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

**CENTRAL GROUND WATER BOARD**

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

# REPORT ON
# AQUIFER MAPPING FOR SUSTAINABLE MANAGEMENT OF GROUND WATER RESOURCES IN ANAKAPALLI DISTRICT, ANDHRA PRADESH


**CENTRAL GROUND WATER BOARD**
**SOUTHERN REGION**
**HYDERABAD**
**MARCH-2024**

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## CONTRIBUTORS' PAGE

| Name | | Designation |
|---|---|---|
| **Principal Author** | | |
| B.J Madhusudan | : | Scientist-B |
| **Supervision & Guidance** | | |
| Shri Ravi Kumar Gumma | | Scientist-D and OIC ,AP SUO CGWB Vishakapatnam |
| G. Krishnamurthy | : | Regional Director, Scientist-E |

# REPORT ON
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# REPORT ON
# AQUIFER MAPPING FOR SUSTAINABLE MANAGEMENT OF GROUND WATER RESOURCES IN ANAKAPALLI DISTRICT, ANDHRA PRADESH

## AT A GLANCE

| S.No. | Item | | Particulars |
|---|---|---|---|
| 1 | District | : | Anakapalli |
| 2 | Revenue Mandals (No.) | : | 24 |
| 3 | Villages | : | 723 Nos |
| 4 | Geographical area | : | 4291 $km^2$ |
| 5 | Mappable area | : | 4291 $km^2$ |
| 5 | Population (2011 Census) | : | 17.5 lakh |
| 6 | Density of population (2011 Census) | : | 402 persons/$km^2$ |
| 7 | Location | : | North latitude - $17^o$ 21' & $17^o$ 59' N latitude and 82°49'- 83°20' |
| 8 | Rainfall (Normal) | : | 883.2mm avg. |
| 9 | Geomorphology | : | Pediplain (41%), Structural hills (34%), Pediments (7%), Flood plains (8%). |
| 10 | Major Rivers | : | Nagavalli |
| 11 | Land Utilization (Ha) (2019-20) | : | Forest: ~36%, barren and uncultivable land 11.5%, land put to non-agricultural use is 12% of the area and Gross croppd area is ~22%. |
| 12 | Soils | : | Sandy loamy soils (40 %) and Clayey soils (51%) |
| 13 | Cropping Pattern (2019-20)<br><br>(Gross cropped Area: 253458Ha) | : | Kharif:<br>Food crops-43%, food grains-21, paddy-17%, cotton-7%, Non food crops-4%<br>Rabi:<br>Food crops-29%, food grains-28%, pulses-22%, oil seeds-4%, Non food crops-11% |
| 16 | Geology | : | Khondalite and Granitic Gneiss |

| | | | |
|---|---|---|---|
| 17 | Hydrogeological data points | : | 145 hydrogeological data points (Exploration CGWB: 43), VES: 102 (CGWB) |
| 19 | Ground water yield (lps) | : | <0.1 to 32 lps (Avg:1.9 lps)<br><br><0.1 in Granites and <0.1 to 13.77 lps (avg: 2 lps) in Metasediments.<br><br>Low yield (<1 lps):48 % of area, Moderate yield (1-3 lps):34% of area and high yield (>3 lps): 18% of area. |
| 20 | Water Levels<br><br>Depth to water levels (m. bgl) | :<br><br>: | wells<br><br>Water table elevations during pre-monsoon season vary from 95.71-308.26 m. amsl and during post-monsoon season vary from 96.39-318.07 m. amsl.<br><br>**Pre-monsoon**: 1.32 to 51.10 m bgl (average: 9.07 m bgl) and majority are in the range of 5- 10 m bgl (52 % area) followed by 10-20 mbgl (34% area, <5 mbgl (11%) and Deeper water levels (> 20 mbgl) occupy 3% of area.<br><br>**Post-monsoon**: 0.89 to 31.02 m bgl (average: 8.00) and majority are in the range of 5-10 m bgl (48% area) followed by 10-20 mbgl (29% area) ,<5 mbgl (22% area) and Deeper water levels ( >20m.bgl) occupy 1% of area. |
| 21 | Water Level Fluctuations (May vs. November) | : | -6.46 to 25.24 m with Average rise of 0.84 m. |
| 22 | Long term water level trends (2014-23) | : | **Pre-monsoon:** Falling trends: 04 wells (0.08 to 0.83 m/yr) Rising trends: 25 wells shows 0.02 to 4.64 m/yr.<br><br>**Post-monsoon:** Falling trends: 14 wells (0.01 to 2.83 m/yr) Rising trends: 31 wells shows 0.02 to 10.52 m/yr. |
| 23 | Hydrochemistry | : | Total 27 Pre Monsoon water samples. |
| 24 | Electrical Conductivity (µ Siemens/cm) | : | **Pre-monsoon**: 540-4060 µ Siemens/cm (avg:1579) |
| 25 | Fluoride mg/l | : | **Pre-monsoon**: 0.1-1.8 mg/L, 10% of samples are more than permissible limits. |
| 26 | Nitrate mg/l | : | **Pre-monsoon**:01-320 mg/L, 35 % of samples are more than permissible limits. |
| 25.2 | Conceptualization | | Weathered zone (~15 m), Fractured zone (13-185 m) |

| | | | | |
|---|---|---|---|---|
| 26 | Aquifer Characterization | : | Weathered zone (~15 m). 10-20m weathering occurs in 52% followed by < 10m in 25% of area and deep weathering occurs in 2 % of area. | Fractured zone( 15-185 m.) Majority of fractures ~80% occurs within 100 m depth. |
| 27 | Aquifer wise Ground water yield | : | <0.1 lps in granite and <0.1 to 13.77 lps in Khondalite. | |
| 27.1 | Transmissivity ($m^2$/day) | : | 1- 240 $m^2$/day, in majority of wells it is < 30 $m^2$/day. | |
| 27.2 | Specific Yield | : | < 1 to 2 % | |
| 27.3 | Storativity | : | 0.00001 to 0.0001 | |
| 28 | Ground water Resources (MCM) (2023) | : | | |
| 28.1 | Net Dynamic groundwater availability | : | 557.62 MCM | |
| 28.2 | Gross GW Draft | : | 203.26 MCM | |
| 28.3 | Provision for Domestic &Industrial (2025) | : | 53.70 MCM | |
| 28.4 | Average Stage of Ground water Extraction (%) | | 28 % | |
| 28.5 | Net GW Availability for future use | : | 57.64 MCM | |
| 28.7 | Categorization of mandals | | • Mandal wise it varies from 11.22 % to 51.8 % | |

# ABBREVIATIONS

| | | |
|---|---|---|
| 2D | : | 2 Dimensional |
| 3D | : | 3 Dimensional |
| ARS | : | Artificial Recharge Structures |
| Avg | : | Average |
| BDL | : | Below Detection Level |
| BW | : | Bore Well |
| CD | : | Check dam |
| CGWB | : | Central Ground Water Board |
| Cr | : | Crore |
| DTW | : | Depth to water |
| DW | : | Dug well |
| EC | : | Electrical conductivity |
| EL | : | East Longitude |
| F | : | Fluoride |
| FP | : | Farm Pond |
| GEC | : | Ground Water Estimation committee |
| GW | : | Ground Water |
| Ha | : | Hectare |
| Ha.m | : | Hectare meter |
| ID | : | Irrigated dry |
| IMD | : | India Meteorological Department |
| $Km^2$ | : | square kilometre |
| LPS | : | Litres per second |
| M | : | meter |
| $M^3$ | : | Cubic meter |
| m bgl | : | Metres below ground level |
| MCM | : | Million cubic meter |
| Mg/l | : | Milligram per litre |
| MI | : | Micro irrigation |
| Min | : | Minimum |
| max | : | Maximum |
| MPT | : | Mini percolation tank |
| NL | : | North Latitude |
| $NO_3$ | : | Nitrate |
| OE | : | Over Exploited |
| PGWM | : | Participatory ground water management |
| PT | : | Percolation tank |
| SGWD | : | State Ground Water Department |
| S | : | Storativity |
| Sy | : | Specific Yield |
| T | : | Transmissivity |
| WCM | : | Water conservation measures |

# 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 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 by nature 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.

**1.1Objectives:** 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.

**1.2Scope 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. 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.

**1.1 Area details:** The district consists of 24 mandals with 723 revenue villages and located in Northen part of Andhra Pradesh State having geographical area of 4291 $km^2$, lies between $17^o$ 21' & $17^o$ 59' N latitude and 82°49'- 83°20' East longitude (Fig.1.1). Out of total area, the hilly and forest area is about 784 $km^2$ (~18%). The list of the mandal with area are provided below:

| S.No. | Mandal | Geographical area (Sq.kms) | Forest/Hilly Area (Sq.kms) |
|---|---|---|---|
| 1 | ANAKAPALLI | 184 | 2 |
| 2 | ATCHUTAPURAM | 151 | 18 |
| 3 | BUTCHAYYAPETA | 193 | 21 |
| 4 | CHEEDIKADA | 118 | 4 |
| 5 | CHODAVARAM | 158 | 13 |
| 6 | DEVARAPALLE | 175 | 28 |
| 7 | GOLUGONDA | 327 | 195 |
| 8 | K KOTAPADU | 157 | 9 |
| 9 | KASIMKOTA | 197 | 40 |
| 10 | KOTAURATLA | 209 | 73 |
| 11 | MADUGULA | 201 | 41 |
| 12 | MAKAVARAPALEM | 155 | 6 |
| 13 | MUNAGAPAKA | 93 | 5 |
| 14 | NAKKAPALLI | 255 | 46 |
| 15 | NARSIPATNAM | 129 | 23 |
| 16 | NATHAVARAM | 289 | 110 |
| 17 | PARAVADA | 151 | 4 |
| 18 | PAYAKARAOPETA | 130 | 17 |
| 19 | RAMBILLI | 147 | 14 |
| 20 | RAVIKAMATAM | 246 | 54 |
| 21 | ROLUGUNTA | 151 | 1 |
| 22 | S RAYAVARAM | 165 | 9 |
| 23 | SABBAVARAM | 193 | 27 |
| 24 | YELAMANCHILI | 117 | 25 |
| | **Total** | **4291** | **784** |

The population of the study area is ~17.5 lakhs (2011 census). The density of population is 402 persons/Km$^2$ (CPO, Anakapalli district).

