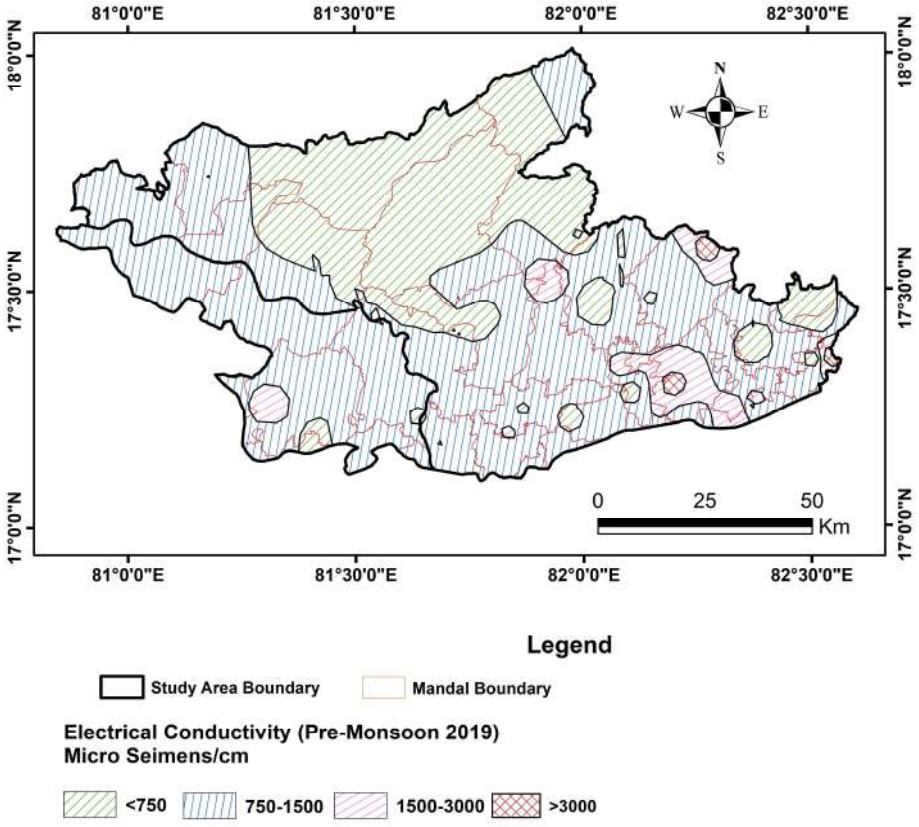


Fig.2.9: Distribution of Electrical conductivity (Pre-monsoon).

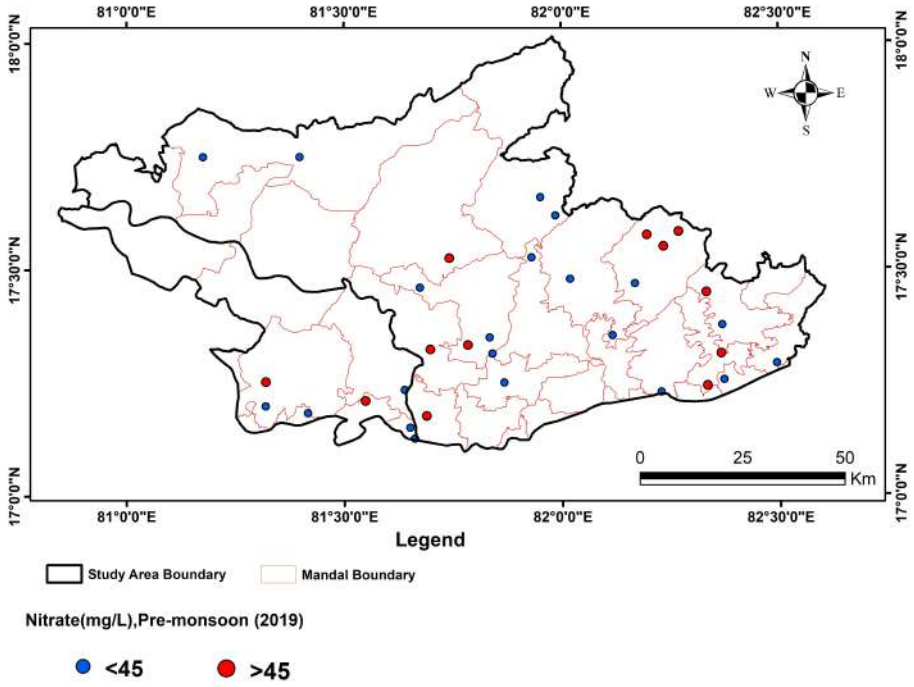


Fig.2.10: Distribution of Nitrate (Pre-monsoon).

