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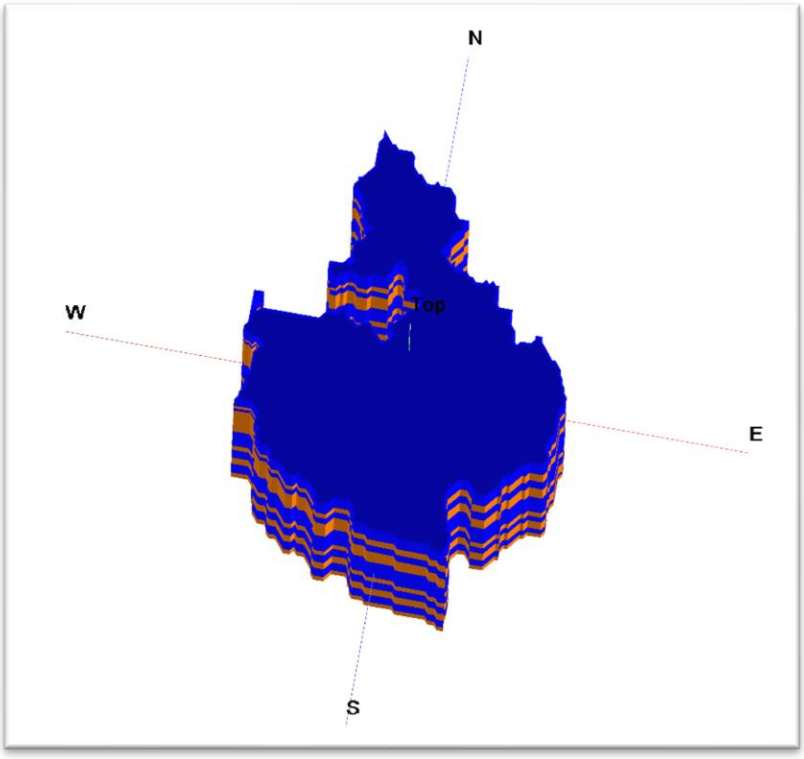
केंद्रीय भूमिजल बोर्ड

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

REPORT ON
AQUIFER MAPPING FOR SUSTAINABLE MANAGEMENT OF GROUND WATER RESOURCES IN WEST GODAVARI DISTRICT, ANDHRA PRADESH STATE



CENTRAL GROUND WATER BOARD
APSUO, VISAKHAPATNAM
MARCH 2024

REPORT ON
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AQUIFER MAPPING FOR SUSTAINABLE MANAGEMENT OF GROUND WATER RESOURCES IN WEST GODAVARI DISTRICT, ANDHRA PRADESH STATE

Figures

Table

REPORT ON
AQUIFER MAPPING AND MANAGEMENT OF WEST GODAVARI DISTRICT, ANDHRA PRADESH STATE (AAP-2023-24)

West Godavari District at a Glance

S. No.	Item		Particulars
1	District	:	West Godavari
2	Area	:	2346 km^2
3	Mandals	:	19
4	Villages	:	380 villages
5	Mappable area	:	2346 sq. kms
6	Population (2011Census)	:	17.78 lakhs
7	Density	:	837 persons/km^2
8	Location	:	North latitude 16°19´ to 16°58´ and east longitude 81°19´ to 81°48´
9	Rainfall (Normal)	:	Normal annual rainfall varies between 1045 mm (Akividu) and 1393 mm (Achanta) with average of 1229 mm.
10	Geomorphology	:	The area is basically occupied by deltaic and coastal plains. The landforms present in the area are mainly fluvial land forms and other forms are of marine. In study area the presence of beach ridge complexes on land indicates the existence palaeo shore lines, which were delineated using the remote sensing studies
11	Major River	:	Godavari
12	Land Utilization	:	Net area Sown is 1,35,523 (~58%), land put to non-agricultural uses is 47,575 ha (20%) and Fish & Prawn culture is 41,580 ha (~18%)., Others is 4%
13	Soils	:	The area is mainly occupied by Very fine, montmorillonite (64 %) (Very Deep, imperfectly drained, cracking clay soils), Fine, montmorillonite (30 %) (Very Deep, imperfectly drained, cracking clay soils) and fine, mixed soils (4 %) (Very deep, well drained, sandy soils).
14	Cropping Pattern (Ha)	:	The total cropped area in the district is 2,29,566 ha. Main crops grown during Kharif are Total food crops 1,05,802 ha (31%), total foodgrains 1,03,235 ha (30%), Rice 1,01,146 ha (29%). total Non food crops 13,727 ha (4%), total oil seeds 10,273 ha (3%) and coconut 8,962 (3%) and during Rabi season are Rice 1,01,605 ha (31%), Total food crops 1,07,741 ha (33%) and Total food grains 1,05,092 ha (33%).
15	Irrigation		The area has the distributary network of the river Godavari. The district is irrigated by both Surface and Ground water sources. Canals and LIS are the main source of irrigation (~88%) and other sources of irrigation are Ground water (~11%) and tanks (1%).
16	Geology	:	Geologically the area is underlain by the recent to sub-recent alluvium comprising Sand, Gravel, Clay and Silt. The alluvium is underlined by sandstones.
17	Hydrogeological data points		

	Exploratory drilling	:	CGWB Exploration: 22
	Water Level	:	23 wells
	Hydro chemical	:	Total: 20, Pre-monsoon:20(CGWB: 20)

18	**Data Interpretation, Integration and Aquifer Mapping**		
19	**Ground water Level Scenario**		
	Depth to water level (m bgl)	:	During pre-monsoon (May, 2011-2020), the water-table elevation ranges from 0.13 – 10.77 meter above mean sea level (m amsl) and general ground flow is towards Bay of Bengal. The average DTWL of 10 years (2011 to 2020) for pre-monsoon varies from 1.49 to 13.04 meter below ground level (mbgl) (average: 4.53 m bgl). Majority of the water levels during this season are in the range of 0 to 5 m covering 67% of the area, followed by 0.5 to 10 m bgl (26%) and >10 m bgl (7 %). The water levels >10 m.bgl occupy in parts of Narasapuram, Poduru and Tadepalligudem mandals. The average DTWL of 10 years (2011 to 2020) for post-monsoon varies from 1.22 to 12.64 m bgl (average: 3.89 m bgl). Majority of the water levels during this season are in the range of 0 to 5 m bgl covering 93% of the area, followed by 5 to 10 m bgl (7%).
20	**Ground Water Quality**		
	Electrical Conductivity (µSiemens/cm)	:	Electrical conductivity varies from 391-5020 (avg: 1824) µ Siemens/cm**.** In 31 % of area EC varies between 1500-2250 µ Siemens/cm, in 27 % area, it is 2250-3000 µ Siemens/cm, in 21 % area, it is >3000 µ Siemens/cm, in 19 % area, it is 750-1500 µ Siemens/cm and it is <750 µ Siemens/cm, in 1 % area.
	Nitrate (mg/l)	:	NO3 ranges from 1-124 mg/L. Nitrate concentration in 80% of samples is beyond permissible limits of 45 mg/L.
	Fluoride (mg/l)	:	Fluoride concentration varies from 0.032-1.09 mg/L and all samples it is within permissible limits of BIS.
22	**Ground water Resources (2022) MCM**		
	Net Dynamic Ground Water availability	:	603 MCM
	Gross GW Draft	:	62 MCM
	Provision for Domestic (2025)	:	11 MCM
	Average Stage of Ground Water development (%)	:	11 %
	Net GW Availability for future irrigation	:	504 MCM
	Categorization of Mandal	:	12 Mandals out of 19 in the district are saline
23	**Major Ground Water Issues Identified**	:	• Ground Water Salinity

			• Aquaculture • Water Logging • Saline Mandal: 1461 sq.km (62%)- Akividu, Bhimavaram, Kalla, Moglathur, Narasapuram, Palacoderu, Palacole, Pentapadu, Poduru, Undi, Veerasavaram, Yelamancili

24	**Ground Water Management Strategies**		
		:	• Awareness campaigns are to be organized to educate the farmers about the aquifer disposition and the bottom of first aquifer in the area which is containing fresh water so that the depth of the filter points should be limited to the bottom of fresh unconfined aquifer in the area. • There should be strict Implementation of Ban on Pumping in the areas which are less than 2kms from the sea. • Aqua Culture activities should not be encouraged beyond 2kms from the coast and also strict Implementation of Ban on Pumping from the first two aquifers for the purpose of Aquaculture. • This problem where quality deterioration due to direct recharge of saline water is taking place can be solved to some extent by installing coastal/tidal regulators on the creeks to arrest the back waters. • For the water-logged areas, Ground water extraction should be encouraged through conjunctive use

EXECUTIVE SUMMARY

The West Godavari district, Andhra Pradesh having geographical area of 2346 km^2, lies between north latitude 16°19´ to 16°58´ and east longitude 81°19´ to 81°48´. The district is bounded by Krishna district in the south, Konaseema in the east, Eluru district in the west and East Godavari district in the North. Administratively the district is governed by 19 revenue mandals. There are 380 villages with a population of ~17.78 lakhs (2011 census). The density of population is 837 persons/ km^2 whereas it is 304 per Sq.km. for the State.

The climate of the district is characterised by dry, sub-humid, mega thermal climate with oppressive summer and good seasonal rainfall. The district receives an average annual normal rainfall of 1229 mm of which SW monsoon contributes 65%, NE monsoon contributes 25% while the rest by winter and summer rainfall.

The area is basically occupied by deltaic and coastal plains. The landforms present in the area are mainly fluvial land forms and other forms are of marine. The study area has some of the important depositional land forms viz. Deltaic plains and Palaeo channels. In study area the presence of beach ridge complexes on land indicates the existence palaeo shore lines, which were delineated using the remote sensing studies. Major part of the district falls under Godavari basin. Godavari river flows N to S direction in the area. The district is divided into 2 major drainage basins namely Godavari and Yerrakalva. The drainage density in the area is sparse due to high permeability of alluvial soils.

The land use pattern in the study area indicates that the area is mostly agrarian. Out of total geographical area of 2,34,640 ha, Net area Sown is 1,35,523 (~58%), land put to non-agricultural uses is 47,575 ha (20%) and Fish & Prawn culture is 41,580 ha (~18%).

The total cropped area in the district is 2,29,566 ha, out of which net area sown is 1,35,523 ha and area irrigated more than once is 1,10,840 ha. Main crops grown during Kharif are Total food crops 1,05,802 ha (31%), total foodgrains 1,03,235 ha (30%), Rice 1,01,146 ha (29%). total Non-food crops 13,727 ha (4%), total oil seeds 10,273 ha (3%) and coconut 8,962 (3%) and during Rabi season are Rice 1,01,605 ha (31%), Total food crops 1,07,741 ha (33%) and Total food grains 1,05,092 ha (33%).The area is under the command of Godavari Canal System. The canal system remains operational for 11 months with a one-month closure period during April-May. The district is irrigated by both Surface and Ground water sources. Canals and LIS are the main source of irrigation (~88%) and other sources of irrigation are Ground water (~11%) and tanks (1%).

The area is mainly occupied by Very fine, montmorillonite (64%), Fine, montmorillonite (30 %) and fine, mixed soils (4 %). Geologically the area is underlain by the recent to sub-recent alluvium comprising Sand, Gravel, Clay and Silt. The alluvium is underlined by sandstones.

As on date, CGWB drilled 22 no's bore wells in alluvium area ranging in depth 24 m-305 m. During pre-monsoon (May, 2011-2020), the water-table elevation ranges from 0.13 – 10.77 meter above mean sea level (m amsl) and general ground flow is towards Bay of Bengal. The average DTWL of 10 years (2011 to 2020) for pre-monsoon and post-monsoon were analyzed, the avg. DTWL varies from 1.49 to 13.04 meter below ground level (m bgl) (average: 4.53 m bgl) and 1.22 to 12.64 m bgl (average: 3.89 m bgl) during pre-monsoon and post-monsoon seasons respectively. Majority of the water levels during Pre-Monsoon season are in the range of 0 to 5 m covering 67% of the area, followed by 0.5 to 10 m bgl (26%) and >10 m bgl (7 %). The water levels >10 m.bgl occupy in parts of Narasapuram, Poduru and Tadepalligudem mandals. Majority of the water levels during post-monsoon season are in the range of 0 to 5 m bgl covering 93% of the area, followed by 5 to 10 m bgl (7%).

Groundwater is mildly alkaline to alkaline in nature with pH in the range of 6.68-8.29 (Avg: 7.62). Electrical conductivity varies from 391-5020 (avg: 1824) µ Siemens/cm. In 31 % of area EC varies between 1500-2250 µ Siemens/cm, in 27 % area, it is 2250-3000 µ Siemens/cm, in 21 % area, it is >3000 µ Siemens/cm, in 19 % area, it is 750-1500 µ Siemens/cm and it is <750 µ Siemens/cm, in 1 % area. NO3 ranges from 1-98 mg/L. Nitrate concentration in 80% of samples is beyond permissible limits of 45 mg/L. Fluoride concentration varies from 0.032-1.09 mg/L and all samples it is within permissible limits of BIS.