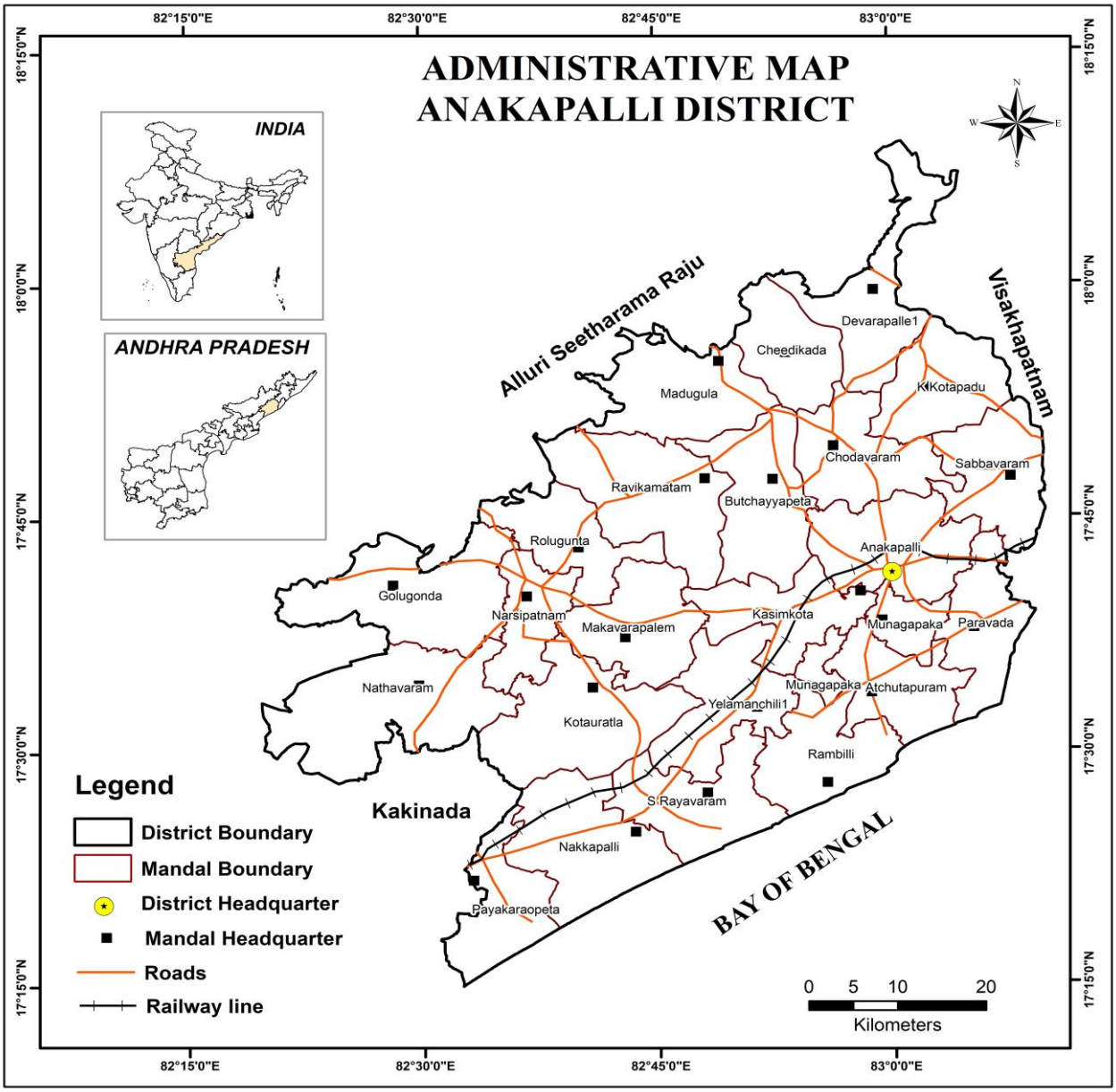


**Fig-1.1 Administrative map of Anakapalli District, A.P.**

**1.2 Physiography, Climate and Rainfall:** The district has differing climatic conditions in different parts of it. Near Coast the air is moist and relaxing, but gets warmer towards the interior and cools down in the hilly areas on account of elevation and vegetation. April to June are warmest months. The district receives annual rainfall of 883.2mm. of which south-west monsoon during 2022-23. The mandal wise rainfall is given in below and the Physiography and isohyetal map is shown as Fig. 1.2 and the status of rainfall during 2022 is shown as Fig.1.3.