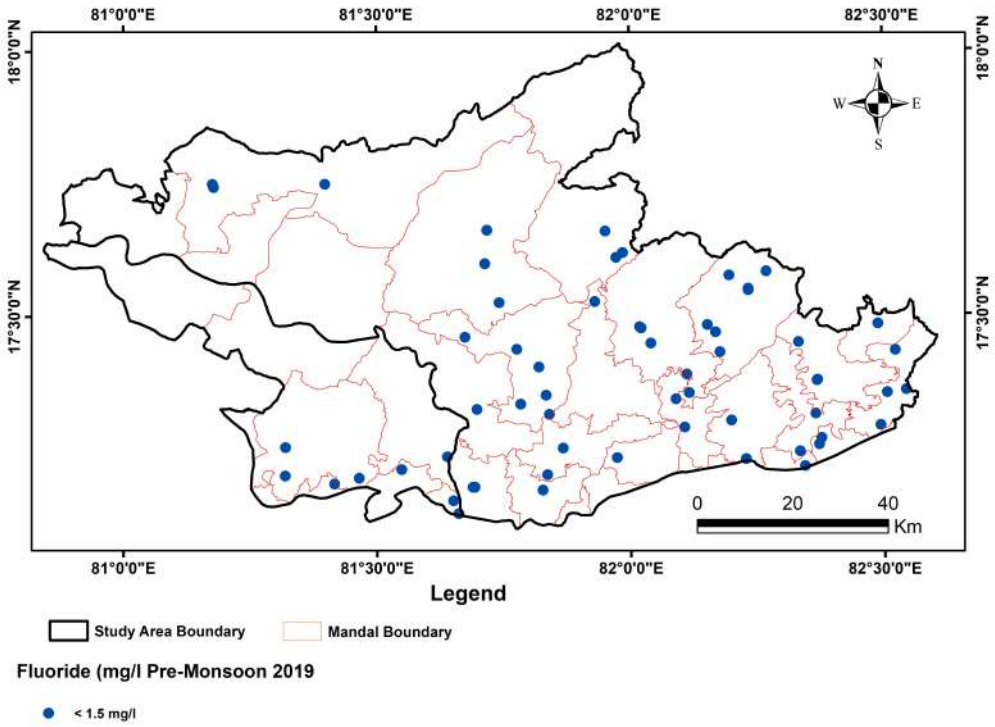


Fig.2.11: Distribution of Fluoride (Pre-monsoon).

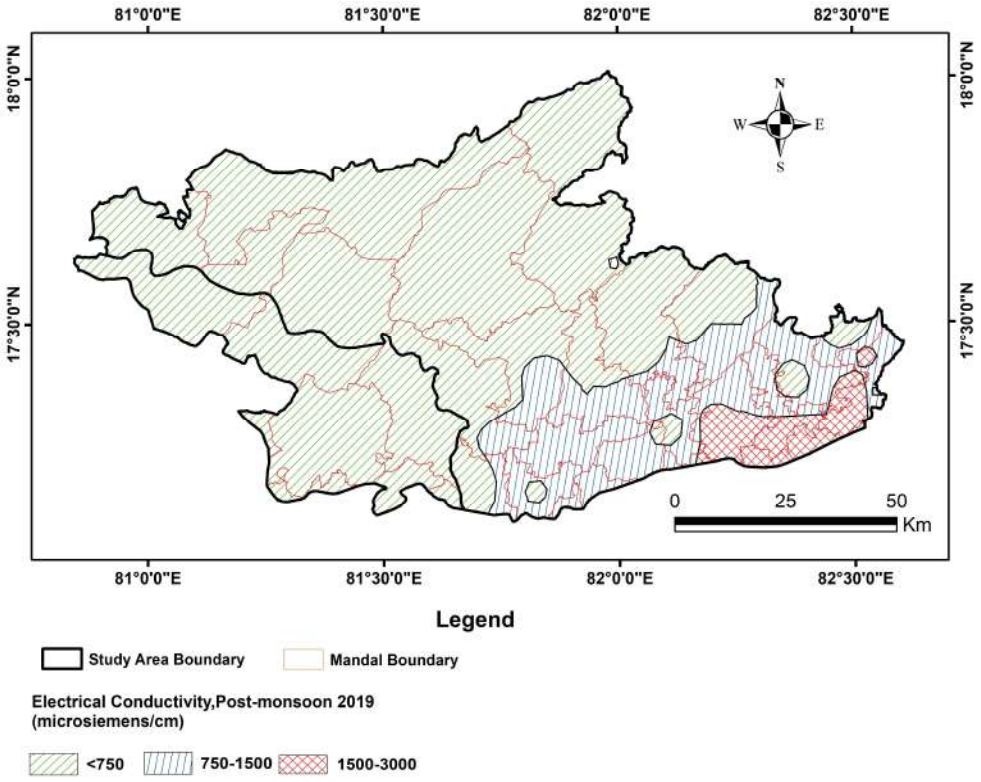


Fig.2.12: Distribution of Electrical conductivity (post-monsoon).