Aquifers from the area can be conceptualized in to two principal aquifers namely, Alluvium and Sandstone. The data indicates that there are multi aquifers in the area with intervening thick clay beds. These sand beds which act as aquifers in the area and there are five distinct beds which behave as regional aquifer. The study of the different sections indicate that the alluvium thickness is increasing from north to south and there are five aquifers exist up to a depth of 300 m in the study area. The shallow aquifer thickness is varying from place to place. The first aquifer which is present up to a maximum of 34m below MSL is unconfined whereas the other aquifers are confined. The ground water quality of shallow aquifer is fresh, whereas the deeper alluvial aquifers of are saline. Sandstone aquifers encountered below the alluvium are yielding fresh quality of ground water.

As per 2022 GEC report, the net dynamic replenishable groundwater availability is 603 MCM, gross ground water draft for all uses 62 MCM, provision for drinking and industrial use for the year 2025 is 11 MCM. The stage of ground water development in the area is 11%.

The study reveals that waterlogging is a common issue in the region. Factors contributing to waterlogging include surface water irrigation, minimal groundwater withdrawal, flat terrain, high rainfall, poor drainage, and soil characteristics. The groundwater in shallow aquifers is generally fresh except in areas near the coast and isolated patches inland. Deeper aquifers consistently contain saline water. The origin of this salinity is due to Palaeo Salinity, Leakage from Bottom Aquifer and Sea Water.

The effective management of water resources in areas facing various challenges requires a combination of awareness campaigns, regulatory measures, and sustainable practices.

Conjunctive Use of Water Resources: To reduce the pressure on groundwater, conjunctive use of surface and groundwater resources should be promoted. This involves limiting surface water for tail end areas and encouraging groundwater use in upper and middle reaches, ultimately leading to a more sustainable water balance.

To reduce quality deterioration due to sea water intrusion, supplying surface water to tail end areas should be a top priority. There should be strict Implementation of Ban on Pumping in the areas which are less than 2kms from the sea and also pumping from the first two aquifers for the purpose of Aquaculture.

Management to Prevent Direct Recharge of Saline Water: This problem can be solved to some extent by installing coastal/tidal regulators on the creeks to arrest the back waters.

Managing Uncontrolled Pumping during less surface water availability: In areas where uncontrolled pumping becomes a problem during less surface water availability, top priority should be given for providing surface water for the gross irrigated area in the tail end areas of the command and Artificial Recharges Measures should be encouraged to be practiced in upper reaches such that the ground water head is always 2m above MSL.

Management for Waterlogging issues: Waterlogged areas can benefit from groundwater extraction through a network of filter points and the distribution of water to canals for irrigation. Implementing a ban on surface water supply in such areas can help mitigate waterlogging issues.

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.

1.2 Scope of study: The main scope of study is summerised 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. To formulate groundwater management plans.

1.3 Area Details: The West Godavari district, Andhra Pradesh having geographical area of 2346 km^2, lies between north latitude 16°19´ to 16°58´ and east longitude 81°19´ to 81°48´(**Fig.1.1**). The district is bounded by Krishna district in the south, Konaseema in the east, Eluru district in the west and East Godavari district in the North. Administratively the district is governed by 19 revenue mandals. There are 380 villages with a population of ~17.78 lakhs (2011 census). The density of population is 837 persons/ km^2 whereas it is 304 per Sq.km. for the State.

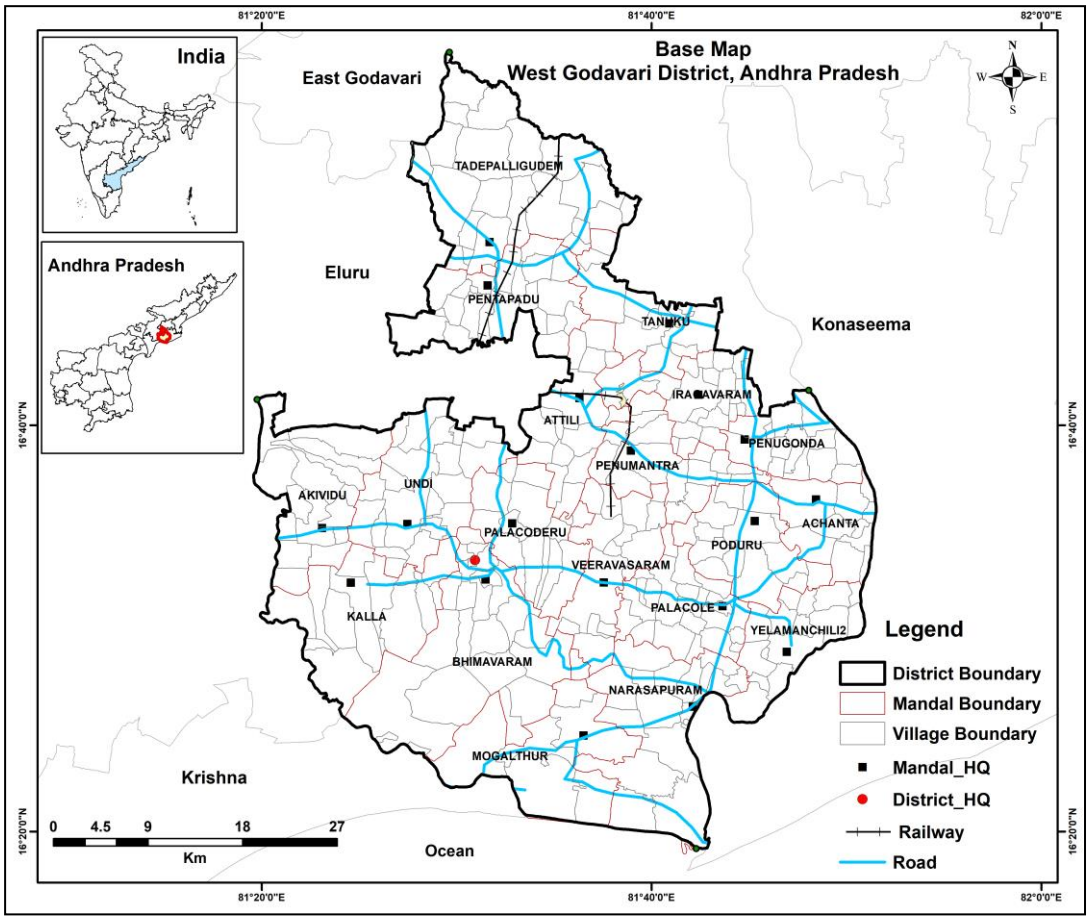


Fig.1.1: Location map of West Godavari district.

1.4 Climate and Rainfall: Climatologically the area experiences dry, sub-humid, mega thermal climate with oppressive summer and good seasonal rainfall. The normal mean daily minimum and maximum temperatures are 28 °C and 36 °C during May and 20°C and 29 °C during December. Normal annual rainfall varies between 1045 mm (Akividu) and 1393 mm (Achanta) with average of 1229 mm, actual rainfall is 975 mm (**Fig. 1.2**). The south west monsoon sets in the second week of June and lasts till September end. October and November receive rainfall from north east monsoon. The winter starts from December and lasts till mid-February followed by summer season upto early June. The South West monsoon contributes ~65 %, North East monsoon contributes ~25%, and remaining by winter and summer season. Mandal wise normal rainfall is provided in table.

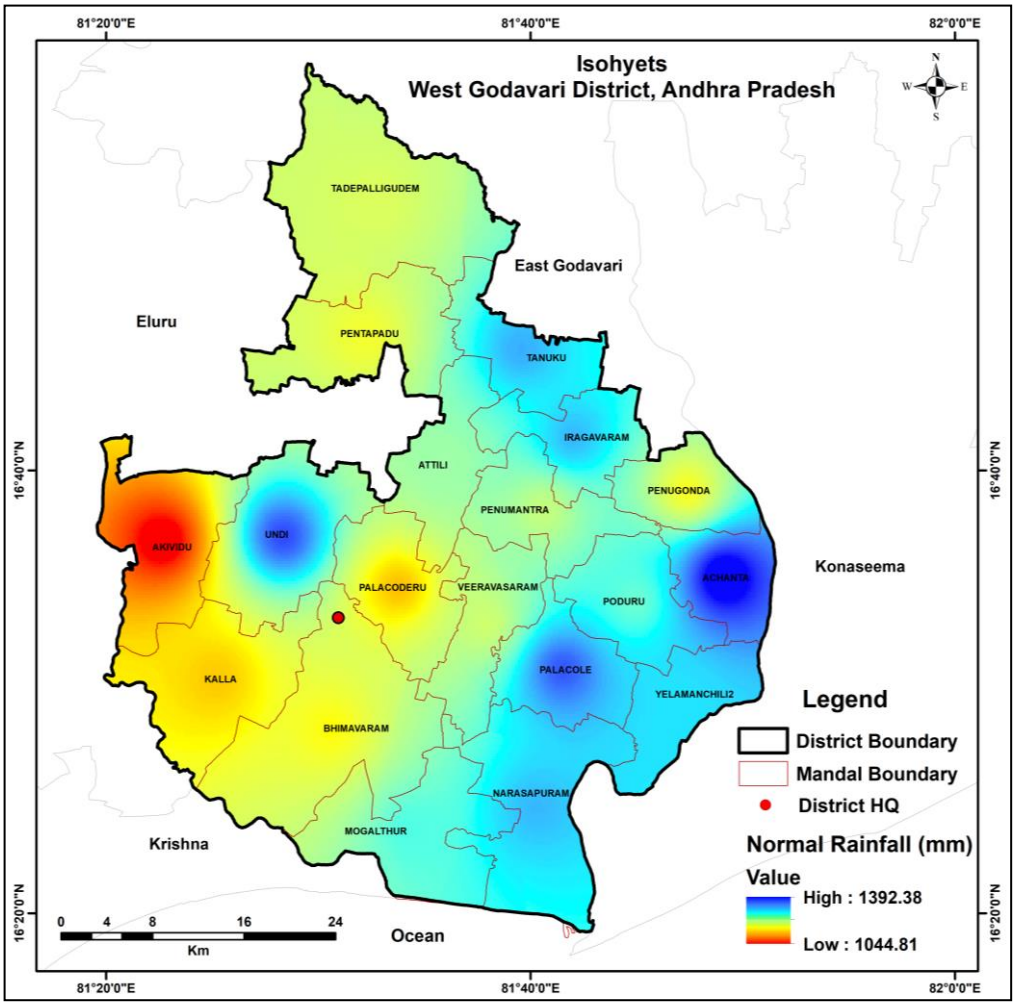


Fig.1.2: Isohyetal map of West Godavari district.

Table: 1.1 Mandal wise Normal Rainfall in West Godavari District, AP

SL.No	Mandal	Normal Rainfall
1	ACHANTA	1393
2	AKIVIDU	1045
3	ATTILI	1224
4	BHIMAVARAM	1162
5	IRAGAVARAM	1292
6	KALLA	1137
7	MOGALTHUR	1253
8	NARASAPURAM	1292
9	PALACODERU	1132
10	PALACOLE	1335
11	PENTAPADU	1172
12	PENUGONDA	1167
13	PENUMANTRA	1204
14	PODURU	1244
15	TADEPALLIGUDEM	1190
16	TANUKU	1297
17	UNDI	1341
18	VEERAVASARAM	1198
19	YELAMANCHILI	1274

1.5 Geomorphological Set up:

The area is basically occupied by deltaic and coastal plains. The landforms present in the area are mainly fluvial land forms and other forms are of marine. Various landforms occurring in the area are presented in **Fig.1.3.** Land forms derived from the streams are known as fluvial land forms. These land forms can be due to erosional or depositional processes. The study area has some of the important depositional land forms viz. Deltaic plains and Palaeo channels.

Shoreline Development- Present is the key to the past. The geomorphic features present in the coast indicate the possible shoreline in the past if similar structures are present on land. In study area the presence of beach ridge complexes on land indicates the existence palaeo shore lines, which were delineated using the remote sensing studies. The details and percentage of geomorphological features of the area is given in the **Table 1.2**

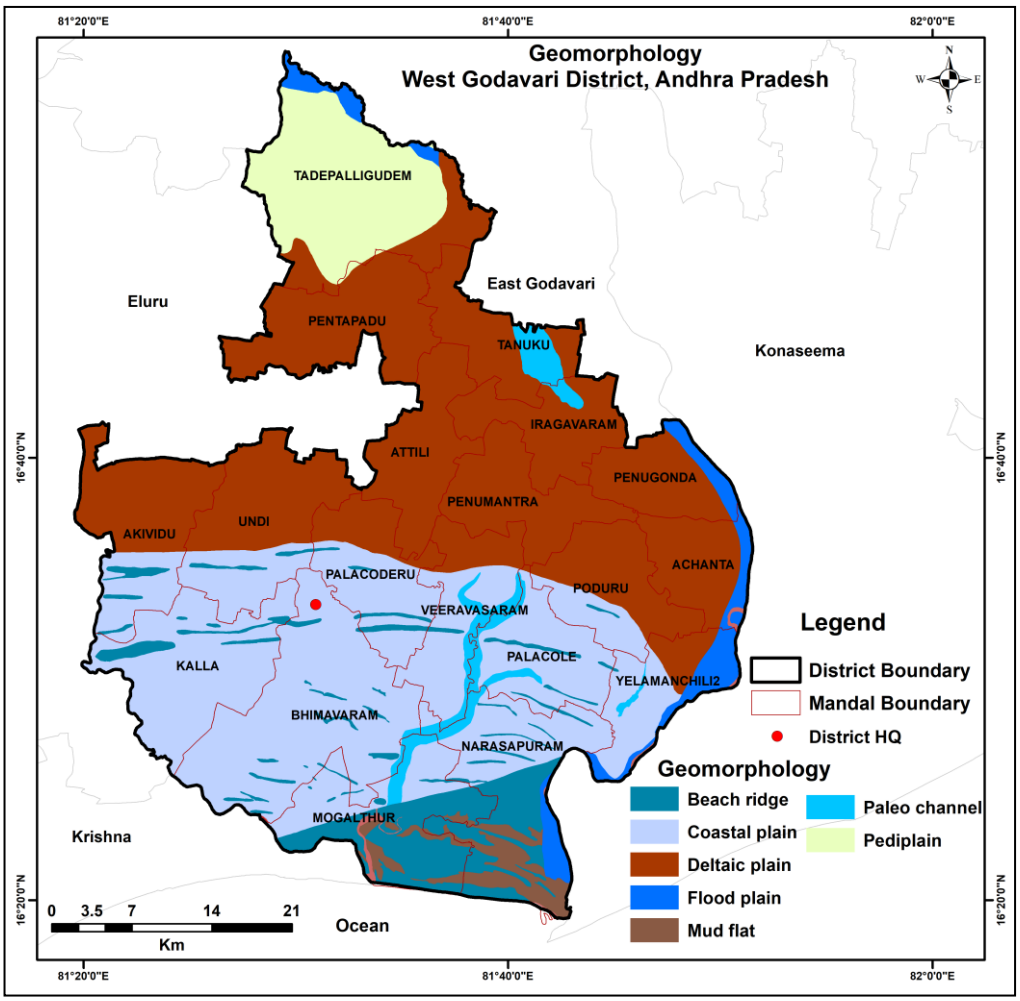


Fig.1.3: Geomorphology of West Godavari district.