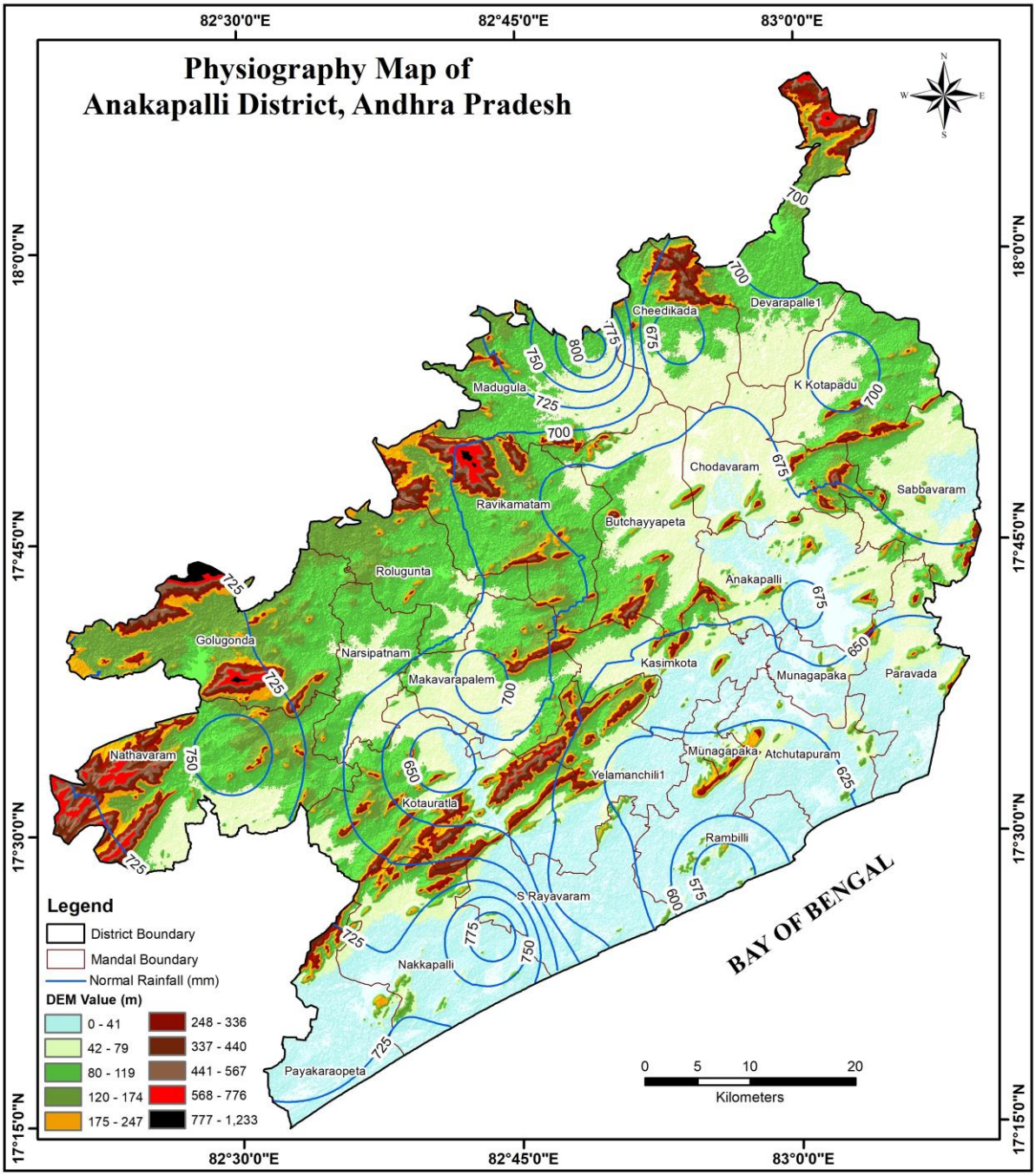


**Fig-1.2 Physiography and Isohytal map of Anakapalli District, A.P**

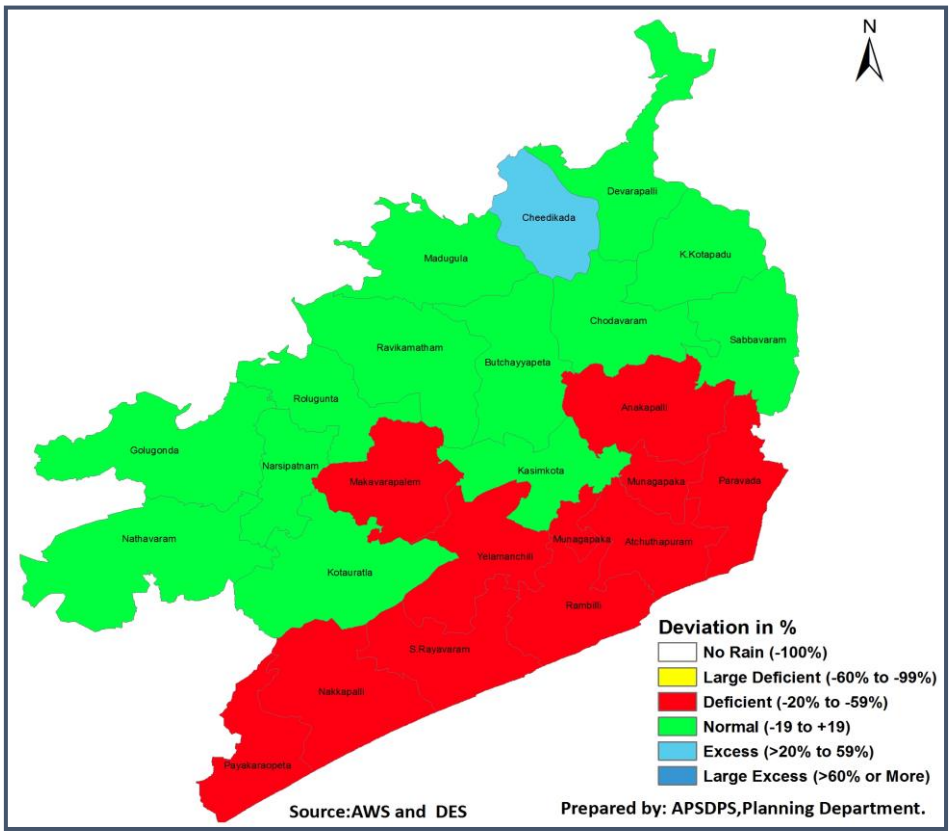


**Fig-1.3 Status of Rainfall of Anakapalli District, A.P**

**Table 1.1-Table showing Status of Rainfall during 2022-23.**

| S.No. | Mandal | Normal RF | Actual RF | Deviation % | Status |
|---|---|---|---|---|---|
| 1 | ANAKAPALLI | 688.2 | 544.6 | -20.9 | Deficient |
| 2 | ATCHUTAPURAM | 600.7 | 413.6 | -31.1 | Deficient |
| 3 | BUTCHAYYAPETA | 659.2 | 736.6 | 11.7 | Normal |
| 4 | CHEEDIKADA | 661.0 | 930.0 | 40.7 | Excess |
| 5 | CHODAVARAM | 664.3 | 778.8 | 17.2 | Normal |
| 6 | DEVARAPALLE | 705.9 | 793.2 | 12.4 | Normal |
| 7 | GOLUGONDA | 729.3 | 723.3 | -0.8 | Normal |
| 8 | K KOTAPADU | 707.4 | 583.4 | -17.5 | Normal |
| 9 | KASIMKOTA | 645.3 | 655.4 | 1.6 | Normal |
| 10 | KOTAURATLA | 625.8 | 578.1 | -7.6 | Normal |
| 11 | MADUGULA | 810.2 | 685.4 | -15.4 | Normal |
| 12 | MAKAVARAPALEM | 711.6 | 509.0 | -28.5 | Deficient |
| 13 | MUNAGAPAKA | 647.2 | 459.5 | -29 | Deficient |
| 14 | NAKKAPALLI | 793.0 | 470.9 | -40.6 | Deficient |
| 15 | NARSIPATNAM | 708.6 | 819.5 | 15.7 | Normal |
| 16 | NATHAVARAM | 764.1 | 742.4 | -2.8 | Normal |
| 17 | PARAVADA | 635.7 | 496.0 | -22 | Deficient |
| 18 | PAYAKARAOPETA | 745.3 | 476.0 | -36.1 | Deficient |
| 19 | RAMBILLI | 557.0 | 337.5 | -39.4 | Deficient |
| 20 | RAVIKAMATAM | 667.2 | 601.1 | -9.9 | Normal |
| 21 | ROLUGUNTA | 713.0 | 665.6 | -6.6 | Normal |
| 22 | S RAYAVARAM | 626.8 | 493.5 | -21.3 | Deficient |
| 23 | SABBAVARAM | 684.6 | 576.1 | -15.8 | Normal |
| 24 | YELAMANCHILI1 | 614.0 | 417.6 | -32 | Deficient |

**1.5 Soil :** Soil texture is the single most important physical property of the soil and alone will provide status of water flow potential, water holding capacity, fertility potential, and suitability for many urban use. The soils in the district are mainly red loams, sandy loams, sandy soils and black cotton soils. Red loamy soils are pre-dominant and occupy about 70% in the district. Sandy loamy soils are largely confined to the coastal areas and to certain stretches in the interior mandals of Chodavaram, Narsipatnam, K. Kotapadu and Madugula. Black cotton soils occur in parts of K. Kotapadu, Devarapalli, Chedikada, Paderu and Hukumpeta mandals. Red Loamy soils are poor textured and easily drained. Sandy loamy soils largely confined to the coastal areas (Nakkapalli, Payakaraopeta, S. Rayavaram, Rambilli, Atchutapuram and Paravada Mandals) and to certen stretches in the interior Mandals (Chodavaram, Narsipatnam, K. Kotapadu and Madugula). Black cotton soils having sizeable chunks of area (K. Kotapadu, Devarapalli and Cheedikada Mandals). 45% of the soils in the district are low in organic content and 55% in Phosphorous content. The pH ranges between 6.59, 7.83 the pH is slightly acidic (6.5 & 6.9) in residential and agricultural cum residential soils.

The soil from industrial area and agricultural area having pH are near to neutral (7.5 & 7.8). Above 7.5 pH values generally have high calcium carbonate and cause iron, manganese, copper, Zinc, and boron ions to be less available to plants. The distribution of soil types in Ankapalli district is shown in Fig.1.4.

Soil infiltration tests were conducted in three different soil types in different locations of Ankapalli district to know the infiltration capacity of soils by using double ring infiltrometer at various locations during 2019. Depending on the soil types, the basic infiltration rate varies from 1.5 to 3.3 cm per hour, low infiltration rate generally observed in clay and silty type soils and high infiltration rate observed in sandy type of soils. Apart from type of soil, the soil compactness, porosity, permeability and vegetation play a dominant role in the infiltration rate.

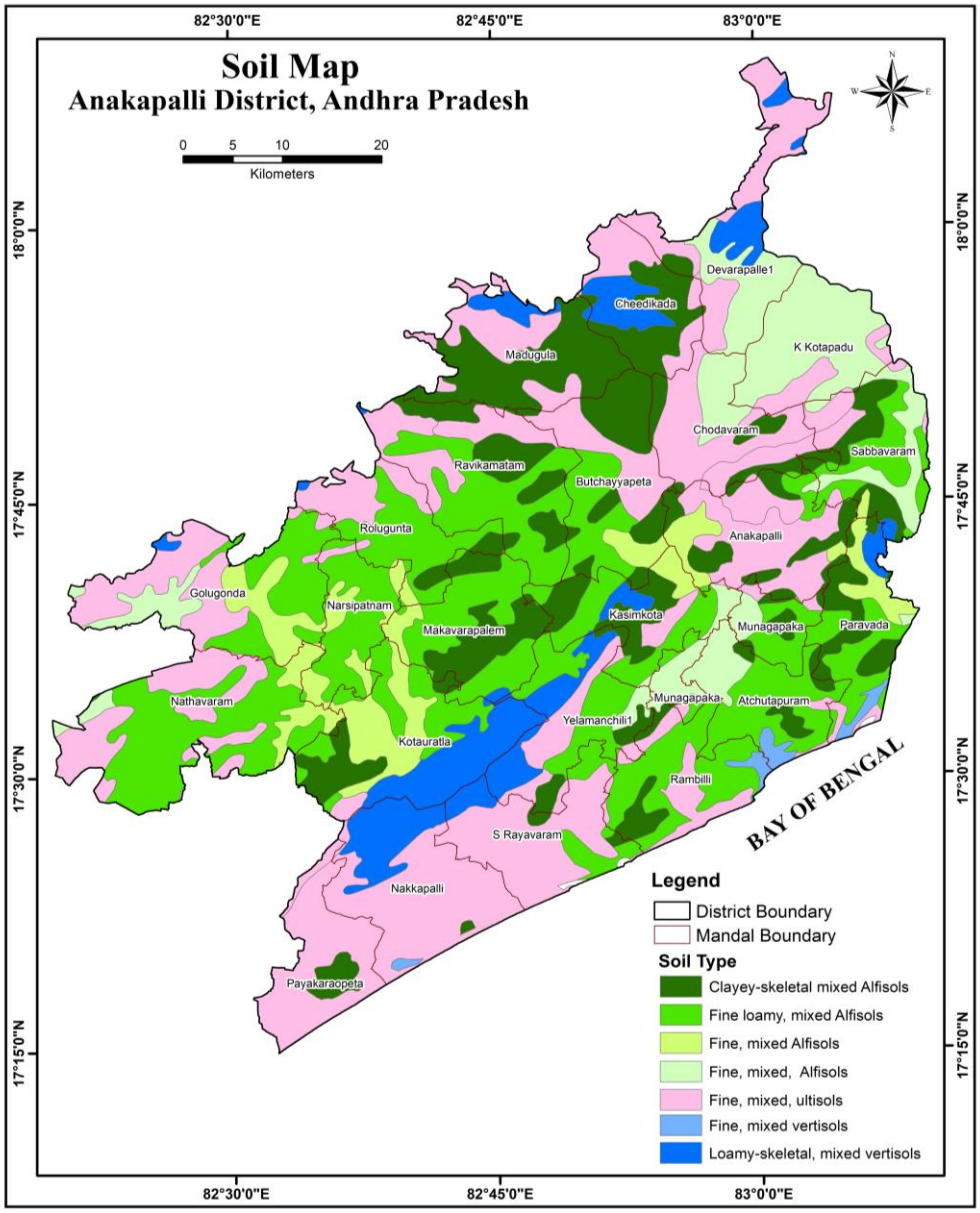


**Fig-1.4 Soil Map of Anakapalli District, A.P**

**1.3 Geomorphology:** Pediplain, Structural hills, pediments and alluvial plains, are the major geographic units in the study area. The details and percentage of geomorphological features of the area is given in the table and depicted in Fig-1.5.

| Geomorphology | Area (sq.kms) | % |
|---|---|---|
| Pedipalin | 2304 | 54 |
| Structural Hills | 674 | 16 |
| Pediment | 525 | 12 |
| Alluvial Plain | 228 | 5 |
| | | |
| Others | 560 | 13 |
| **Total** | **4291** | **100** |