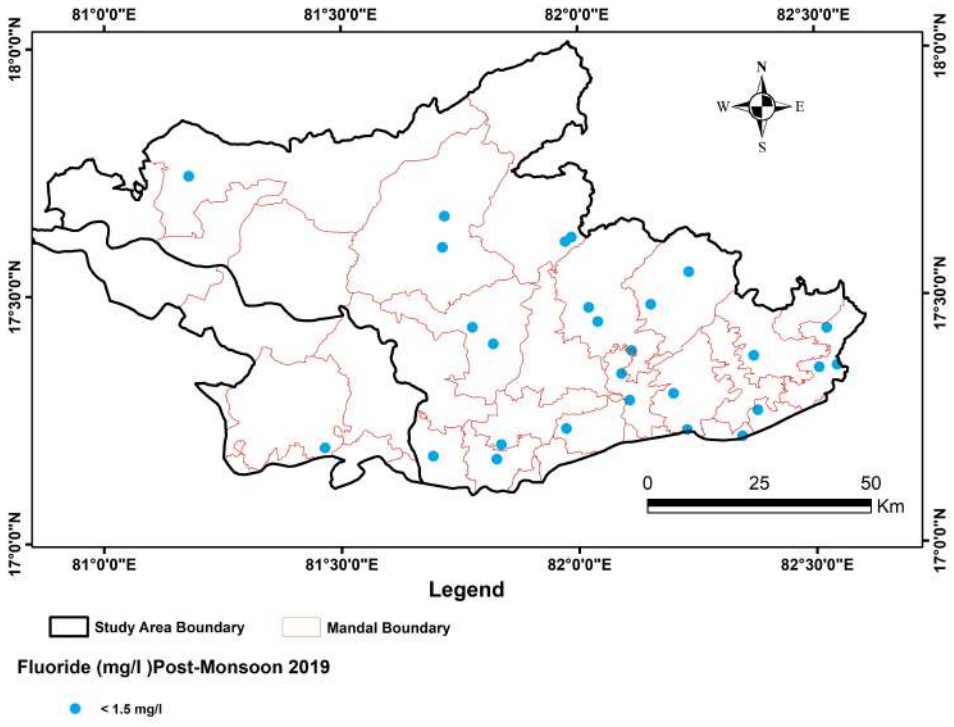


Fig.2.13: Distribution of Fluoride (Post-monsoon).

3. DATA INTERPRETATION, INTEGRATION AND AQUIFER MAPPING

Conceptualization of 3-D hydro geological model and preparation of 3-D map, panel diagram and hydro geological sections was carried out by interpreting and integrating representative 70 data (both hydro geological and geophysical) points. The data is calibrated for elevations with Shuttle Radar Topography Mission (SRTM) data. The lithological information was generated by using the RockWorks-16 software and generated 3-D map for parts of East & West Godavari district (**Fig.3.1)** and hydrogeological sections.

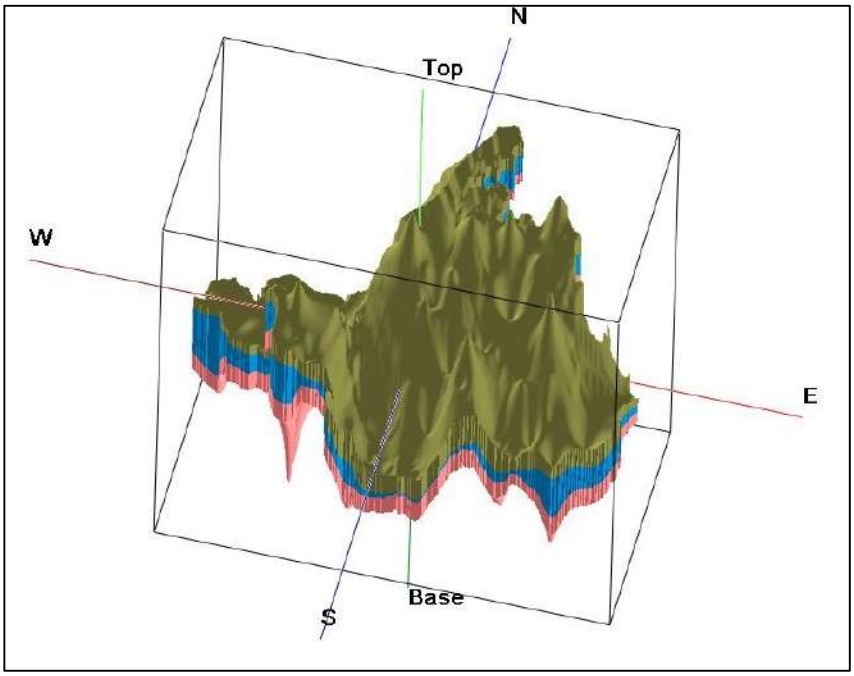


Fig.-3.1:3D Model for study area.

3.1 Conceptualization of aquifer system in 3D

Aquifers were characterized in terms of potential and quality based on integrated hydrogeological data and various thematic maps. Weathered zone is considered up to the maximum depth of weathering and first fracture encountered (below weathered depth) and the fractured zone (fractured granite) is considered up to the depth of deepest fracture below weathered zone.