Table: 1.2 Geomorphology of West Godavari District, AP

Geomorphology	Area (Sq.kms)	%
Deltaic plain	973	42
Coastal plain	837	36
Pediplain	181	8
Beach ridge	165	7
Flood plain	75	3
Paleo channel	61	3
Mud flat	48	2

1.6 Drainage and Structures: Major part of the district falls under Godavari basin. River Godavari starts as a trickle at Nasik in Maharashtra. If flows through the States of Marashtra and Andhra Pradesh. Godavari river flows N to S direction in the area. The district is divided into 2 major drainage basins namely Godavari and Yerrakalva. The drainage density in the area is sparse due to high permeability of alluvial soils. Map depicting drainage, River, tanks and river basin is presented in **Fig.1.4.**

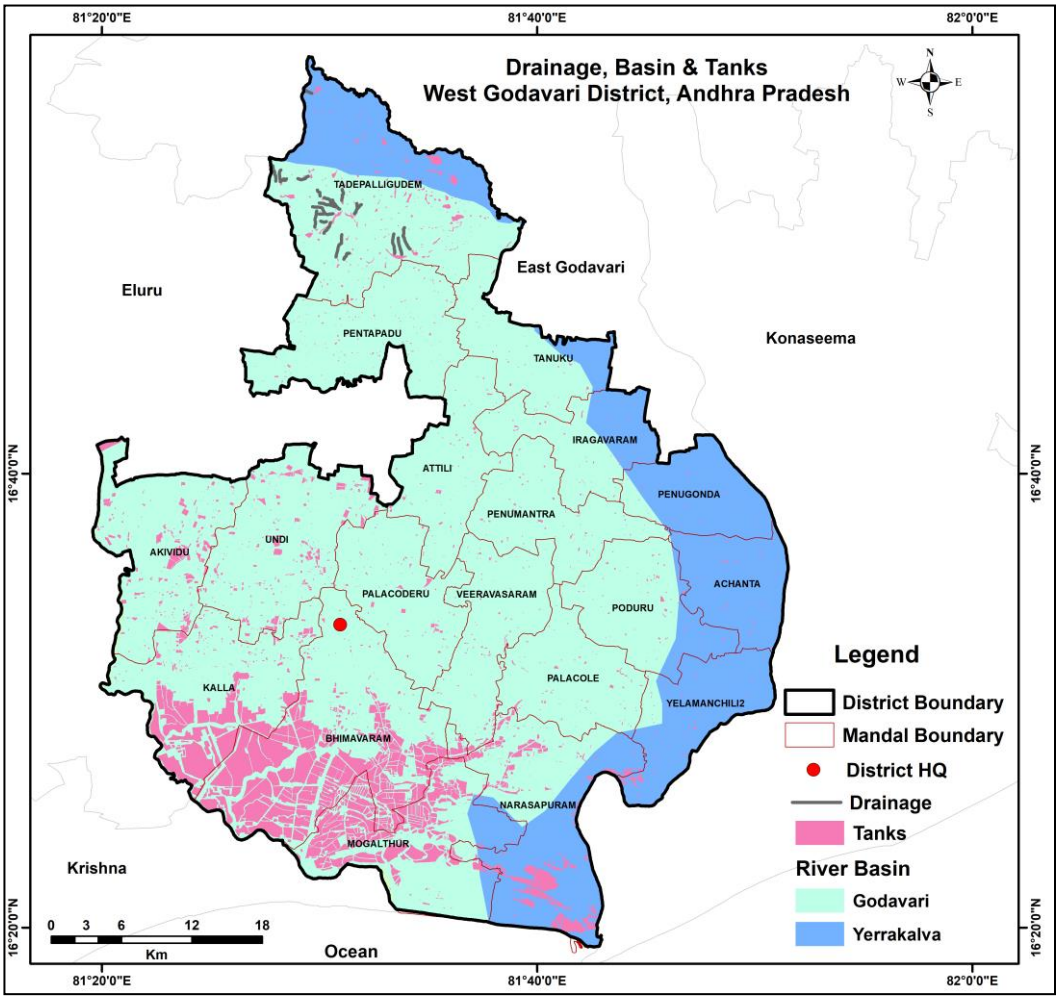


Fig.1.4: Drainage, River, Basin and Tanks.

1.7. Land Use and Land Cover: The land use pattern in the study area indicates that the area is mostly agrarian. Out of total geographical area of 2,34,640 ha, Net area Sown is 1,35,523 (~58%), land put to non-agricultural uses is 47,575 ha (20%) and Fish & Prawn culture is 41,580 ha (~18%). Land use and land cover map of the district is depicted in **Fig. 1.5** and graphical presentation is depicted in **Fig-1.5a.**

Table: 1.3. 12 classifications of Land Use in West Godavari District, AP

Sl. No	LULC	Area (Ha)
1	Total Geographical Area	234640
2	Total Cropped Area	229566
3	Net Area Sown	135523
4	Area Sown More than Once	110840
5	Land put to Non.Agricultural uses	47575
6	Fish & Prawn Culture	41580
7	Misc. Tree crops & groves not included in net area sown	2754
8	Permanent Pastures & other grazing lands	2198
9	Current Fallows	1632
10	Barren & Uncultivable Land	1349
11	Other Fallows	1138
12	Cultivable waste	888

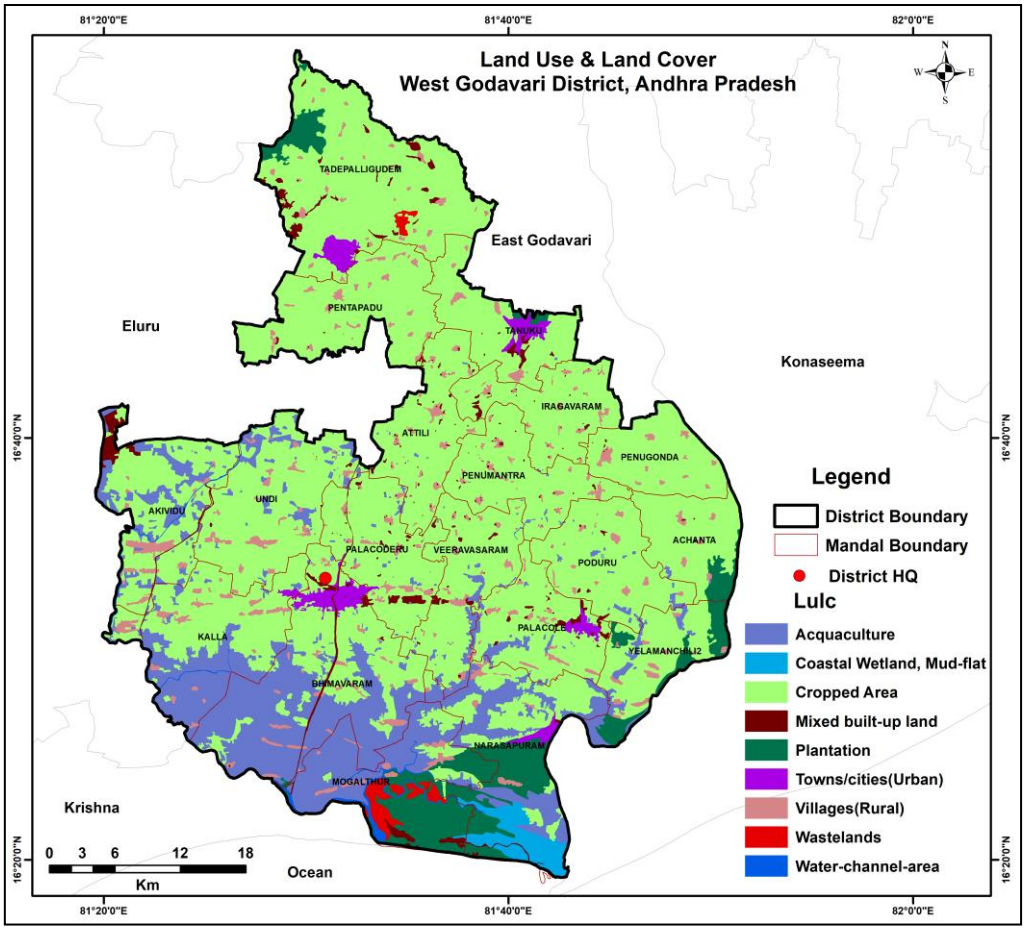


Fig.1.5: Land use and land cover of West Godavari district

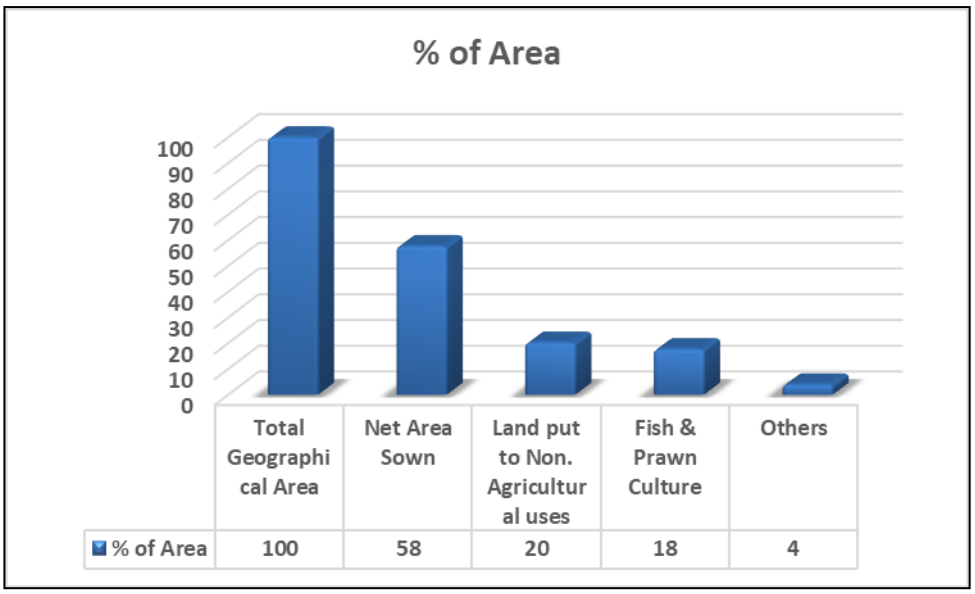


Fig.1.5a: Graphical presentation of Land Use of West Godavari District

1.8 Agriculture and Irrigation: The total cropped area in the district is 2,29,566 ha, out of which net area sown is 1,35,523 ha and area irrigated more than once is 1,10,840 ha. The details of cropped area are presented in **Fig-1.6**. Main crops grown during Kharif are Total food crops 1,05,802 ha (31%), total foodgrains 1,03,235 ha (30%), Rice 1,01,146 ha (29%). total Non food crops 13,727 ha (4%), total oil seeds 10,273 ha (3%) and coconut 8,962 (3%) and during Rabi season are Rice 1,01,605 ha (31%), Total food crops 1,07,741 ha (33%) and Total food grains 1,05,092 ha (33%).