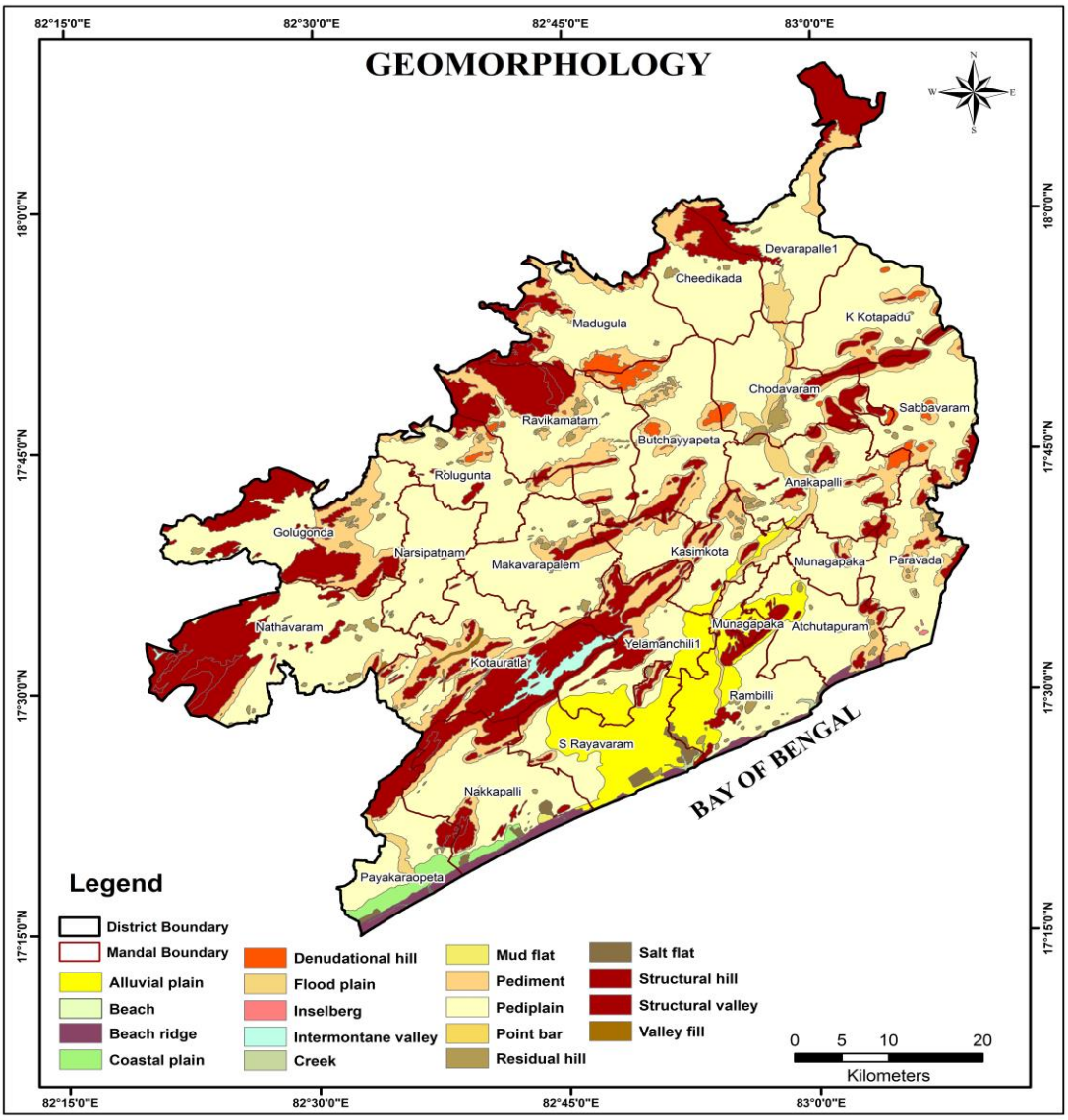


**Fig-1.5 Geomorphology of Ankapalli District, A.P**

**1.7 Drainage and Basins:** The study area is mainly drained by tributaries of river Nagavalli. The drainage is dendritic and parallel in nature. The district is divided into five major drainage basins namely Tandava, Varaha, Sarada & Gosthani and sub basins of major rivers with their tributaries. No major river/perinial rivers are flowing across the district. The drainage map of Ankapalli district is shown as Fig.1.6. The drainage density is less in the plains because of the high infiltration and permeable characteristics of the sediments.

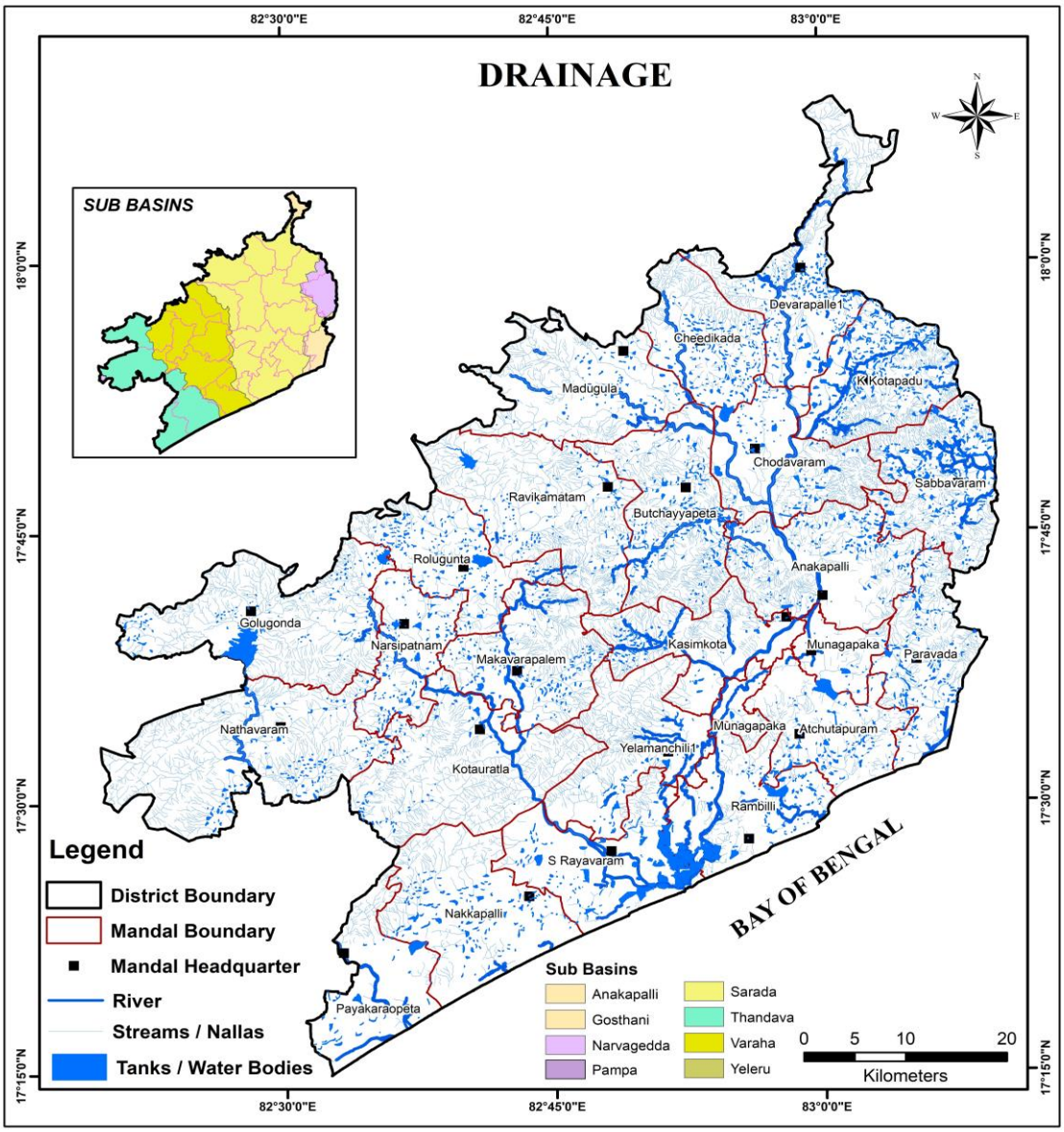


**Fig 1.6- Drainage of Anakapalli District, A.P**

**1.7 Land use and cropping pattern (2019-20)** The total geographical area of the district is 4.29 lakh hectares, of this 0.07 lakh hectares alone is cultivable waste while 0.78 lakh hectares is forest area. The rest is distributed among “Barren and uncultivable land” about 0.62 lakh hectares and “Land put to non agricultural uses” about 0.56 lakh hectares. Out of the cultivable area, the net area sown form 1.53 lakh hectares while fallow (current and old) lands constitute about 0.50 lakh hectares. During Khariff season, main crops grown are Paddy, Ragi Bajra, Jawar, Sugarcane, groundnut seasum, etc. During Rabi season, main crops grown are Paddy, maize, etc. Land use and land cover map of the study area is depicted in Fig. 1.7.