3.2 Hydrogeological Sections

Hydrogeological sections are prepared in NE-SW directions (**Fig.3.2**).

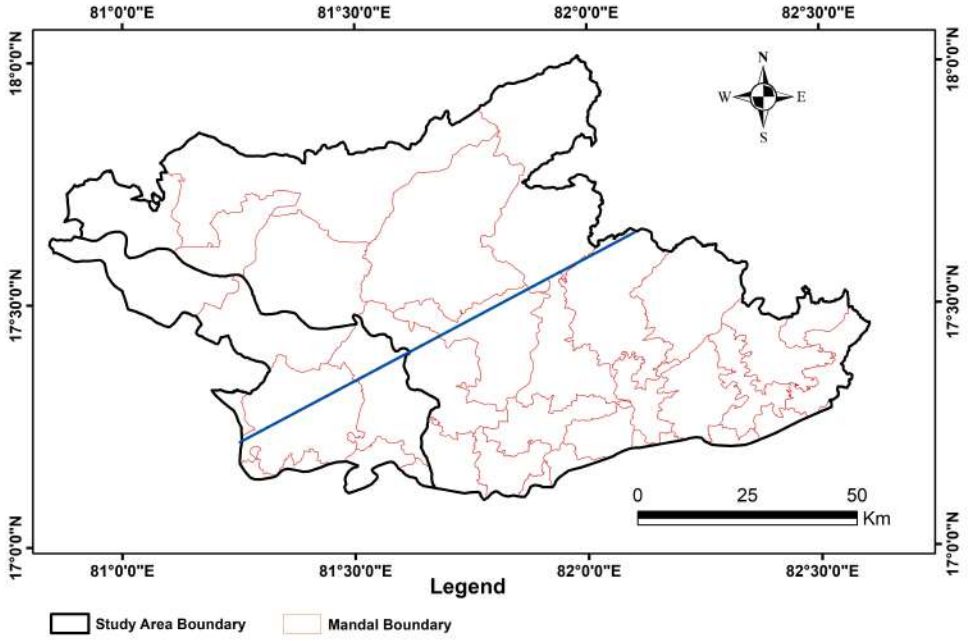


Fig.-3.2: Map showing orientation of hydro geological Section

3.2.1 Hydrogeological Cross Section NE-SW': The section drawn along the NE-SW direction (**Fig.3.3**). It depicts weathered Granitic gneiss followed by fractured and massive granitc Thick fractured zones in Granite are seen at Appannapalem and Dondapudi.

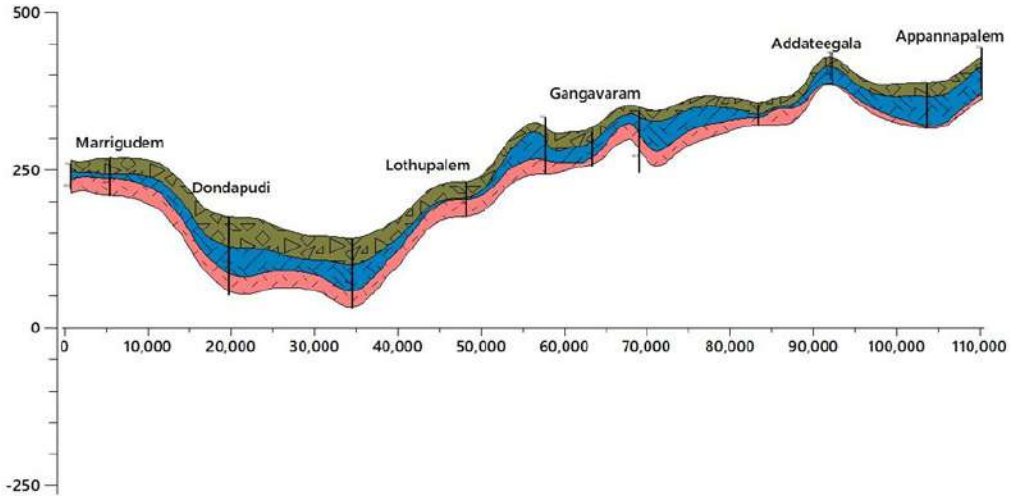


Fig.3.3: Hydrogeological Cross Section in NE-SW directions in Study Area.