The area is under the command of Godavari Canal System. The canal system remains operational for 11 months with a one-month closure period during April-May. The Sir Arthur Cotton Barrage at Dowlaiswaram serving the irrigation needs of the deltaic area since 1852, for both Kharif and Rabi seasons. During Kharif time sufficient or excess flow are available in the river. In general, there will not be any problem of shortfall of water for irrigation during Kharif period. The Godavari Eastern, Central and Western Deltas area served by mainly 3 major canal systems. They are the Eastern Delta Canal System, Central Delta Canal System and Western canal system. When the irrigation system was first established in 1852, the drainage system was also formulated with the branches of Godavari and the available rivulets. Since then, these natural valleys are called as drains and being utlised for irrigation system. The graphical representation of area irrigated by different sources in the district is presented as **Fig. 1.8b**. The major/Medium irrigation projects in the

district are Eastern Godavari Delta, Godavari Western Delta, Thatipudi LIS, ISRMC Polavaram and Chagalnad LIS projects **(Fig-1.8 a).**

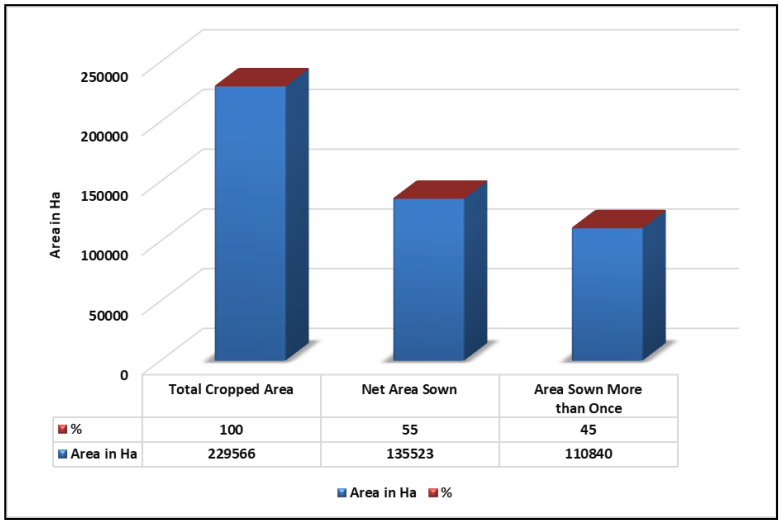


Fig.1.6: Graphical presentation of Cropped Area of West Godavari District

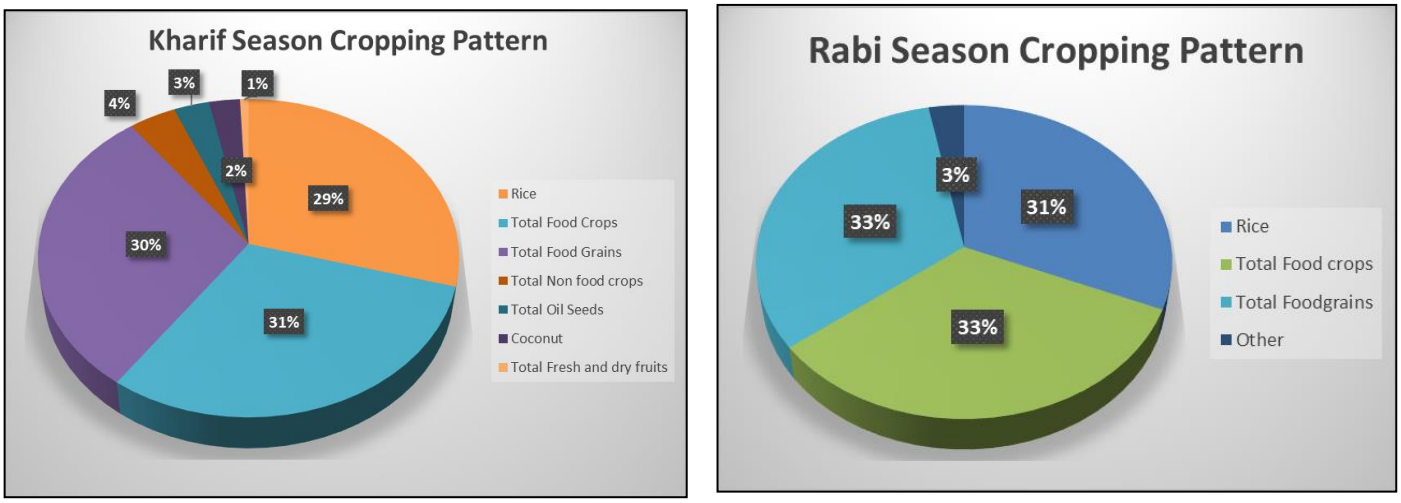


Fig.1.7: Cropping pattern in Kharif & Rabi

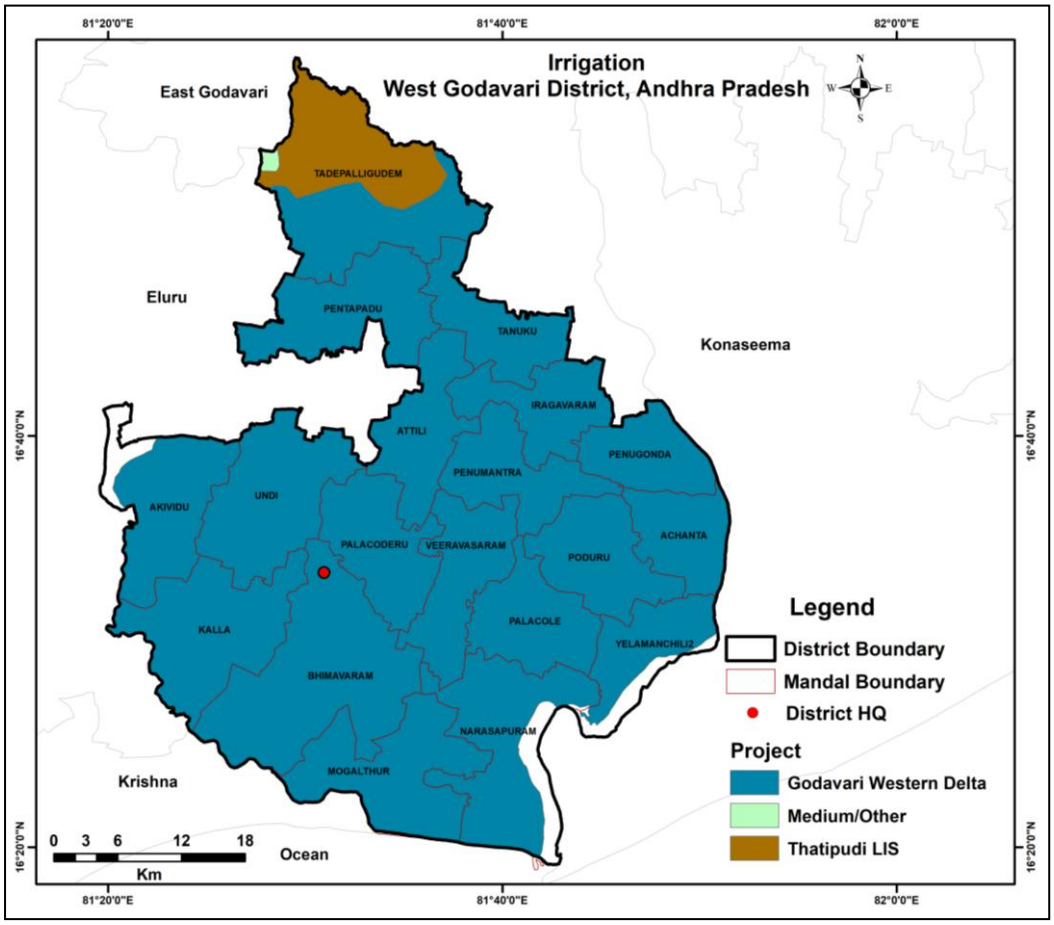


Fig.1.8a: Irrigation projects in West Godavari district

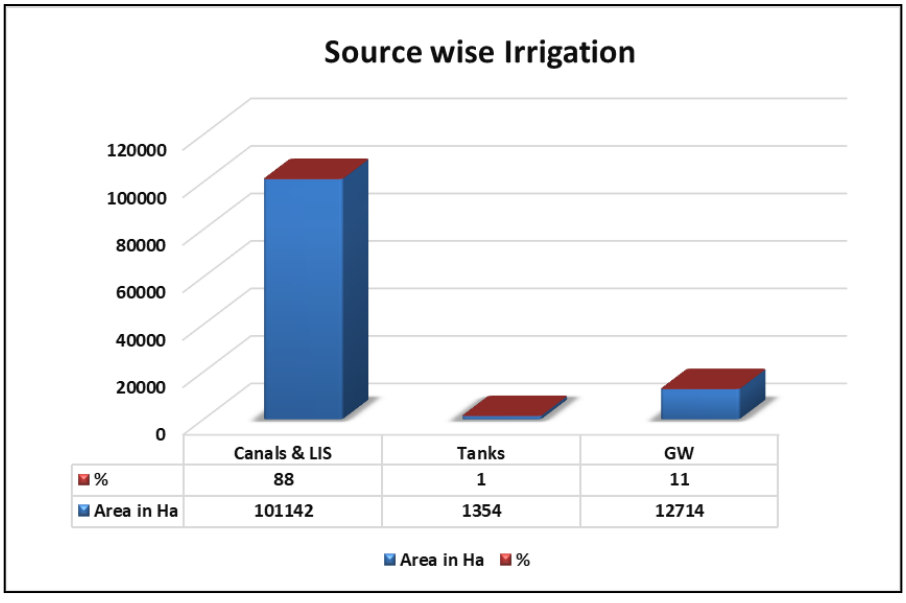


Fig.1.8 b: Area Irrigated by Different Sources

1.9 Soils: The area is mainly occupied by Very fine, montmorillonite (64 %) (Very Deep, imperfectly drained, cracking clay soils), Fine, montmorillonite (30 %) (Very Deep, imperfectly drained, cracking clay soils) and fine, mixed soils (4 %) (Very deep, well drained, sandy soils). (**Fig.1.9**)

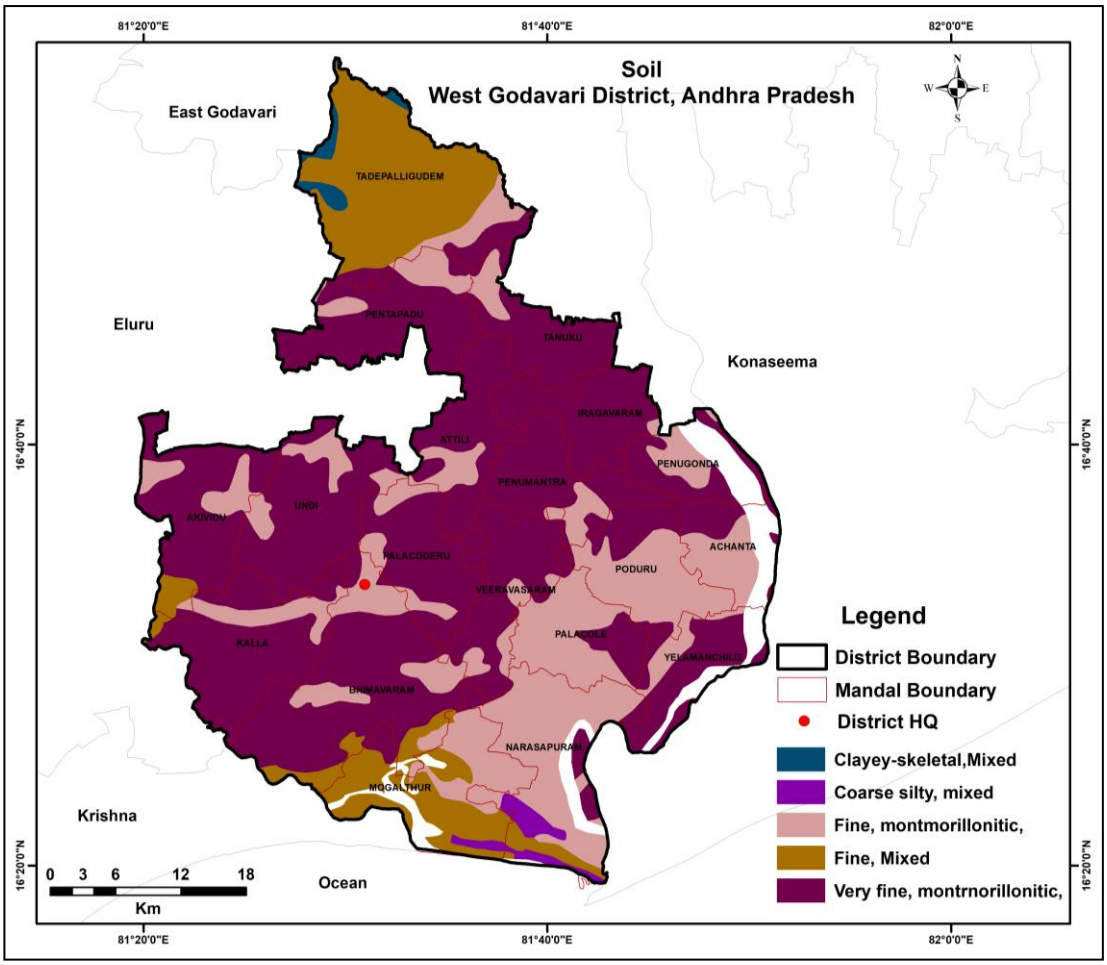


Fig.1.9: Soil map of West Godavari district.