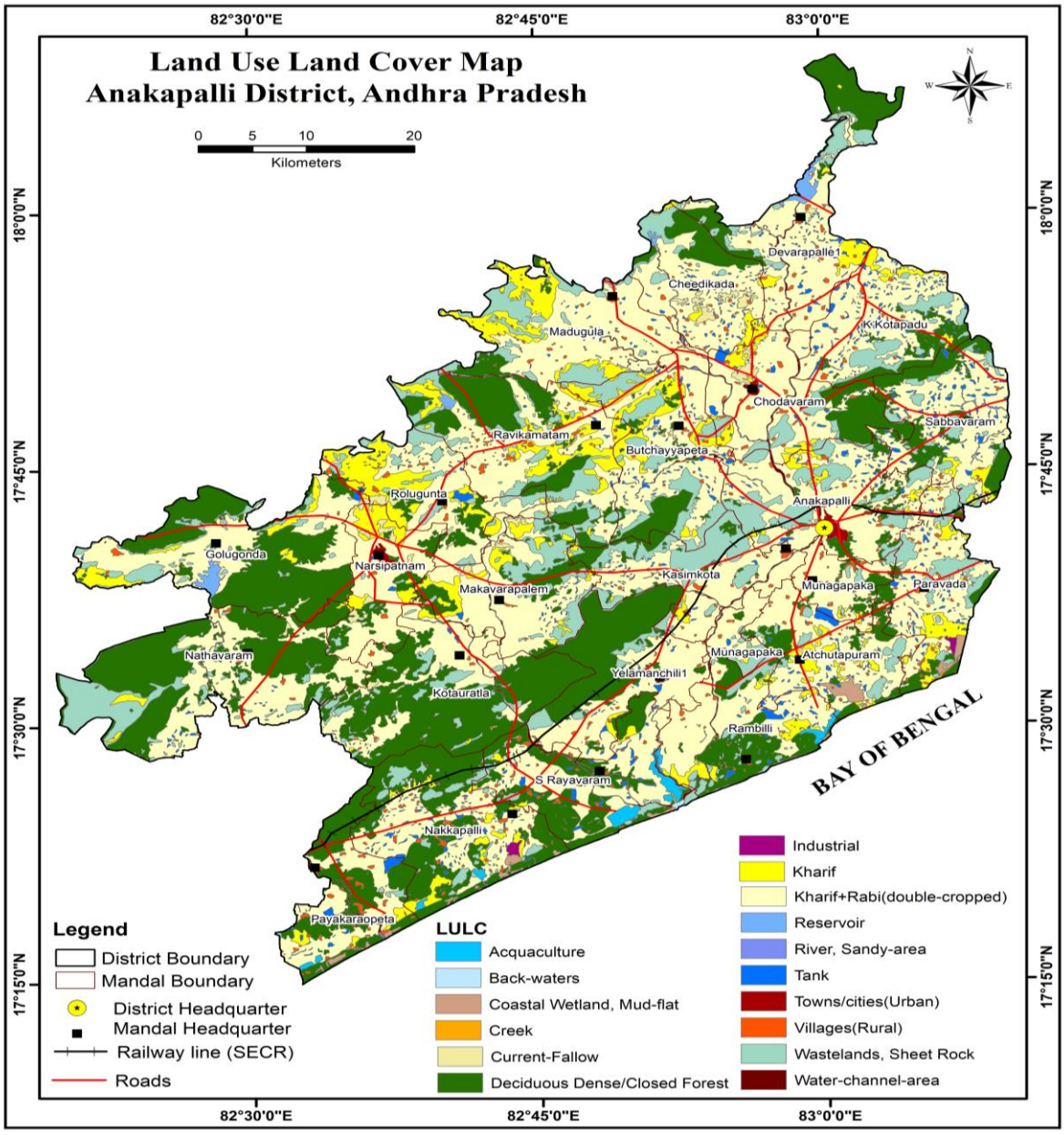


**Fig 1.7- Land Use Land cover map of Ankapalli District, A.P**

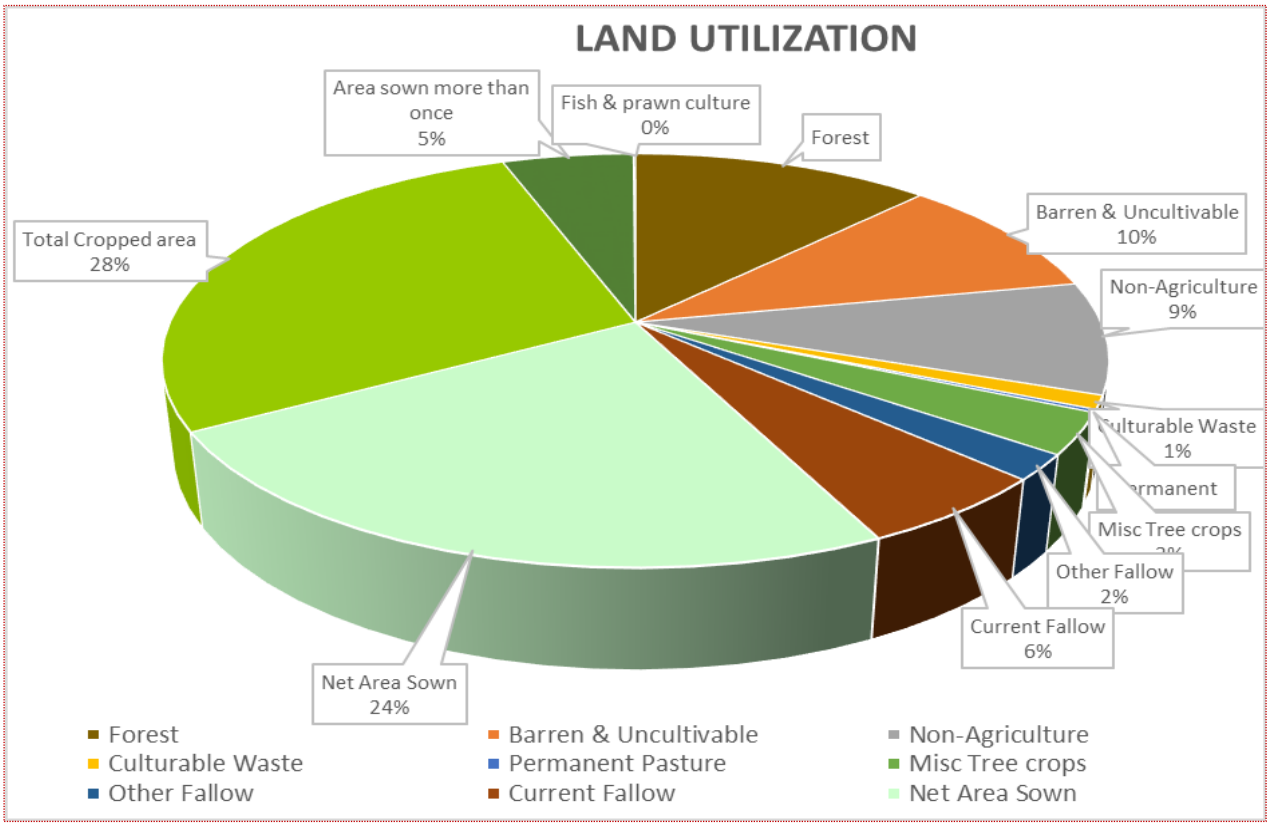


**Fig 1.8- Land utilization of Ankapalli District, A.P**

**1.8 Irrigation:** Since there is some Major Irrigation system, only about 36% of the cropped area is irrigated under the Ayacut of the Medium Irrigation system and Minor Irrigation Tanks. The rest of the cultivated area is covered under dry crops depending upon the vagaries of the monsoon. The productivity of the crops is normal. The area covered under different Irrigation projects is given below.

**Table 1: Area covered under Different Irrigation projects**

| S.No. | Name of the Project | Area (Sq.km) |
|---|---|---|
| 1 | Upparandhra Sujala Sravanthi | 1106 |
| 2 | Thandava | 122 |
| 3 | Indira Sagar Pollavaram | 199 |
| 4 | Yelluru | 436 |
| 5 | Medium Command | 160 |
| | **Total** | **2023** |

At present there are 2682 Minor Irrigation Tanks in the district with storage capacity of ~ 200 MCM. Out of total gross irrigated area of 99,753 ha, ~ 60% (60573 Ha) is irrigated through surface water and ~40% (39180 ha) is irrigating through borewell & dugwells. The area irrigated under different sources is given below:

**1.9 Prevailing water conservation/Recharge practices:** In the district there are ~869 Check dams and ~82 percolation, mini percolation tanks constructed under MGNREGS with combine capacity of 16.89 MCM.

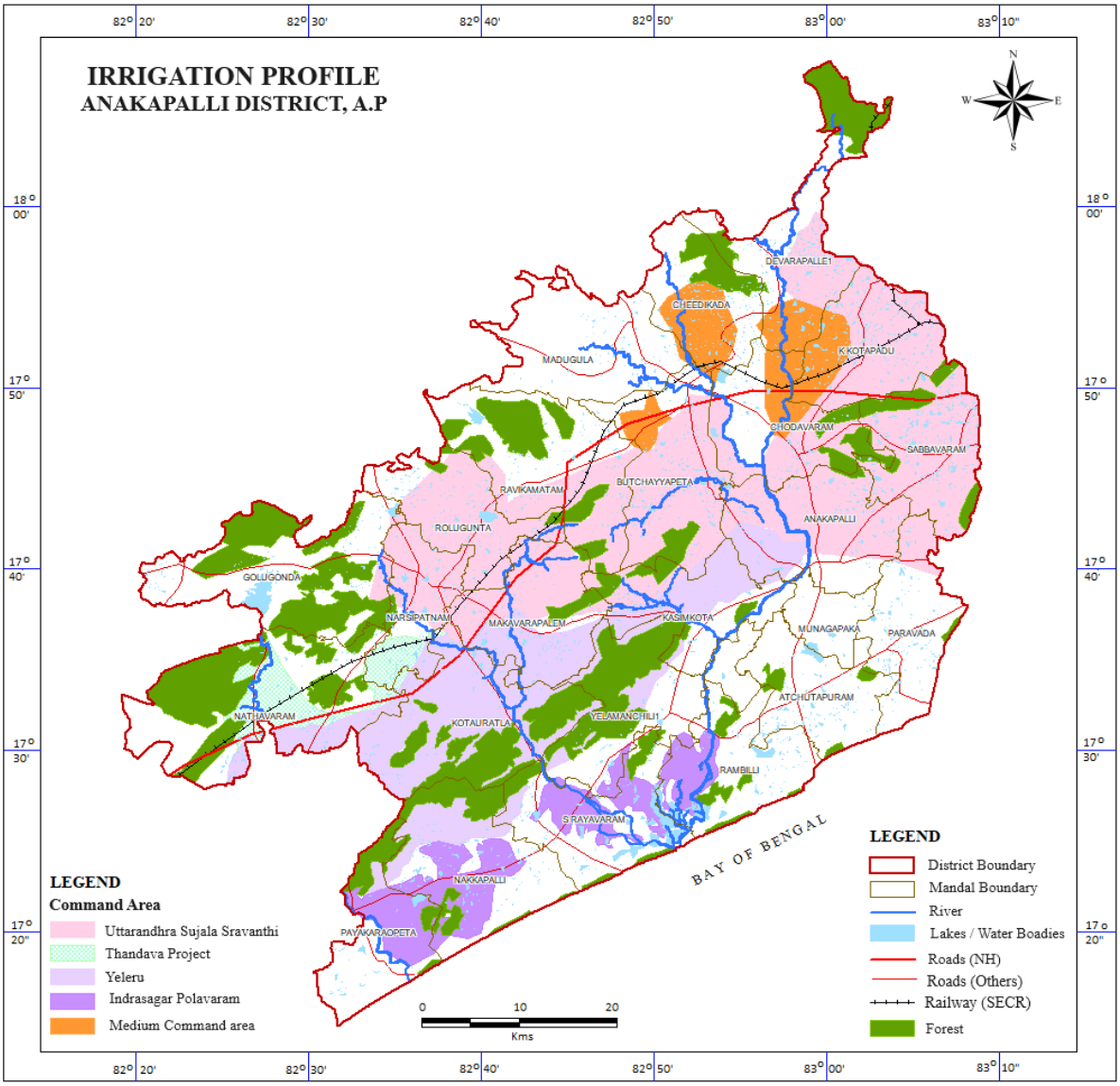


**Fig- 1.9 Irrigation Map of Ankapalli District, AP**

**1.10 Geology:** The area is underlain by the Khondalite and granite gneiss of Archaean age (Fig 1.10). The geological succession is shown below