3.3 Aquifer Characterization

3.3.1 Weathered zone: The Weathered zone (avg. ~18 m) varies from 5 to 40 m bgl. Spatial distribution of weathering depth zone map is given in **Fig.3.4**. Thickness of weathered zone is in the range of 10 - 20 m in most part of area (~54 %) followed by >20 m (~34 %) and shallow (<10 m) weathering occurs in rest of the area

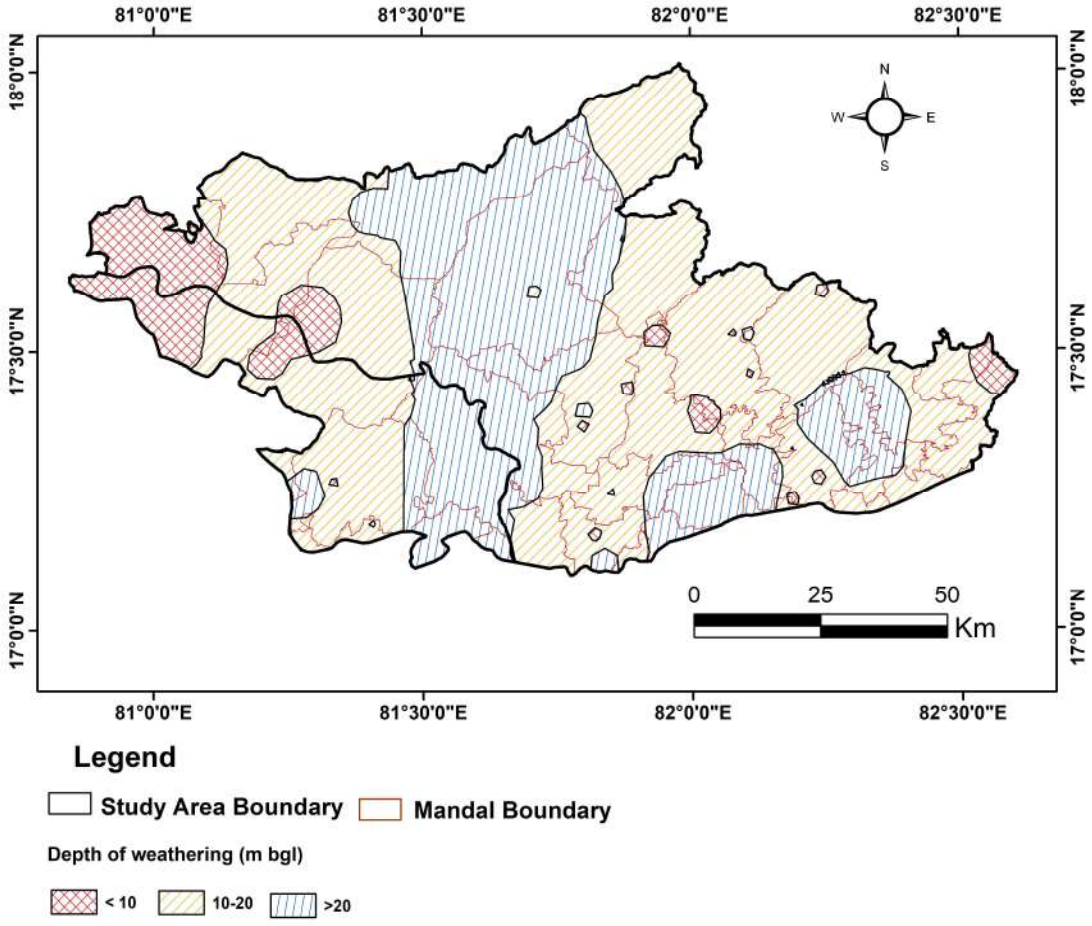


Fig.3.4: Depth to weathered zone, Study Area

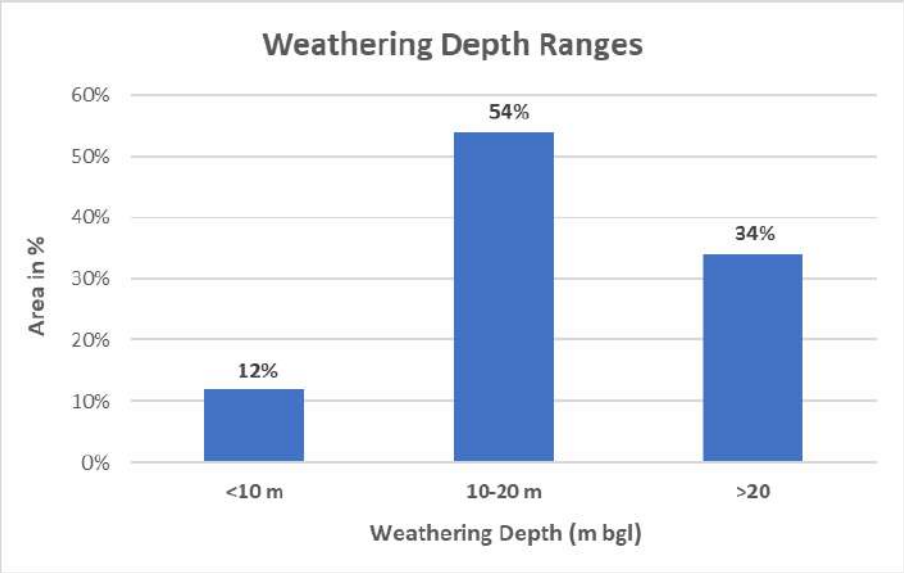


Fig.3.4a-Depth wise weathered zone distribution

3.3.2 Fractured zone:

The Occurrence of fractures are discrete and more predominant fractures occurr in between the depth range of 30 to 60 m (67 %), followed by < 30 m (28 %),60 to 100 m (3 %) and deep fractures in the range of 100-140 m occur in 1 % area (Thatukur, Buttayagudem) **(Fig.3.5).**