1.10 Geology: Geologically the area is underlain by the recent to sub-recent alluvium comprising Sand, Gravel, Clay and Silt. The alluvium is underlined by sandstones. The sandstones formations are encountered at different depth in the boreholes drilled by CGWB in the northern part of the area at shallow depths. The general geological succession of the area is shown in **Table 1.4**. The geological map of the area is given as **Fig. 1.10.**

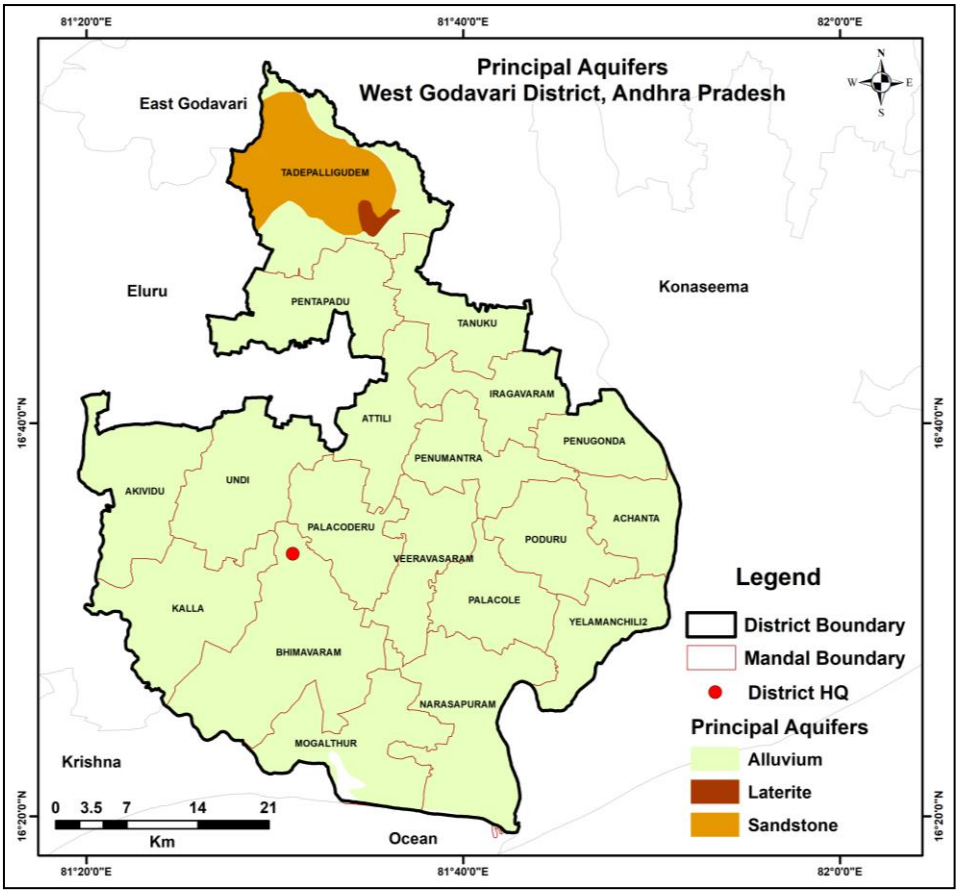


Fig.1.10: Geology of West Godavari district.

Table-1.4: Geological Succession in West Godavari District

Age	System	Formation	Lithology
Recent to Sub-Recent		Alluvium	Gravel, sand, silt, and clay
Mio-Pliocene		Rajahmundry	Sandstone and shale/ clay
Upper Cretaceous to Lower Eocene		Deccan Traps	Basalt
Lower Cretaceous to Lower Triassic	Upper Gondwana	Tirupathi	Sandstone and shale/ clay
		Raghavapuram	Sandstone and shale/ clay
		Gollapalli	Sandstone and shale/ clay
	Lower Gondwana	Chintalapudi	Sandstone and shale/ clay
---------- Unconformity ----------			
Archaean			Khondalites and Gneisses

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 (multi-aquifer) in the area is Alluvium and Sandstone. The occurrence and movement of ground water in these rocks is controlled by the degree of interconnection of primary pores/voids. Based on 65 hydrogeological data points, hydrogeological map is prepared. The details of data availability (**Fig.2.1)** is given bellow-

Organisation	Water Level	Water Quality	Aquifer Geometry
			EW
CGWB/SGWD	23	20	22

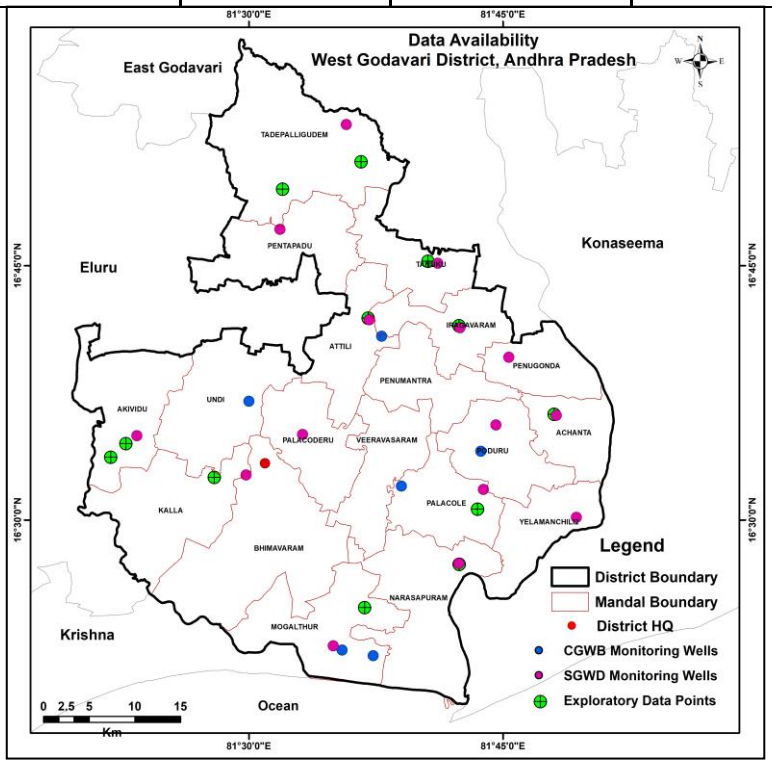


Fig. 2.1: Hydrogeological data availability.

2.1.1 Hydrogeology. The area is underlain by deltaic and coastal alluvium consisting of fine to medium sand, silt and gravel with intercalations of clay of recent age followed by sandstones of Mio Pliocene age. The sandstone formations are not exposed in the deltaic area but encountered at shallow to greater depths. Hydrogeological map of the area is

presented as **Fig.2.2.** Ground water in alluvium occurs under unconfined conditions in shallow aquifers, whereas semiconfined to confined conditions in the deeper aquifers. Buried/Paleo channels existing in central delta are promising potential zones. Overall, the ground water development is insignificant in the area except in few mandals.

Shallow aquifer is being tapped by dug wells and by filter points/ shallow tube wells in the area. The depth of the wells generally ranges from 3 to 12 m bgl. In the areas near coast wells are restricted 3 to 4 m. The yield of the wells varies in between 25 and 90 m3/hr. T and S are varying from 250 to 6200 m2/day and $3.14x10^{-3}$ to $5.5x10^{-4}$ respectively. Rainfall, canal system and the river Godavari are the main source of recharge. The fresh ground water is limited to shallow aquifer. The depth of these fresh water shallow aquifers varies considerably from place to place. The exploratory data reveals that the thickness of this aquifer is restricted to a maximum depth of 34 m. The deeper aquifers are not being tapped as the quality of the water is saline. In the Godavari delta the deeper alluvial aquifers explored down to 300 m depth contains saline water, whereas sandstone aquifers encountered below alluvium yielded fresh water.

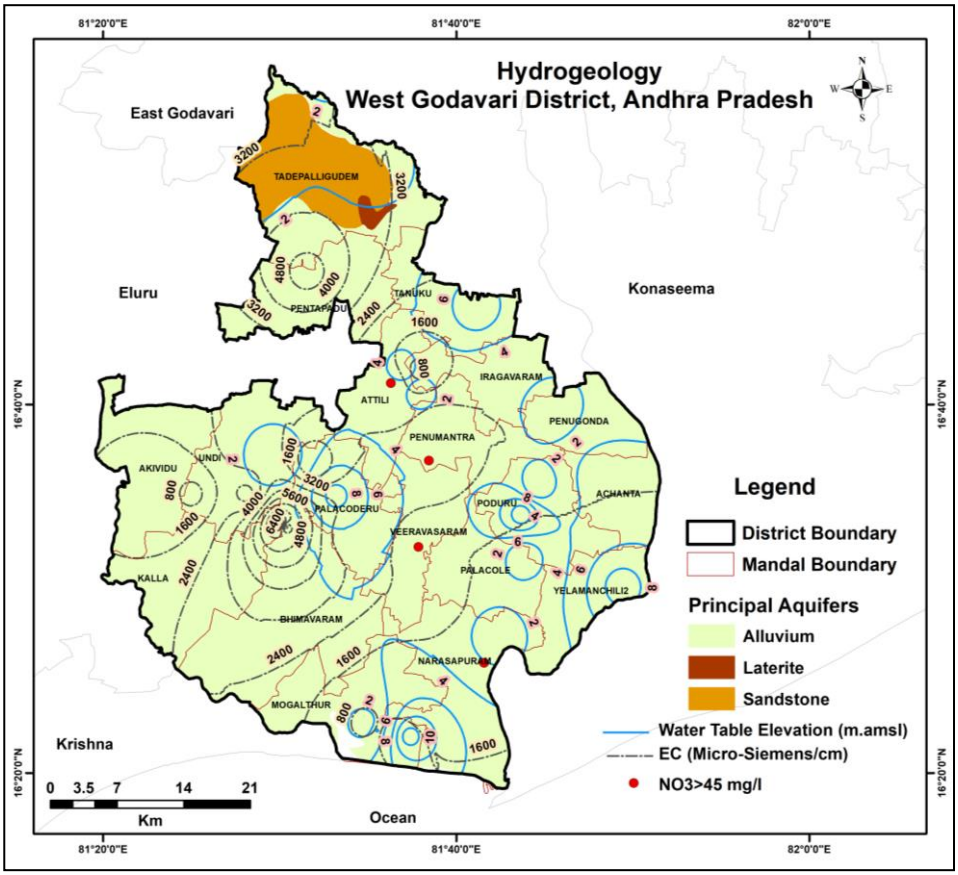


Fig.2.2: Hydrogeological map of West Godavari district.

2.1.2 Exploratory Drilling: As on date, CGWB drilled 22 no's bore wells in alluvium area ranging in depth 24 m-305 m.

2.2 Water Levels: Ground water levels from 23 wells (CGWB: 06 and SGWD: 17) were monitored during pre-monsoon and post-monsoon seasons respectively.

2.2.1 Water Table Elevations: During pre-monsoon (May, 2011-2020), the water-table elevation ranges from 0.13 – 10.77 meter above mean sea level (m amsl) and general ground flow is towards Bay of Bengal. (**Fig.2.3**)

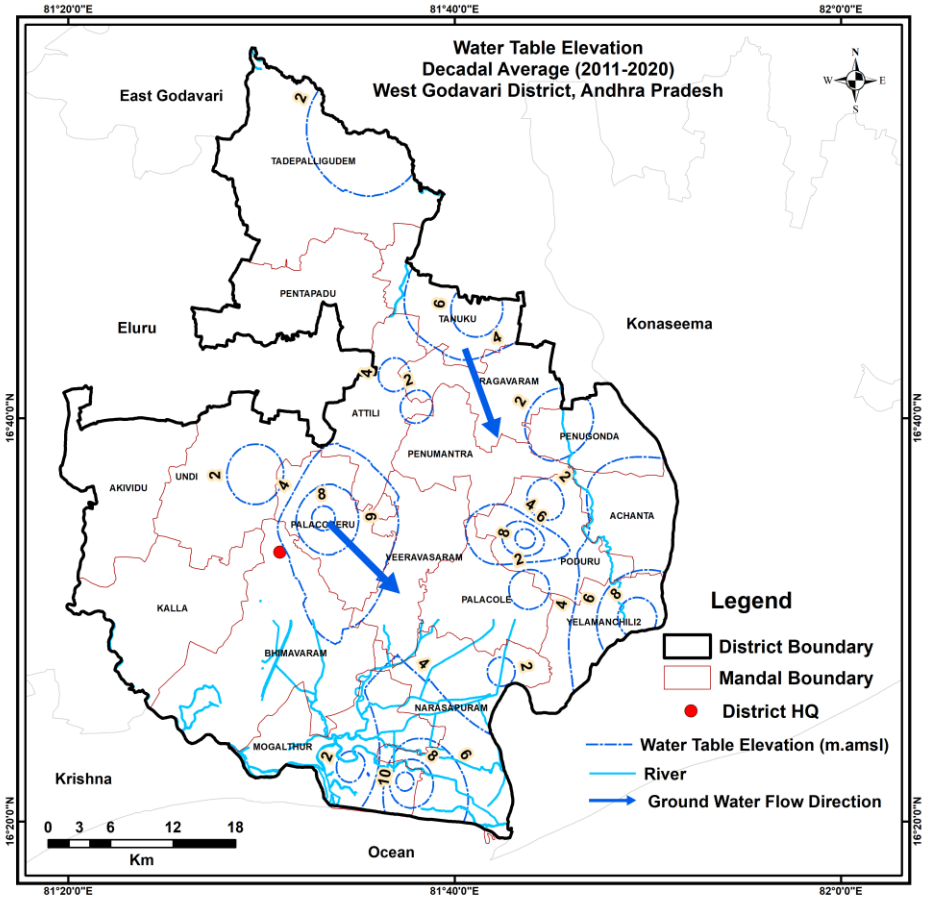


Fig.2.3: Water table elevations (m amsl) during pre-monsoon season

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 1.49 to 13.04 meter below ground level (m bgl) (average: 4.53 m bgl) and 1.22 to 12.64 m bgl (average: 3.89 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 0 to 5 m covering 67% of the area, followed by 0.5 to 10 m bgl (26%) and >10 m bgl (7 %). The

water levels >10 m.bgl occupy in parts of Narasapuram, Poduru and Tadepalligudem mandals. (**Fig.2.4**).