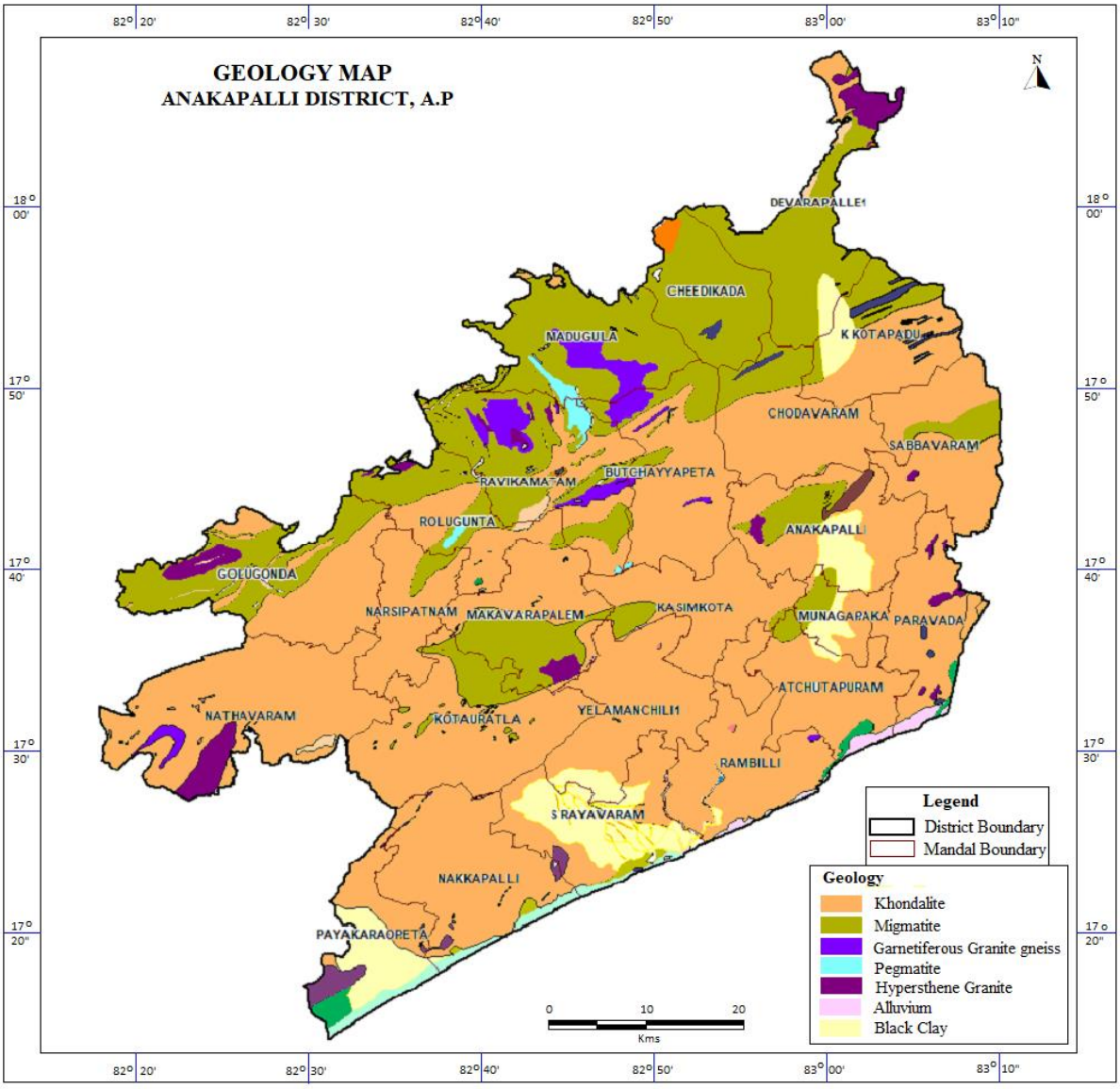


**Fig-1.10 Geology Map of Anakapalli District, A.P**

# 2. DATA COLLECTION AND GENERATION

carried out by Central Ground Water Board (CGWB) and State Ground Water Department (SGWD) in Ankapalli district. As a part of ground water exploration studies 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). Various hydrogeological investigations were, CGWB had constructed 26 number of exploratory wells/ observation wells/ piezometers and 30 wells were constructed by SGWD in Ankapalli district. These data from 56 wells are used to prepare 2D aquifer maps in parts of Ankapalli district. The geophysical VES sounding data also used for drawing of aquifer delineation. The locations of exploratory wells of CGWB, wells of SGWD and VES are shown in Fig.2.1.

## 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 | Vertical Electrical Sounding (VES), bore-hole logging, 2-D imaging etc. |

| | | | |
|---|---|---|---|
| | | generation | |
| | | 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 Meta sediments (Shales and quartzites) and 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 213 hydrogeological data points (Exploration: 139, Geophysical: 20 and well inventory: 54) hydrogeological map is prepared (Fig.2.1).

**2.1.1 Ground water occurrences and movement**: Ground water occurs under unconfined and semi-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 100 m depth. The storage in granite rocks is primarily confined to the weathered zone and its overexploitation, mainly for irrigation purpose, has resulted in desaturation of weathered zone at many places. At present,

extraction is mainly through boreholes of 60-100 m depth, with yield between <1 to 11 litres/second (lps). Majority of fractures occur within 100 m depth and deepest fracture is encountered at the depth of 109 m depth (Rayavaram, Yerragondapalem).

**2.1.2 Exploratory Drilling:** As on 31/03/2022, APSIDC drilled 117 bore wells (exploratory) and SGWD drilled 20 wells in the study area. Data analysed from APSIDC wells indicates, 3 wells are of shallow depth (30 m), 108 nos are of 30-60 m, 06 nos are of 60-100 m depth**.** An analysis exploratory bore wells drilled by SGWD indicate that 2 bore wells are <30 m depth, 17 bore wells are of 30-60 m depth and remaining 03 wells are of 60-100 m depth range. The depth to the deepest fracture occurred in these formation is 68 m at Giddaluru and deepest fractured dechiphered through VES studies is 109 m (Rayavaram, Yerragondapalem).

**2.1.3 Ground water Yield:** Ground water yield from weathered and fractured aquifer varies from <1 to 32 lps (Ayyavari peta, Ardhaveedu Mandal). Based on the combined data of APSIDC, CGWB and SGWD. In most of the area yield varies from 1 to 5 lps.

**2.2 Water Levels (2022):** Ground water levels from 24 Piezometers of SGWD are utilized for Water levels of pre-monsoon and post-monsoon season.

**2.2.1 Water Table Elevations:** During pre and post-monsoon season (May and November) of 2015, the water-table elevation ranges from 100 to 250 (m amsl) respectively and general ground flow is towards NE direction.

**2.2.2 Depth to Water Levels (DTW):** The DTW varies from 10 to 63 meter below ground level (m bgl) during Pre-monsoon period and (average: 37 m bgl) and 9 - 60 m bgl (average: 35) during post-monsoon season of 2016 respectively.

**Pre-monsoon season:** About 4724 mappable area, Water levels are deep in the study area mainly in the range of 30 to 50 m bgl. Majority of the water levels during this season are in the range of 30 to 40 m cover ~ 25% of area, followed by 40-50 m bgl (24% of area). Deep water levels at the range of 50 to 60 m bgl occupy ~6% of area mostly in north central part of the study area (Fig.2.1). Shallow water levels (10-20, 20-30 mbgl) occur in the central parts of the study area covering 12% of area.

**Post-monsoon season:** About 4724 mappable area, the water levels during this season are in the range of 10-20 m (~8 %), 20-30 m (14%), 30-40 m (18%), 40-50 mbgl (38% ), 50-60 m bgl (14%) and >60 m bgl (6%) (Fig-2.2).

**2.2.3 Water Level Fluctuations (May vs. November):** The water level fluctuations vary from -13.13 to 37.38 m with average fall of - 5.03 m and rise of 9.92 m (Fig-2.3). Out of 25 wells, in 12 wells (50%) shows fall in water levels (-0.03 to -13.13 m) and 10 wells shos rise in water levels (0.06 to 37.38 m) is observed and 3 wells show neither rising nor fall in water levels.