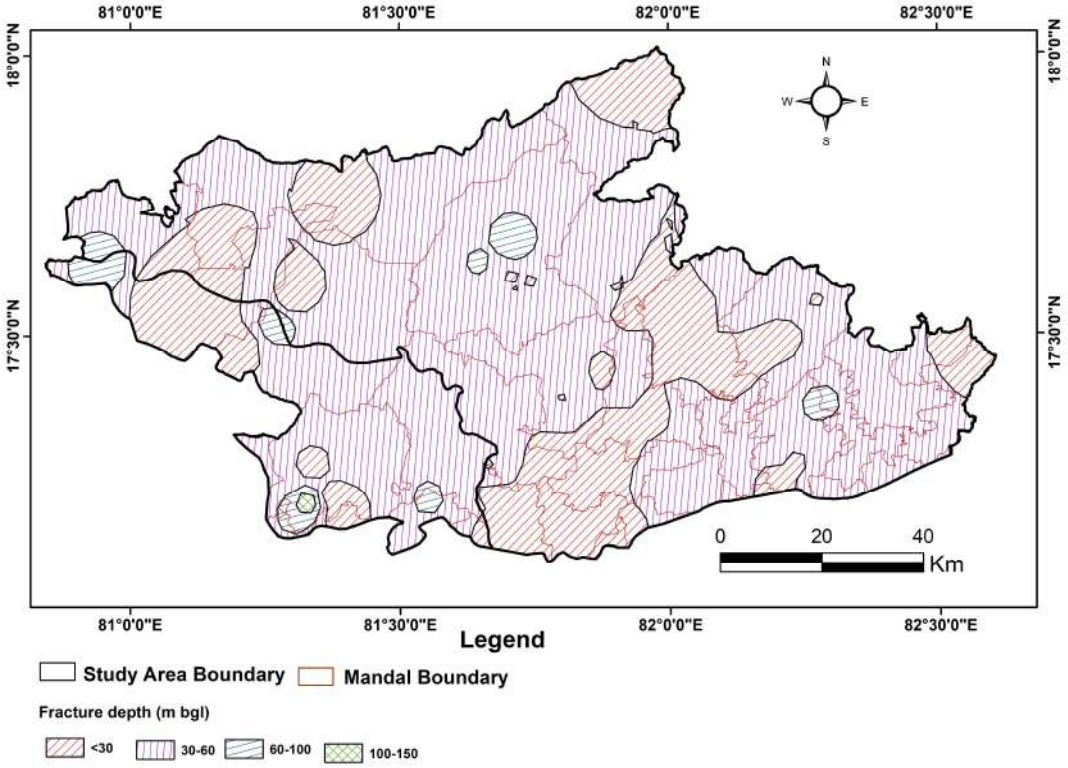


Fig.-3.5: Depth to Fractured zone, Study area.