Post-monsoon season: Majority of the water levels during this season are in the range of 0 to 5 m bgl covering 93% of the area, followed by 5 to 10 m bgl (7%). (**Fig.2.5**).

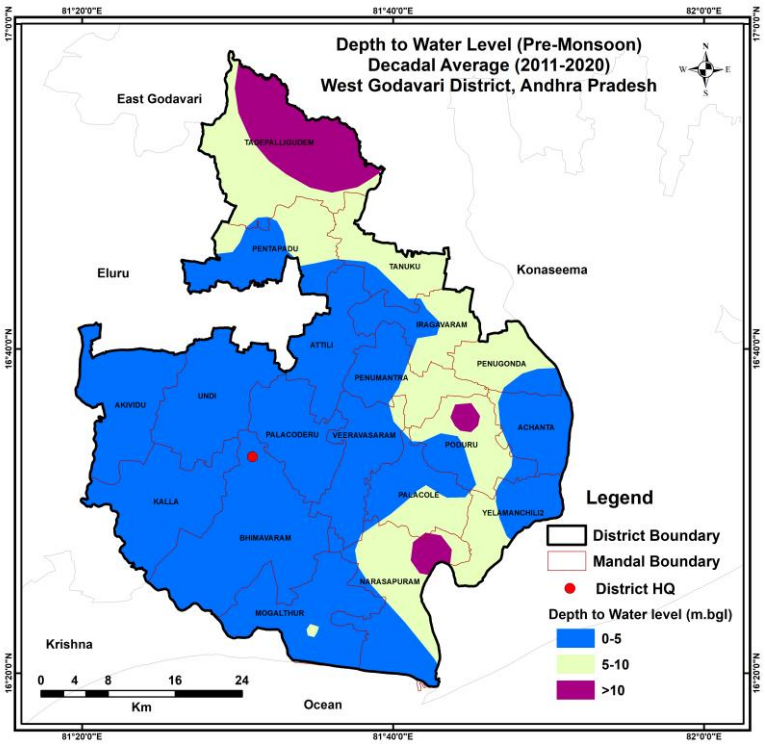


Fig.2.4: Depth to water levels Pre-monsoon

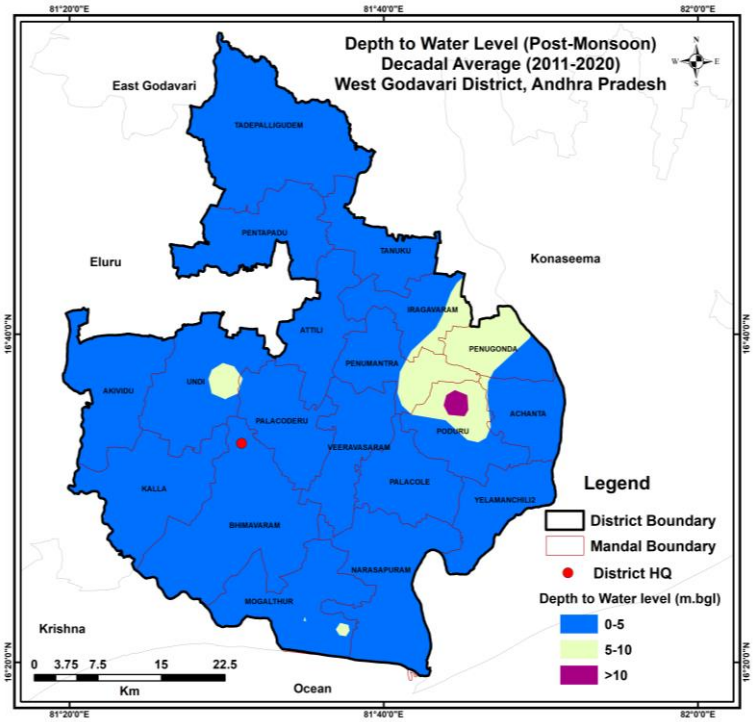


Fig.2.5: Depth to water levels post-monsoon

2.3 Hydro chemical Studies

To understand chemical nature of groundwater, total 25 data is utilized from ground water monitoring wells of CGWB during the pre-monsoon season of 2022. 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.

2.3.1 Pre-monsoon (May)

Groundwater is mildly alkaline to alkaline in nature with pH in the range of 6.68-8.29(Avg: 7.62). Electrical conductivity varies from 391-5020 (avg: 1824) µ Siemens/cm**.** In 31 % of area EC varies betweem 1500-2250 µ Siemens/cm, in 27 % area, it is 2250-3000 µ Siemens/cm, in 21 % area, it is >3000 µ Siemens/cm, in 19 % area, it is 750-1500 µ Siemens/cm and it is <750 µ Siemens/cm, in 1 % area (**Fig.2.7).** NO_3 ranges from 1-98 mg/L. Nitate concentration in 80% of samples is beyond permissible limits of 45 mg/L (**Fig.2.8**). Fluoride concentration varies from 0.032-1.09 mg/L (**Fig 2.9**) and all samples it is within permissible limits of BIS.

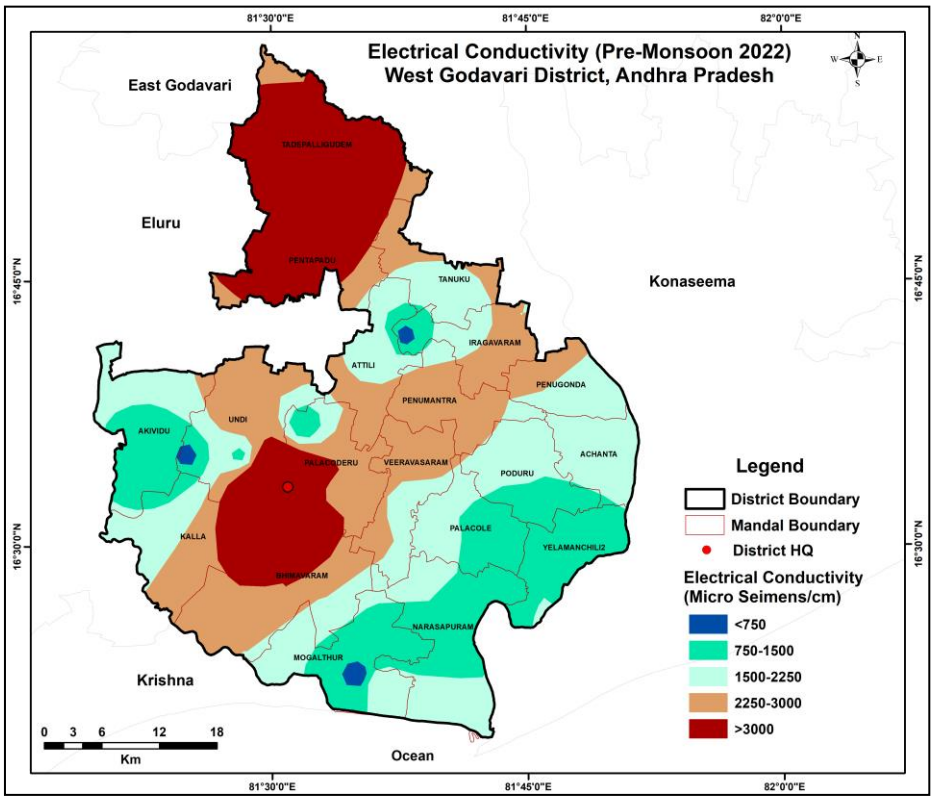


Fig.2.6: Distribution of Electrical conductivity (Pre-monsoon)

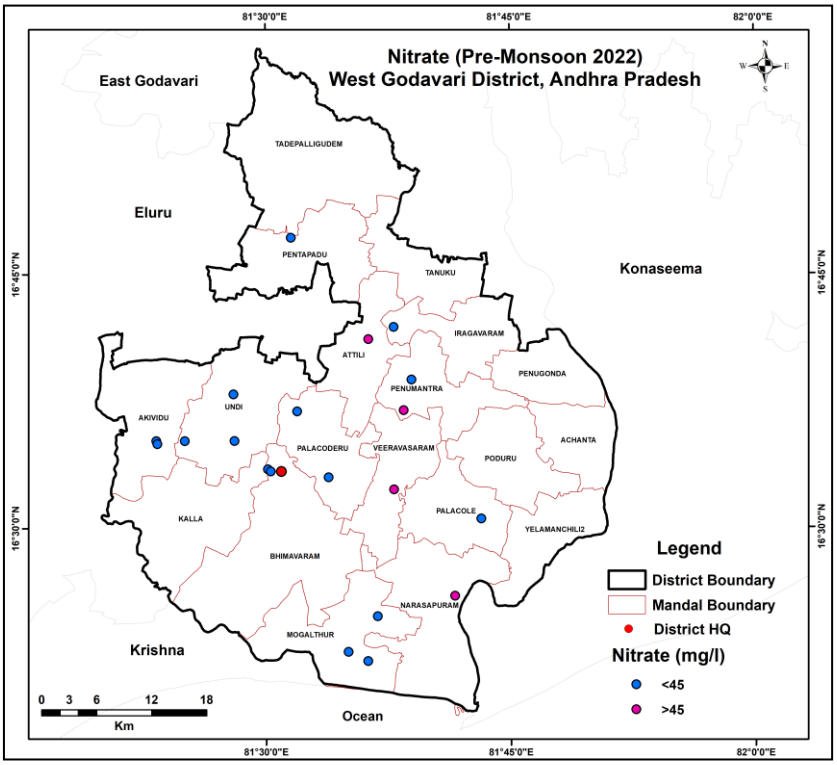


Fig.2.7: Distribution of Nitrate (Pre-monsoon).

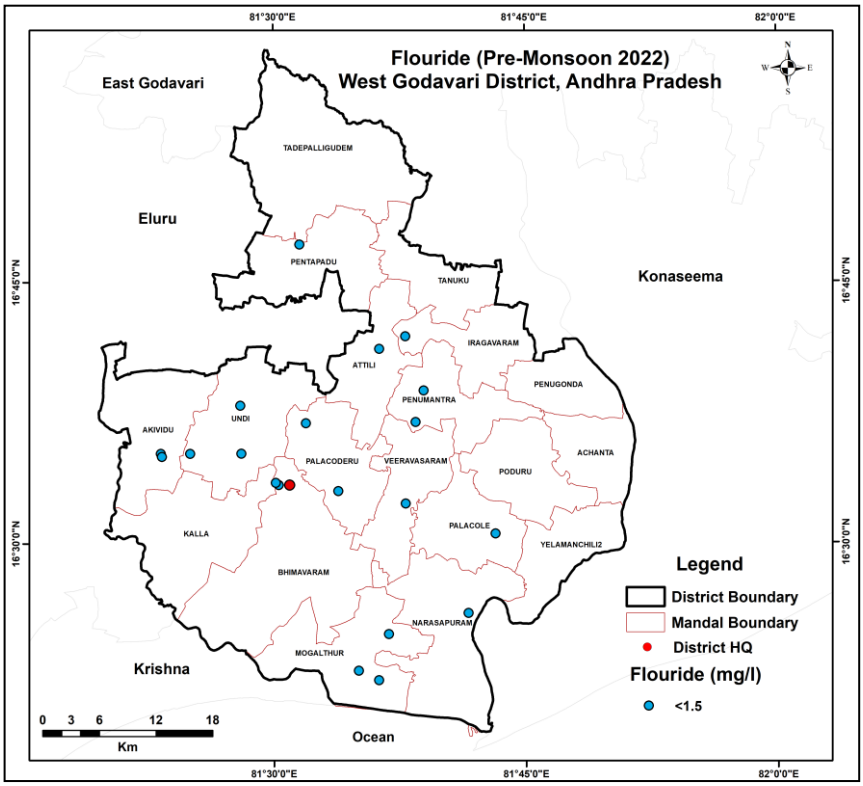


Fig.2.8: Distribution of Fluoride (Pre-monsoon).