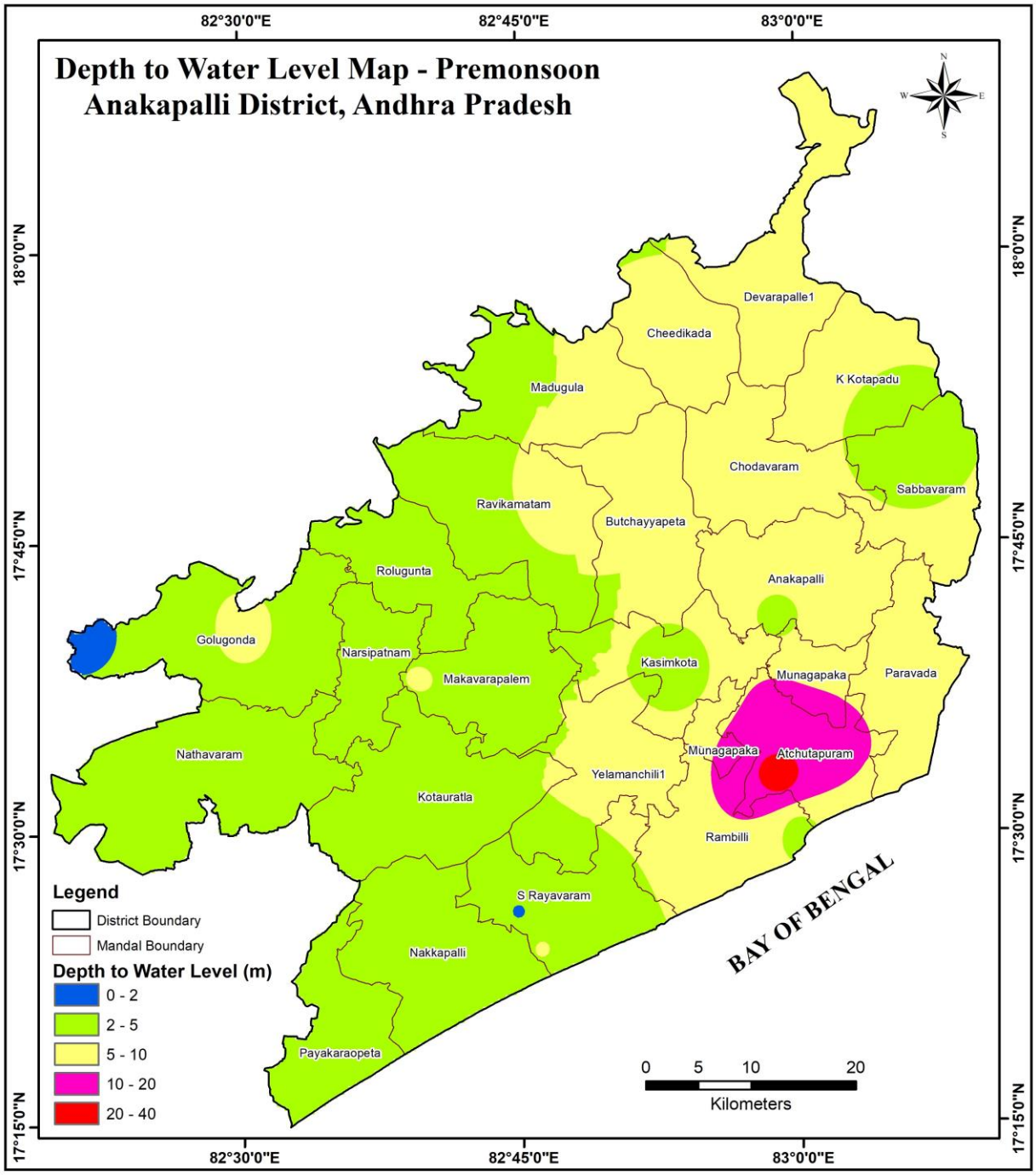


**Fig- 2.1 Depth to Water Level (Pre Monsoon- 2022)**

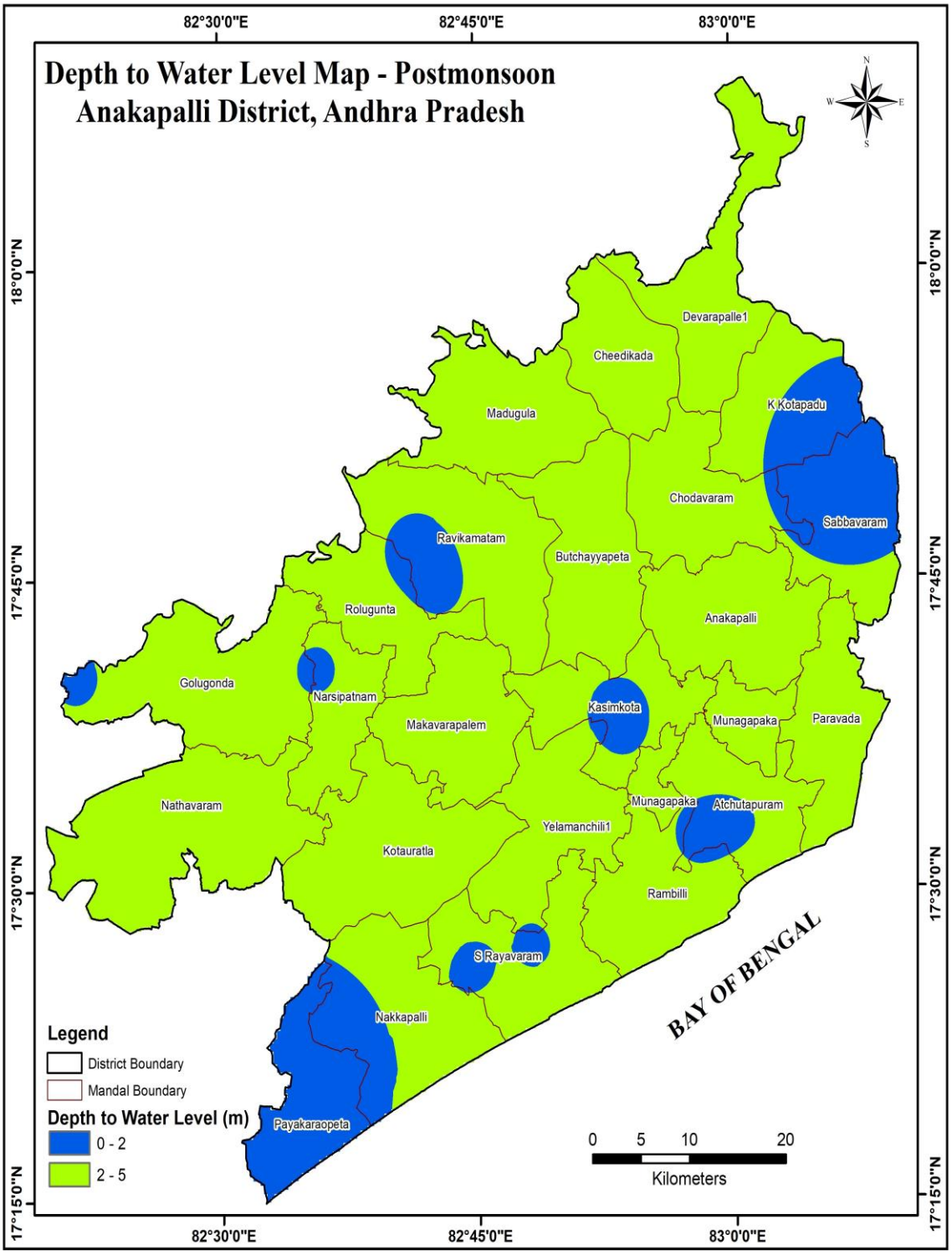


**Fig- 2.2 Depth to water Levels (Post Monsoon May 2022)**

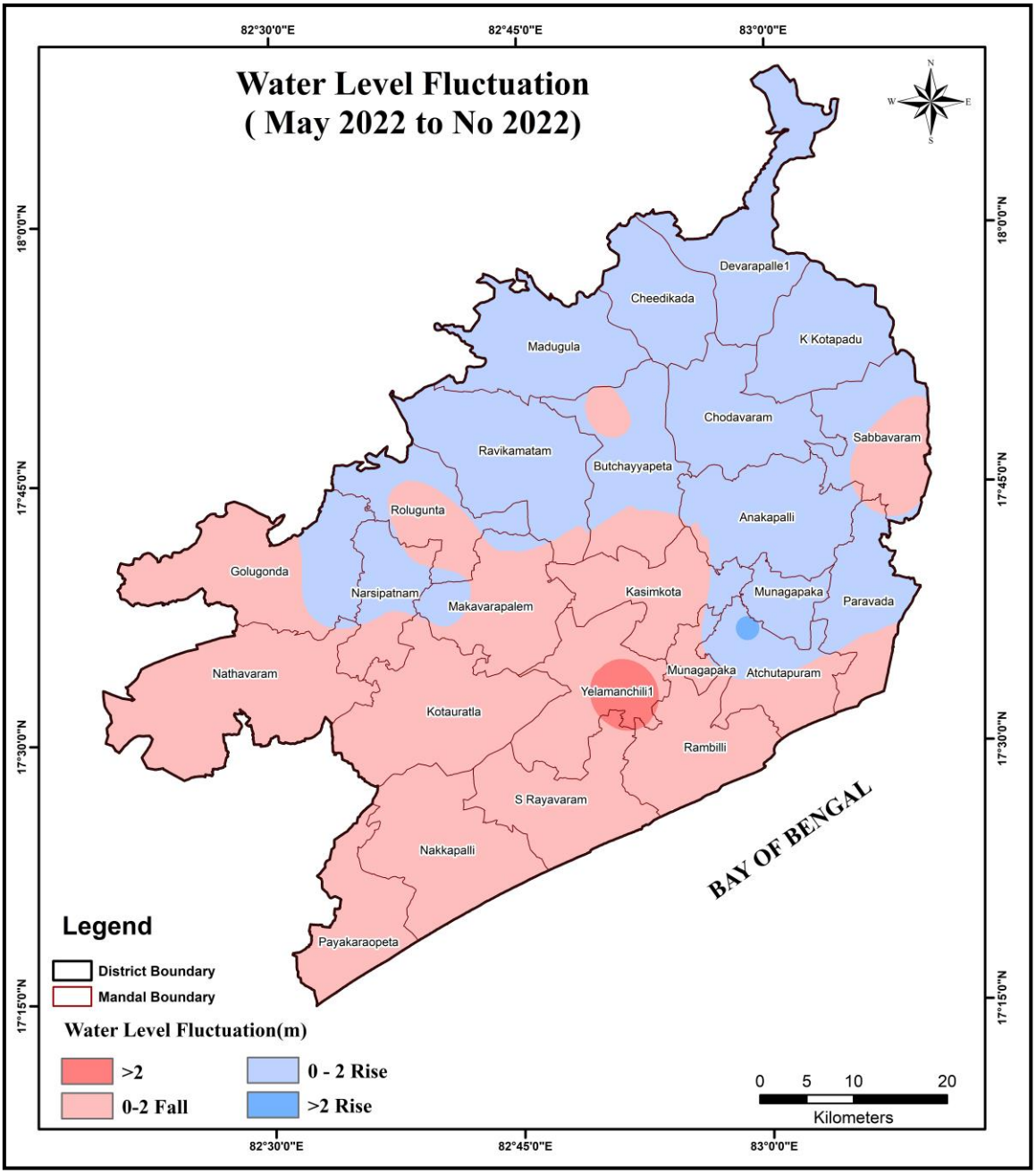


**Fig.2.3: Water Level Fluctuations (m) (Nov with respect to May-2022).**

## 2.2 Hydro-chemical Studies

To understand chemical nature of groundwater, total 27 data from Rural Water Supply (RWS) is utilized. From the parameters namely pH, EC (in µS/cm at 25 ° C), TDS and $NO_3$ and F analyzed by that department ground water quality maps of EC, No3 and F for pre and post monsoon sesons are prepared.

**Pre-monsoon (May-2022)**

Groundwater from the area is alkaline in nature with pH in the range of 6.62 to 7.47 (Avg: 7.02). Electrical conductivity varies from 540 to 4060 (avg: 1579) µ Siemens/cm. In majority of area covering Southern and South-Eastern part (45 %) EC is in the range of

1500-3000 µ Siemens/cm, in 92 % of the area EC is < 3000 µ Siemens/cm covering Parts of Dornala, Markapuram, Tarlapadu and few parts of Ardhaveedu and Racherla mandals. (Fig-2.4). The Concentration of $NO_3$ ranges from 01-320 mg/l. Nitrate concentration <45 mg/l is observed in 15 samples (62 %) and Nitrate concentration >45 mg/l is observed beyond maximum permissible limit of BIS in 12 samples (38%) (Fig-2.5). The concentration of Flouride ranges from 0.1 – 1.8 mg/l with an average of 0.75 mg/l. In 05 samples (18%), F concentration is observed more than the permissible limits (>1.5 mg/l) In 22 (82%) samples F is with in the Permissible range (<1.5 mg/l) (Fig-2.6).