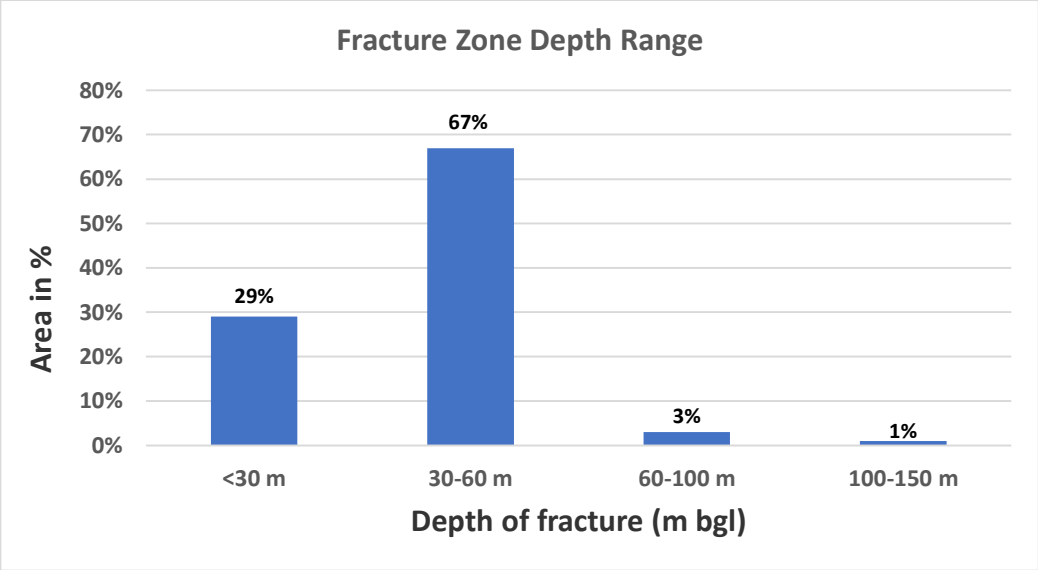


Fig.-3.5b: Depth wise distribution of fractures

4.0 GROUND WATER RESOURCES (2020)

As per Ground Water Resources Assessment (2020), the net dynamic replenishable groundwater availability is 1356.74 MCM, gross ground water draft for all uses is 337.42 MCM, provision for drinking and industrial use for the year 2025 is 45.91 MCM and net annual ground water potential available for future use is 1026.29 MCM. Stage of ground water development is 25.2. All Mandals are categorized as Safe. The summarized mandal wise resources are given in Table-4.1.

.**Table-4.1:** Computed Dynamic ground water resources, Study Area.

Parameters	**Total**
As per GEC 2020	MCM
Net Ground Water Availability)	**1356.74**
Gross Ground Water Draft for all uses	**337.42**
• Irrigation	**285.95**
• Domestic and Industrial use	**51.47**
Allocation of GW for Domestic Utilisation for projected year 2025	45.91
Net GW availability for future use	1026.29
Stage of GW development (%)	25.2

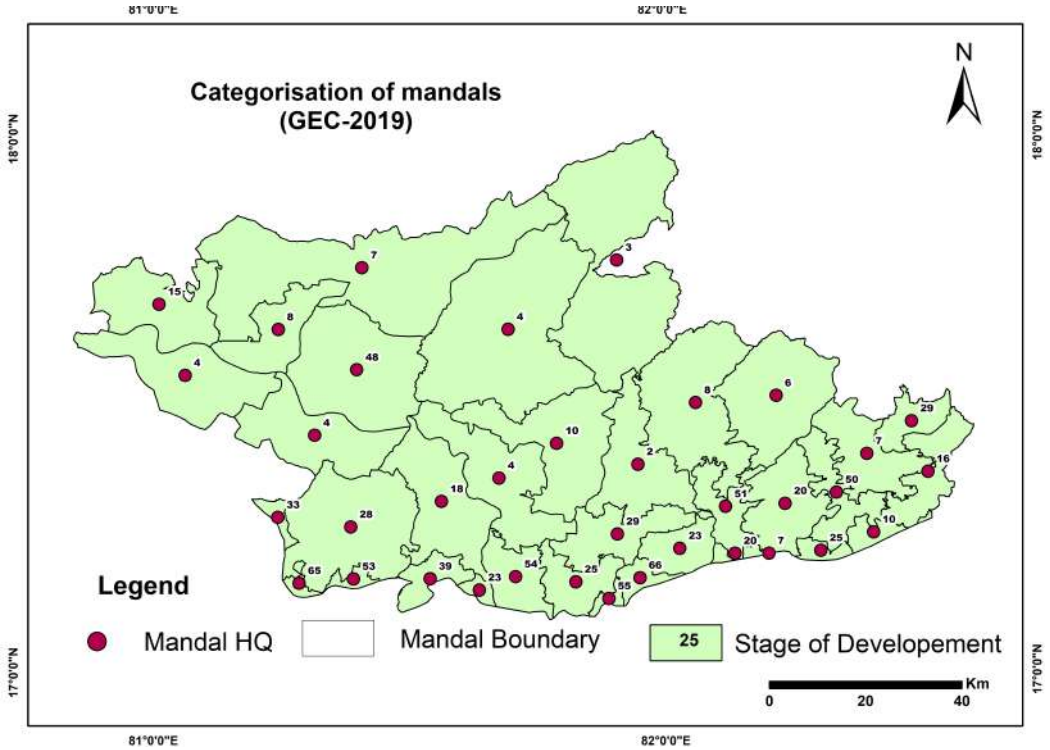


Fig 4.1-Categorisation of Mandals

5. GROUND WATER RELATED ISSUES AND REASONS

Groundwater Yield

Low yield (<1 lps) occurs in ~92 % of area and 1 to 3 lps yield occurs in ~8 % of area of the study area.

The low yield is due to crystalline terrain and absence of primary and secondary porosity and less recharge during rainy season. Among the crystalline formations banded gneiss/khondalite have developed moderate to highly fractured zones.

Deep water levels

Deep water levels (> 10 m bgl) are observed during pre as well as post-monsoon season in 13 % and 1.2 % of the area respectively.

Water Logging

In study area at present there is no water logging. However, during post monsoon period in places round Rajavommangi, Sankhavaram, Kirlampudi, Jaggampeta, Gangavaram, Gokavaram, Korukonda, Devipatnam the water levels are < 2.0 m bgl (3 % of area) indicating that these areas are prone for water logging. The water logging conditions may be due to surface water irrigation and can be overcome by conjunctive utilization of both surface and groundwater.