3. DATA INTERPRETATION, INTEGRATION AND AQUIFER MAPPING

Conceptualization of 3-D hydrogeological model was carried out by interpreting and integrating representative 22 data hydrogeological points for preparation of 3-D map and hydrogeological sections. The data (**Fig.2.1**) is calibrated for elevations with Shuttle Radar Topography Mission (SRTM) data. The lithological information was generated by using the RockWorks-17 software and generated 3-D map for West Godavari district (**Fig.3.1).**

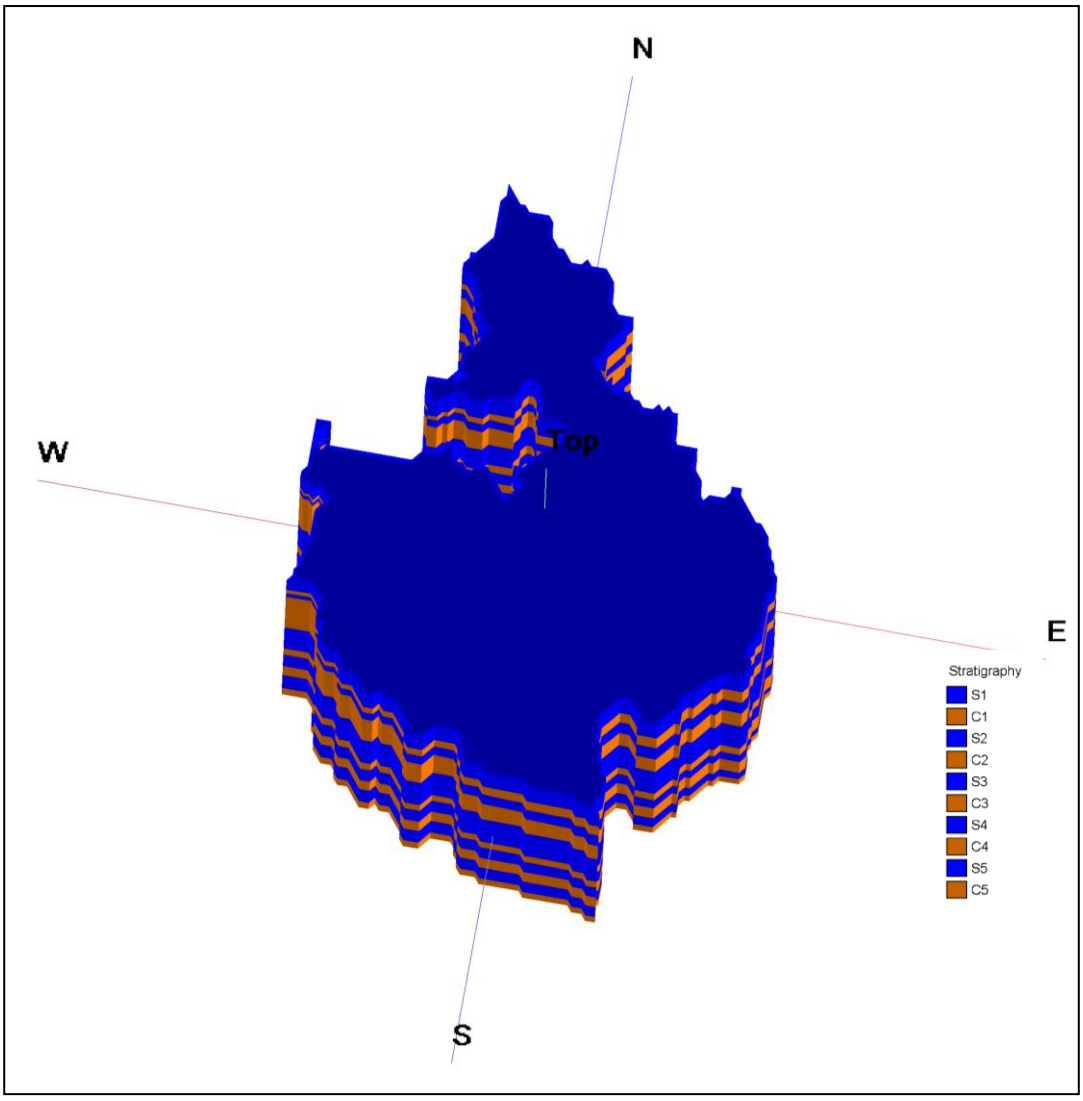


Fig.-3.1: 3-D Model for study area.

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. The detailed analysis of the data reveals that the Alluvium is the principal aquifer system. Ground water occurs in unconfined, semi-confined and confined conditions in the study area depending on the availability of impervious beds.

3.2 Hydrogeological Sections:

Different hydrogeological cross sections are prepared and presented as Fig. 3.2a & b. (**Fig.3.2.**). The data indicates that there are multi aquifers in the area with intervening thick clay beds. The sand beds act as aquifers in the area and there are five distinct beds which behave as regional aquifer. The study of the different sections indicate that the alluvium thickness is increasing from north to south and there are five aquifers exist up to a depth of 300 m in the study area. The shallow aquifer thickness is varying from place to place. The first aquifer which is present up to a maximum of 34m below MSL is unconfined whereas the other aquifers are confined.

The ground water quality of shallow aquifer is fresh, where as the deeper alluvial aquifers of are saline. Sandstone aquifers encountered below the alluvium are yielding fresh quality of ground water. The disposition of aquifers in the area is as given below in Table-3.

Table-3.

Depth range	Type of Aquifer	Quality of water
Upto 34 m	Unconfined Aquifer	Fresh
22 m - 60m	Confined Aquifer I	Brackish to Saline
68 m – 106 m	Confined Aquifer II	Saline
124 m – 203 m	Confined Aquifer III	Saline
212 m – 305 m	Confined Aquifer IV	Saline

There is deterioration of quality of ground water from shallow to deeper aquifers. Shallow aquifer is in unconfined condition and having the fresh ground water with EC ranges from 540 to 1700 micro siemens/cm at 25°C. The second aquifer is confined in nature and quality of the ground water is brackish to saline, where the EC ranges from 3000 to 5650 micro siemens/cm at 25°C. The deeper aquifers are saline with EC ranges from 10600 to > 20000 micro siemens/cm at 25°C and confine in conditions.

Hydrogeological, hydrochemical and geophysical studies reveal that the existence of five distinct aquifers within 300 m bgl in the Godavari deltaic area. The maximum thickness of the alluvium is not established. The first aquifer is under unconfined conditions where as the remaining aquifers are confined in nature. Shallow fresh water aquifer exists to a maximum depth of 34 mbgl, whereas quality of ground water in the deeper aquifers is saline.

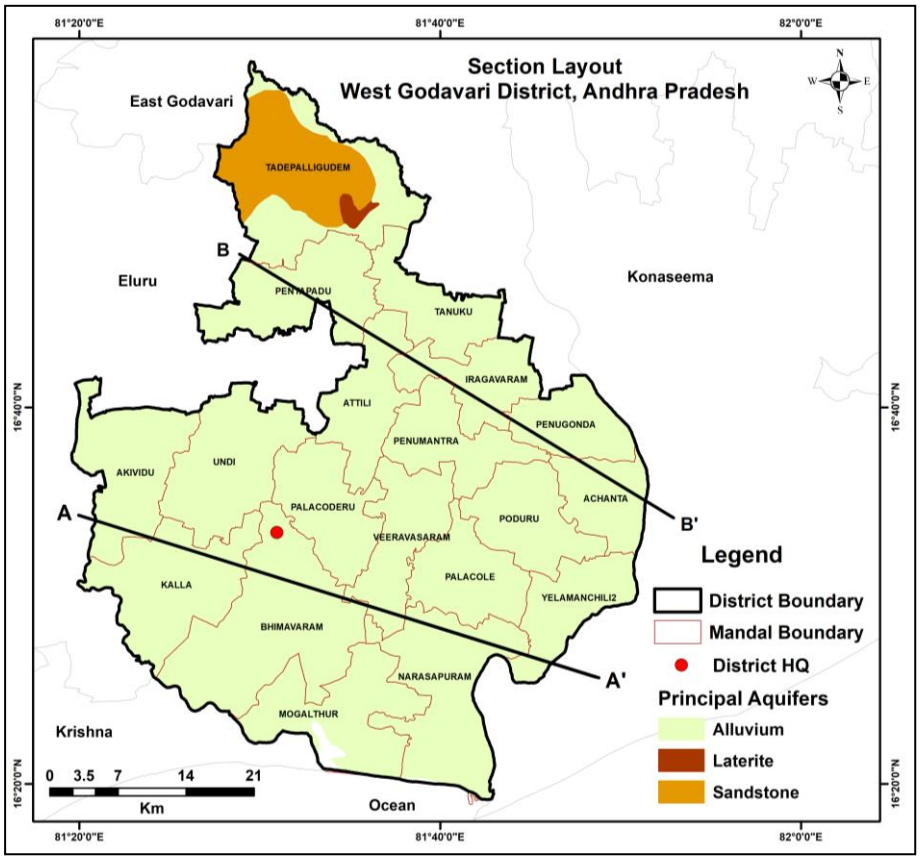


Fig.-3.2: Map showing orientation of hydro geological Sections

Fig.3.2a.

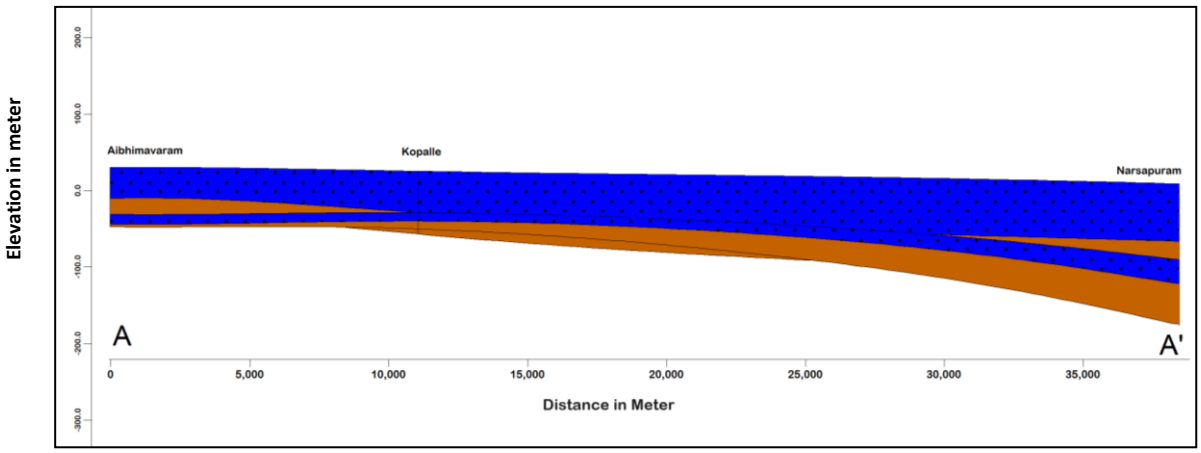
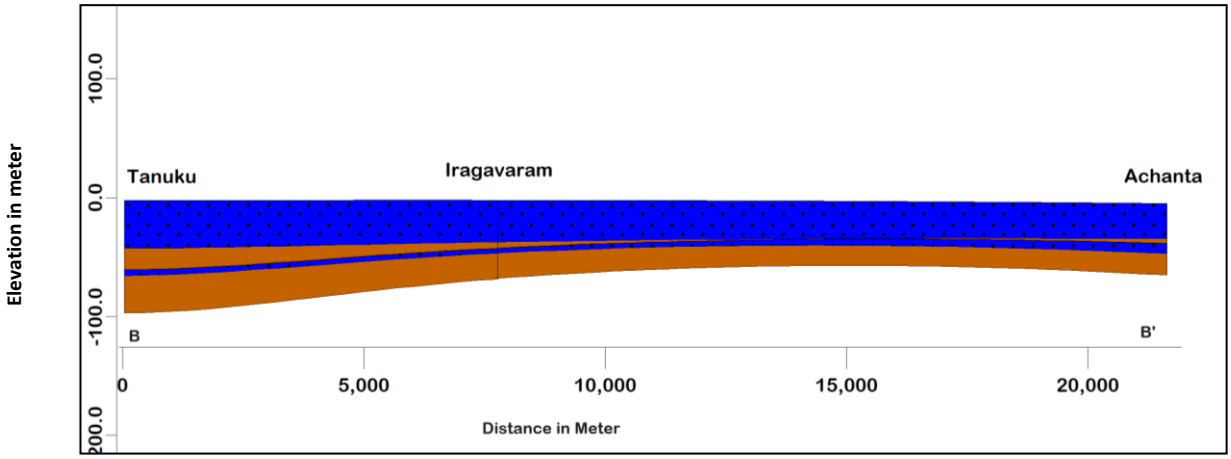


Fig.3.2b

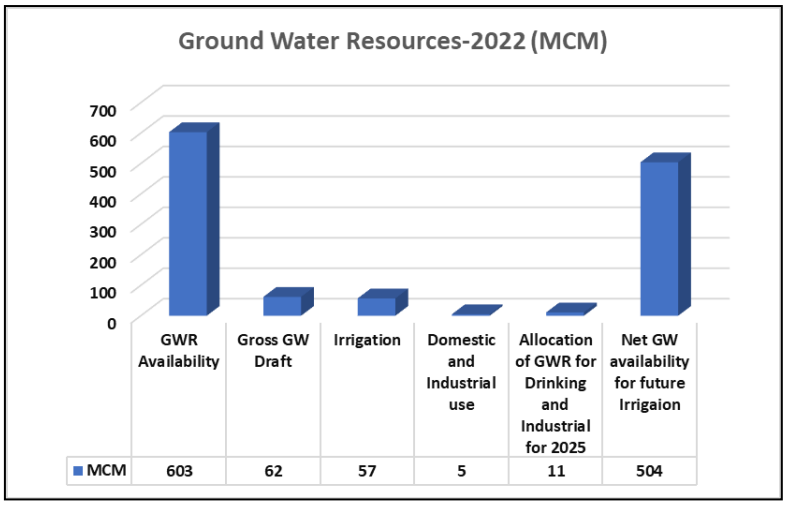

Elevation in meter
100.0
0.0
-100.0
200.0
Tanuku
Iragavaram
Achanta
B
B'
0
5,000
10,000
15,000
20,000
Distance in Meter

4. GROUND WATER RESOURCES (2022)

The dynamic ground water resources are computed as per the guidelines laid down in GEC methodology. As per 2022 GEC report, the net dynamic replenishable groundwater availability is 603 MCM, gross ground water draft for all uses 62 MCM, provision for drinking and industrial use for the year 2025 is 11 MCM and net annual ground water potential available for future irrigation needs is 504 MCM. The stage of ground water development in the area is 11%. The summarized mandal wise resources are given in Table-4. The details of Ground Water resources are provided in Annexure-3 and 4.

Table-4.: Computed Dynamic Ground Water resources, West Godavari District.

Parameters	**Total**
As per GEC 2022	**MCM**
Dynamic (Net GWR Availability)	**603**
• Monsoon recharge from rainfall	115
• Monsoon recharge from other sources	233
• Non-Monsoon recharge from rainfall	15
• Non-monsoon recharge from other sources	240
Gross GW Draft	**62**
• Irrigation	57
• Domestic and Industrial use	05
Provision for Drinking and Industrial use for the year 2025	11
Net GW availability for future irrigation	504
Stage of GW development (%)	**11%**



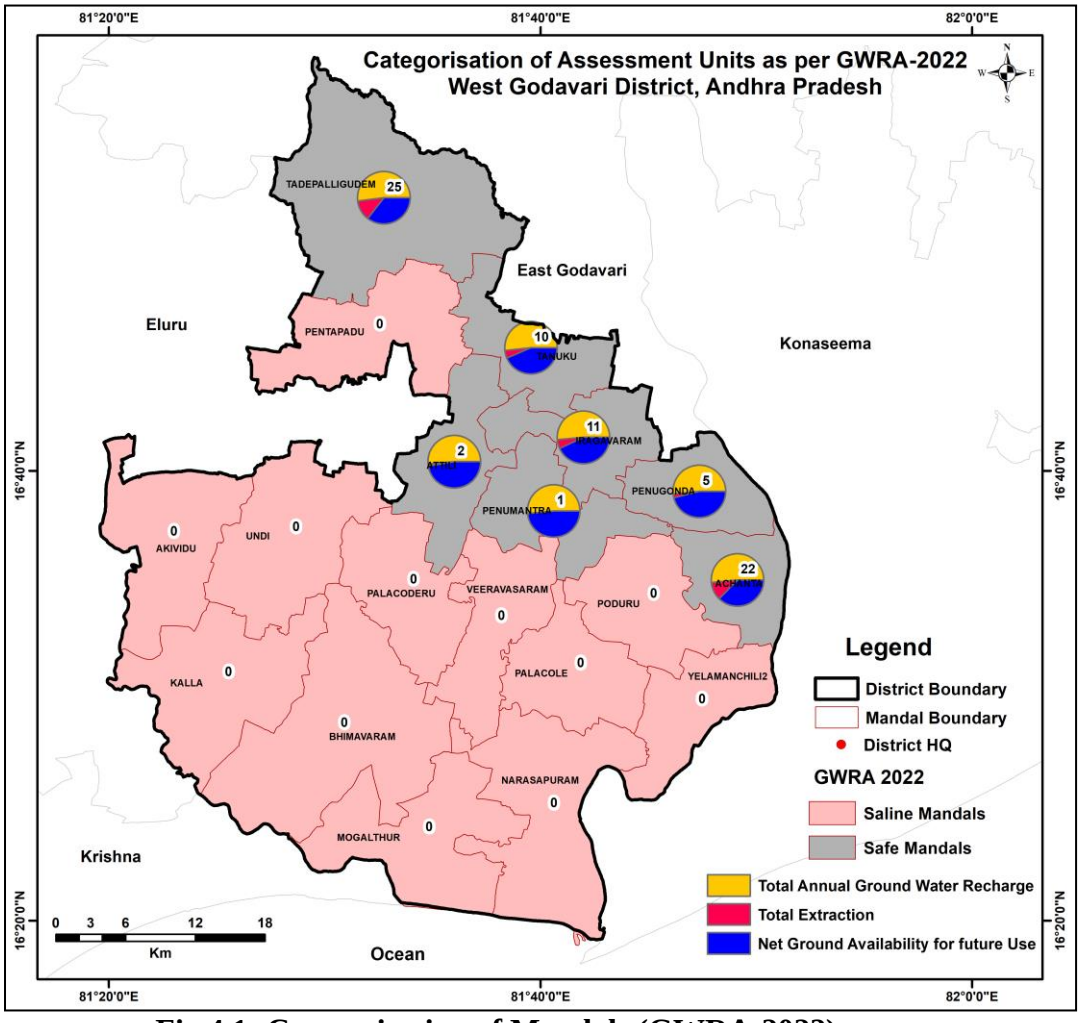


Fig.4.1: Categorisation of Mandals (GWRA-2022)

5. GROUND WATER RELATED ISSUES AND REASONS FOR ISSUES

The study area falls within the depositional cycle of the River Godavari, debouching the inland sediments into the Bay of Bengal. On the southern sides, the delta is bounded by the Bay of Bengal and on the other three sides the delta is bounded by land. Therefore, along the coastal area the action of the saline water is predominant. Since the area is just few meters above mean sea level with very low gradient and large quantum of water from the river Godavari and canal system are applied from landward side on one hand and on the other hand it is bounded by the large saline water body in the form of Bay of Bengal, naturally problems like water logging, saline water intrusion etc., are of great concern. During the last two decades with the advent of prawn culture some of the paddy fields have been converted into tanks for growing the prawns and fish. This took place mostly in the areas along the coast where water is available with the required degree of salinity from the drains/creeks or groundwater by means of filter point/shallow tube wells.

The major considerable ground water issues in the Godavari delta are :

- Water Logging
- Ground Water Salinity
- Aqua Culture

Water Logging:

Water logging is a common feature in irrigation commands of surface water projects. Godavari deltaic area is not an exceptional one. An area of 19 km^2 (1%) is under water logged condition during premonsoon period, whereas during postmonsoon period it is extended to 23 km^2 (1%). The area prone to water logging during premonsoon and postmonsoon periods is 19 km^2 (32 %) and 23 km^2 (27 %) respectively. Irrigation by surface water, minimal withdrawal of ground water, flat topography, high rainfall, poor drainage and nature of soils are responsible for the water logging conditions in the area.

Ground Water Salinity:

In Godavari Delta ground water in shallow aquifers is fresh except in the area near the coast and as isolated patches in inland, whereas in the deeper aquifers ground water is invariably saline. The origin of the salinity in any area can be due to the

following three reasons viz., palaeo salinity, due to leakage from the bottom aquifer, due to sea water intrusion caused by human activity. Based on the studies carriedout by CGWB, the origin of salinity in the unconfined aquifer is discussed in the following paragraphs.

Palaeo Salinity: By palaeo salinity, it is indicated that the ground water being extracted from the aquifer today is the entrapped water in the geologic formation at the time of deposition. By studying the strand lines in the Godavari delta, it can be understood that most of the delta is under sea in the geological past. If the ground water in Godavari delta is palaeo water, the salinity of the ground water in the past, due to marine regression and land upliftment, should be highest and year by year as it is being recharged by the rainfall and canal water, the salinity should follow a declining trend. In the first instance most of the saline water would have drained because of the rejuvenated hydraulic gradient. But the study reveals that the salinity in the area is not uniformly decreasing day by day. Instead, it is varying depending on the ground water being abstracted in the area. This may be leading to change in hydraulic gradient and inducing flow either from the bottom aquifer or from the sea. The salinity was also observed to have a relationship with the proximity to sea. Hence it can be safely concluded that the salinity in the unconfined aquifer in Godavari Delta is not of palaeo salinity.

Leakage from Bottom Aquifer: The Godavari Delta has five aquifers upto a depth of 300 m bgl and the top one is upto maximum of 34 m bmsl and is unconfined in nature and has fresh water. The other four aquifers are saline in nature. The second aquifer which exists in between 22 m and 60 m bmsl is in confined condition and is saline. Normally, in multi aquifer systems, it is possible that the second aquifer may not be fully confined and there exists a flow or leakage between the top unconfined and the bottom (semi) confined aquifer. But long duration pumping tests conducted on well fields by CGWB in the delta indicate that the second aquifer in this area is fully confined and the intervening clay bed is an aquiclude. Even pumping one aquifer does not show any reflection in the other aquifer. In this situation, it can be safely concluded that the salinity in the unconfined aquifer cannot be due to the vertical flow of the saline water from the bottom aquifer

Sea Water Intrusion: The first and foremost indicator of sea water intrusion is reversal of hydraulic gradient and hence there should not be any fresh ground water discharges into the sea. In normal course, the ground water from the aquifer will have a positive hydraulic gradient which is towards the sea and discharges directly onto sea bed. Hence as long as there are fresh water discharges into sea, it can be stated that there is a fresh water lense floating over the bottom saline water in the area and full encroachment by sea water is not present in the area. Because of the human activity, e.g. ground water withdrawal, when the fresh water head falls below mean sea level and reversal of gradient takes place, then the saline sea water flows into the coastal aquifer by contaminating the aquifer permanently and there will not be any fresh water discharges into the sea. The tip of the interface also starts moving towards the land. This type of situation is not present in Godavari Delta as there are huge ground water discharges into the sea at present. But even though there are fresh ground water discharges in to the sea, there is a possibility that the diffusion zone of the saline-fresh water interface interferes with the pumping water level in turn deteriorating the quality of ground water.

Status of Sea Water Ingress in the Unconfined Aquifer: Ground water in the coastal aquifers exists in hydraulic connectivity with the sea water. Hence the situation is very delicate and requires a precise management strategy to obstruct the sea water intrusion or upconing which will either permanently or temporarily deteriorate the ground water quality in the aquifer or in the well. The unconfined aquifer in the delta is maximum to a depth of 34m bmsl and the ground water in this aquifer is fresh excepting small pockets.

6. GROUND WATER DEVELOPMENT AND MANAGEMENT STRATEGIES

The Problems in the Godavari Delta can be summarised as below:

- Limited utilization of fresh ground water resources
- Quality deterioration due to sea water intrusion
- Quality deterioration due to aqua culture
- Quality deterioration due to direct recharge of saline water
- Uncontrolled pumping through filter points during periods of less surface water availability.
- Water Logging

Management Plan for the areas where limited utilization of fresh ground water resources:

When surface water is available plenty, normally people will not extract ground water for any purpose. But it should be encouraged so that the available surface water can be utilised in the tail end areas. Unless and until people understand the aquifer disposition and availability of fresh ground water in the aquifers, people may fail in tapping the available fresh ground water. Hence for encouraging farmers for utilising the fresh ground water resources, Awareness campaigns are to be organized to educate the farmers about the aquifer disposition and the bottom of first aquifer in the area which is containing fresh water so that the depth of the filter points should be limited to the bottom of fresh unconfined aquifer in the area,

The available fresh ground water may be encouraged to extract through conjunctive use. One option can be limiting surface water for the tail end areas and encouraging GW usage in upper and middle reaches. It can also be attempted that the Government can extract ground water through a network of filter points preferably in the shallow water table areas and supply the water through the canal system for irrigating the lower command. The surplus surface water will lead to enhanced command / gross irrigated area. This can lead to less extraction of ground water near the sea because of availability of surface water in tail end areas i.e., near the sea.

Management Plan for the areas where quality deterioration due to sea water intrusion is taking place:

In the area where already sea water intrusion is taking place and is observed by quality deterioration, top priority should be given for supplying surface water for the gross irrigated area in the tail end areas of the command so that the ground water extraction is reduced and in turn sea water intrusion and quality deterioration. There should be strict Implementation of Ban on Pumping in the areas which are less than 2kms from the sea and also pumping from the first two aquifers for the purpose of Aquaculture.

Artificial Recharges Measures should be practised in upper reaches such that the ground water head is always 2m above MSL which in turn maintain the natural hydraulic gradient towards sea.

Management Plan for the areas where quality deterioration due to aqua culture is taking place:

For controlling quality deterioration due to Aquaculture, Aqua Culture activities should not be encouraged beyond 2kms from the coast and also strict Implementation of Ban on Pumping from the first two aquifers for the purpose of Aquaculture.

Management Plan for the areas where quality deterioration due to direct recharge of saline water is taking place:

Direct recharge from sea water is possible where the back waters are reaching areas beyond 2 kms from the coast and the same water is used for spreading in the ponds for aqua culture and pisciculture. The back waters available in the creeks should be arrested beyond 2kms from the coast by maintaining the flows in the creek either from direct river water or drain water from the irrigation canals. Aqua Culture Should not be encouraged beyond 2kms from the coast.

This problem can be solved to some extent by installing coastal/tidal regulators on the creeks to arrest the back waters. As the creeks in most of the area are used for navigation by the fishing industry, it is required to install navigable coastal regulators i.e., regulators with gates, which can stop the flow of back waters and at the same time it will not disturb the navigation through the channel when required.

Management Plan for the areas where uncontrolled pumping through filter points during periods of less surface water availability:

As this problem exists only in case where surface water is not available in the area, top priority should be given for providing surface water for the gross irrigated area in the tail end areas of the command. Based on the availability of surface water, ground water in the upper reaches should be pumped into the canal network such that it should not arise a need for pumping in the tail end areas especially areas less than 2kms from the coast. Strict Implementation of Ban on Pumping in the areas which are less than 2kms from the sea. Artificial Recharges Measures should be encouraged to be practised in upper reaches such that the ground water head is always 2m above MSL.

Management Plan for the areas which are water logged or prone to water logging:

For the water-logged areas, Ground water extraction should be encouraged through conjunctive use. Pumping the ground water through a net work of filter points and pump the water in the canals for catering the irrigation needs of the lower reaches of the command. There should be strict Implementation of Ban on Surface Water Supply for Irrigation and Industrial purpose.

Acknowledgment

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