Pollution (Geogenic and Anthropogenic)

Nitrate concentration in the entire district is within the permissible limits except in 11 mandals during pre-monsoon period which may be of local anthropogenic activity.

The high concentration of EC (> 3000 μ Siemens/cm) in <1 % of the area is observed during pre-monsoon period.

Ground water Development

The present stage, ground water development in the district varies from 2 to 66 percent. The stage of GW development is high in Gandepalli (66%), Jangareddigudem (65%), Rajanagaram (55%).

6. GROUND WATER DEVELOPMENT AND MANAGEMENT STRATEGIES

6.1. Groundwater Development:

At present, the stage of ground water development in the study area is quiet low (25%). The total utilization of ground water is 337 MCM against the total ground water potential of 1026 MCM available for future use. There is scope for ground water development for irrigation by construction of additional wells. Government of Andhra Pradesh had proposed to bring 8217 ha of land under irrigation through ground water by constructing 4576 no. of bore wells in 883 villages of 24 mandals of study area with an estimated cost of 323 crores.

6.2. Groundwater Management Strategies:

6.2.1. Supply Side Measures:

Artificial Recharge: Under PMKSY- Watershed, MGNREGS, the Govt of AP had constructed 298 no. of CDs & 2230 no. of PTs in the study area. Considering the existing AR structures and the less stage of ground water development, it is recommended for desiltation and maintenance of existing PTs and CDs instead of new artificial recharge structures. In future, construction of artificial recharge structure can be taken up in specific areas based on requirement. The study area forms recharge zone and suitable for adoption of water conservation structures.

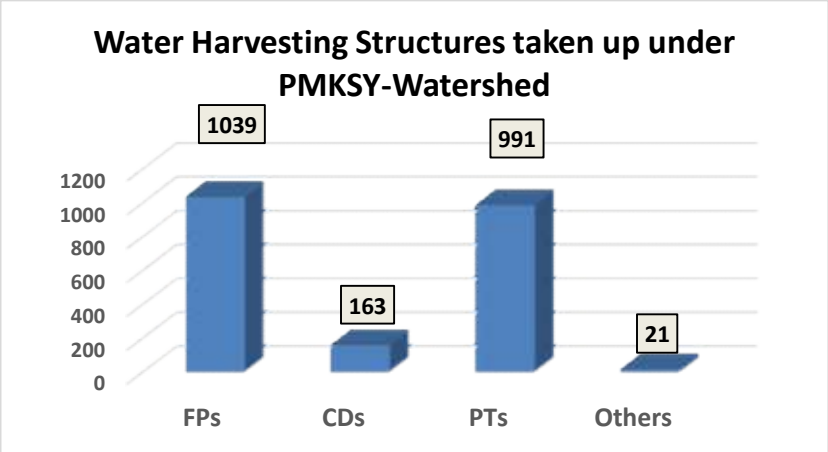


Fig 6.1 - Water Harvesting Structures taken up under PMKSY-Watershed

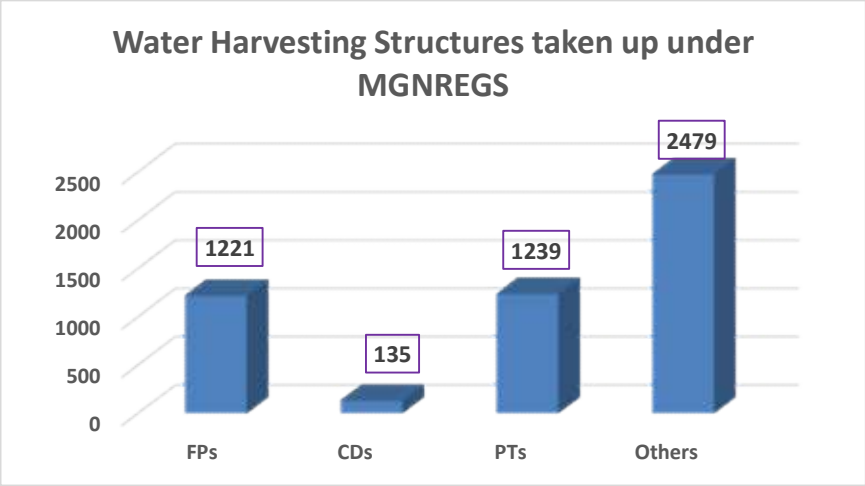


Fig 6.2-Water Harvesting Structures taken up under MGNREGS

6.2.2. Demand Side Measures:

Micro-irrigation: The sustainability of bore well is low because of hard/ crystalline rock. The yield of bore well is <1.0 lps identified in 92% of area and 1.0 to 3.0 lps found in 8% of the area is due to low interconnection among fracture. As sustainability of bore well is low, the sprinkler and drip irrigation system with suitable cropping pattern wherever feasible may be practiced as a measure for groundwater conservation, protection and management. Micro irrigation is recommended in all villages i.e 100 ha per village. Total area of 146,300 ha can be taken up under micro irrigation to tackle the low sustainability issues and long term water conservation and management.

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