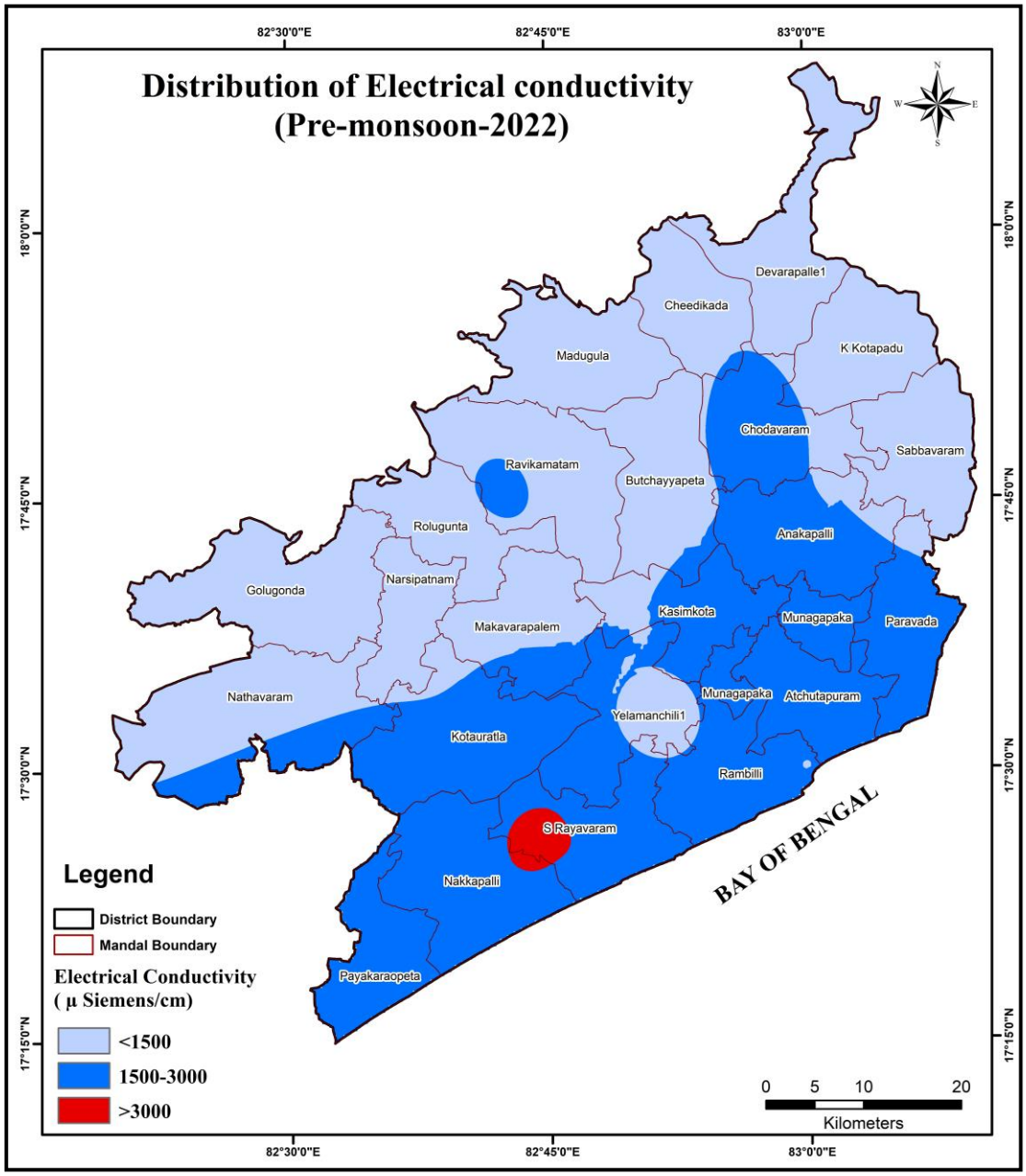


**Fig.2.4: Distribution of Electrical conductivity (Pre-monsoon-2022)**

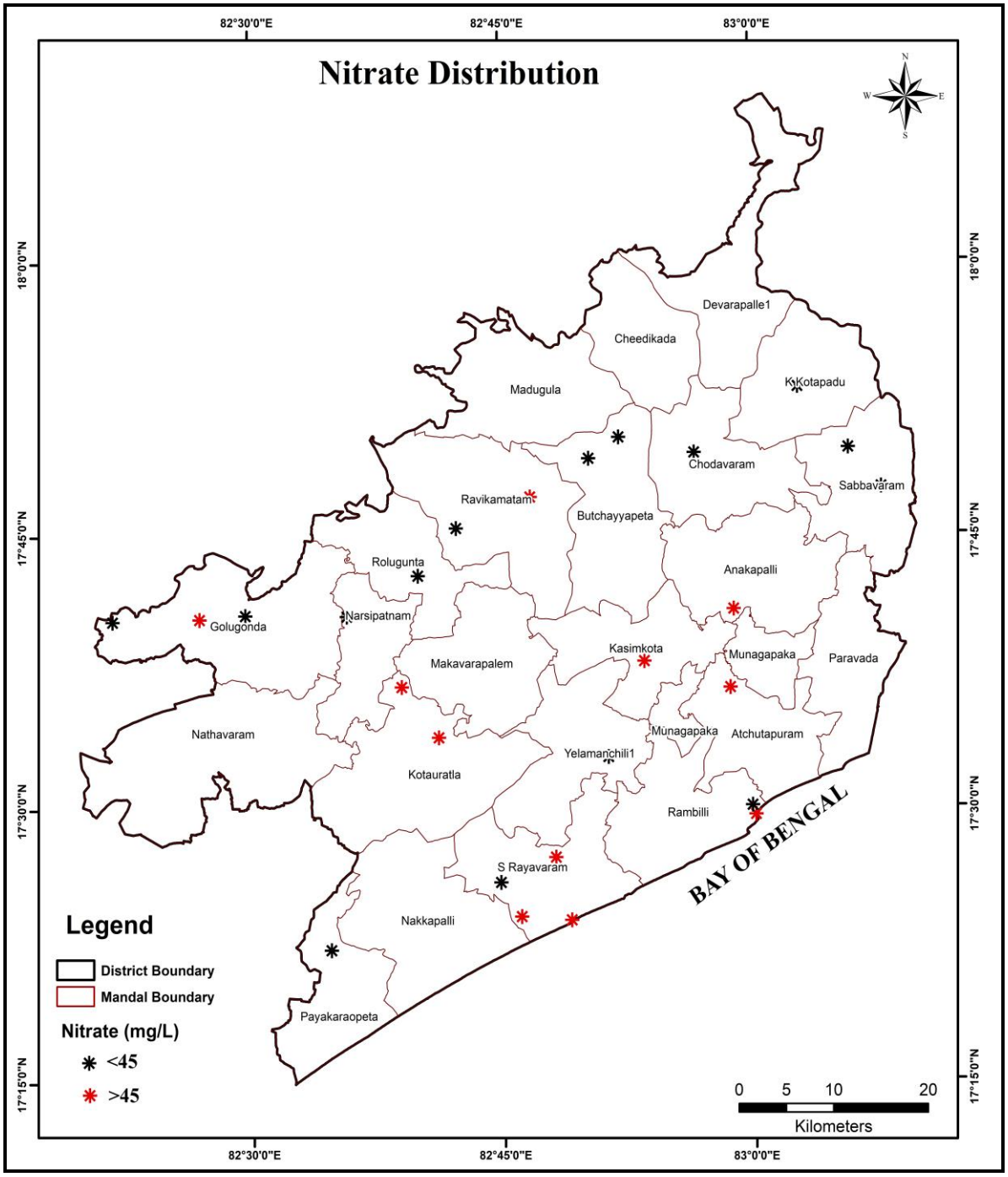


**Fig.2.5: Distribution of Nitrate (Pre-Monsoon- 2022)**

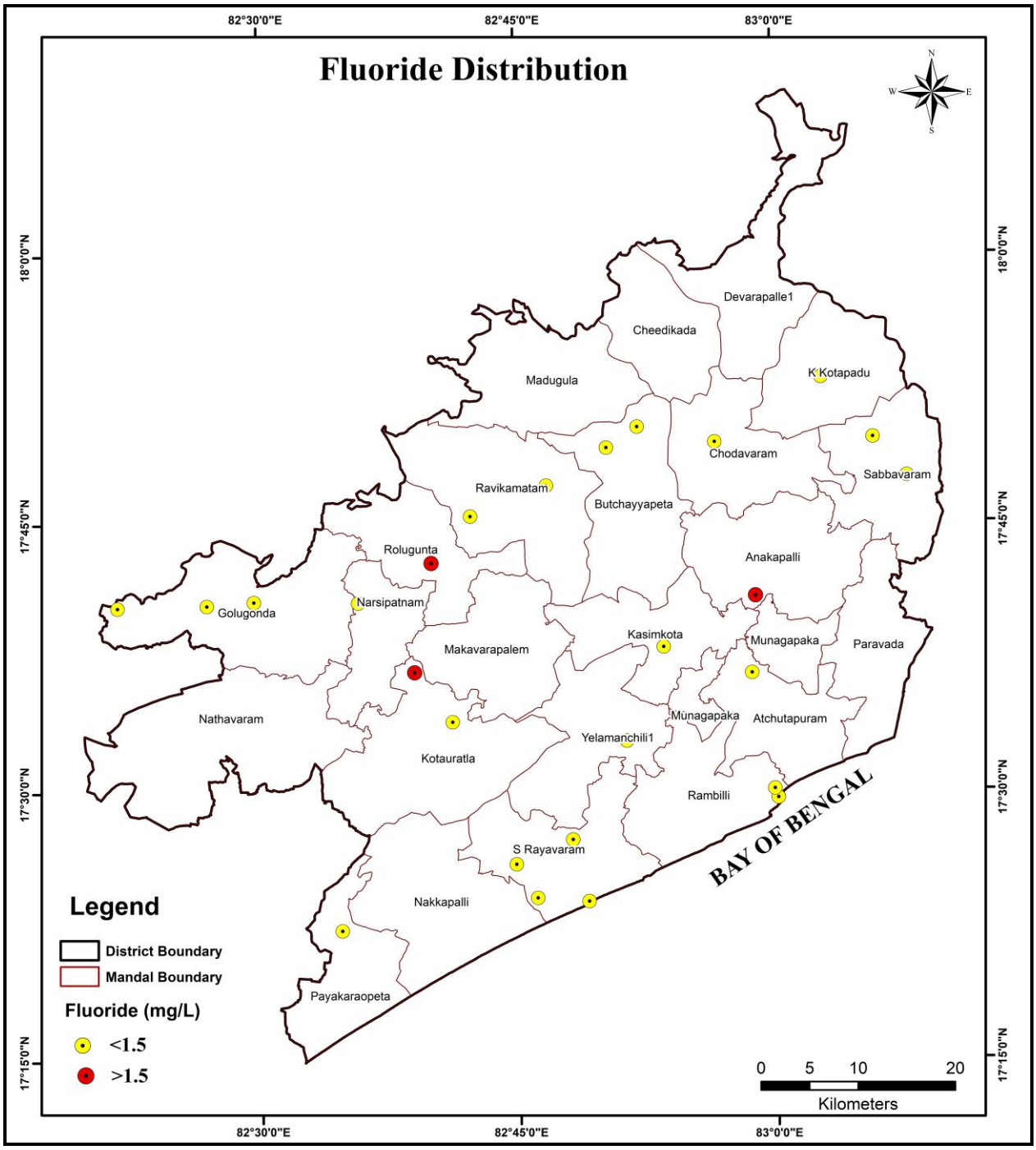


**Fig-2.6 Distribution of Fluoride (Pre-monsoon-2022)**

# 3. DATA INTERPRETATION, INTEGRATION and AQUIFER MAPPING

Conceptualization of 3-D hydrogeological model was carried out by interpreting and integrating representative 210 data points (APSIDC Bore wells: 120, SGWD: 12, CGWB:1, Geophysical: 21 and 56 well inventory data) down to 200 m is used for preparation of 3-D map, panel diagram and hydrogeological sections. The data (Fig.3.1) 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 Ananthapuramu study area (Fig.3.1**)** and hydrogeological sections (Fig-3.1 a,b,c).

### 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) generally down to ~20 m depth and the fractured zone (fractured granite) is considered up to the depth of deepest fracture below weathered zone (~20-120 m).

### 3.2 Hydrogeological Sections

Hydrogeological sections (3 nos) are prepared in NW-SE, W-E and SW-NE directions (**Fig. 3.3**).

**3.2.1 NW-SE Section:** The section drawn along the NW-SE direction covering distance of ~100 kms (Fig.3.3a). It depicts thick fractured zone in NNE parts compared to massive nature of Meta sediments in SSW parts. The weathering is showing uniform thickness in the section.

**3.2.2 W-E Section:** The section drawn along the W-E direction covering distance of ~100 kms (Fig.3.3b). It depicts very thin weathering parts in central part and is hilly. The weathering is showing uniform thickness in the section.

**3.3.3 SW-NE Section:** The section drawn along the W-E parts covering distance of ~60 kms (Fig.3.3c). It depicts uniform occurrence of weathering and fracture zone in central parts and shows massive nature in West and eastern partrs of the section.

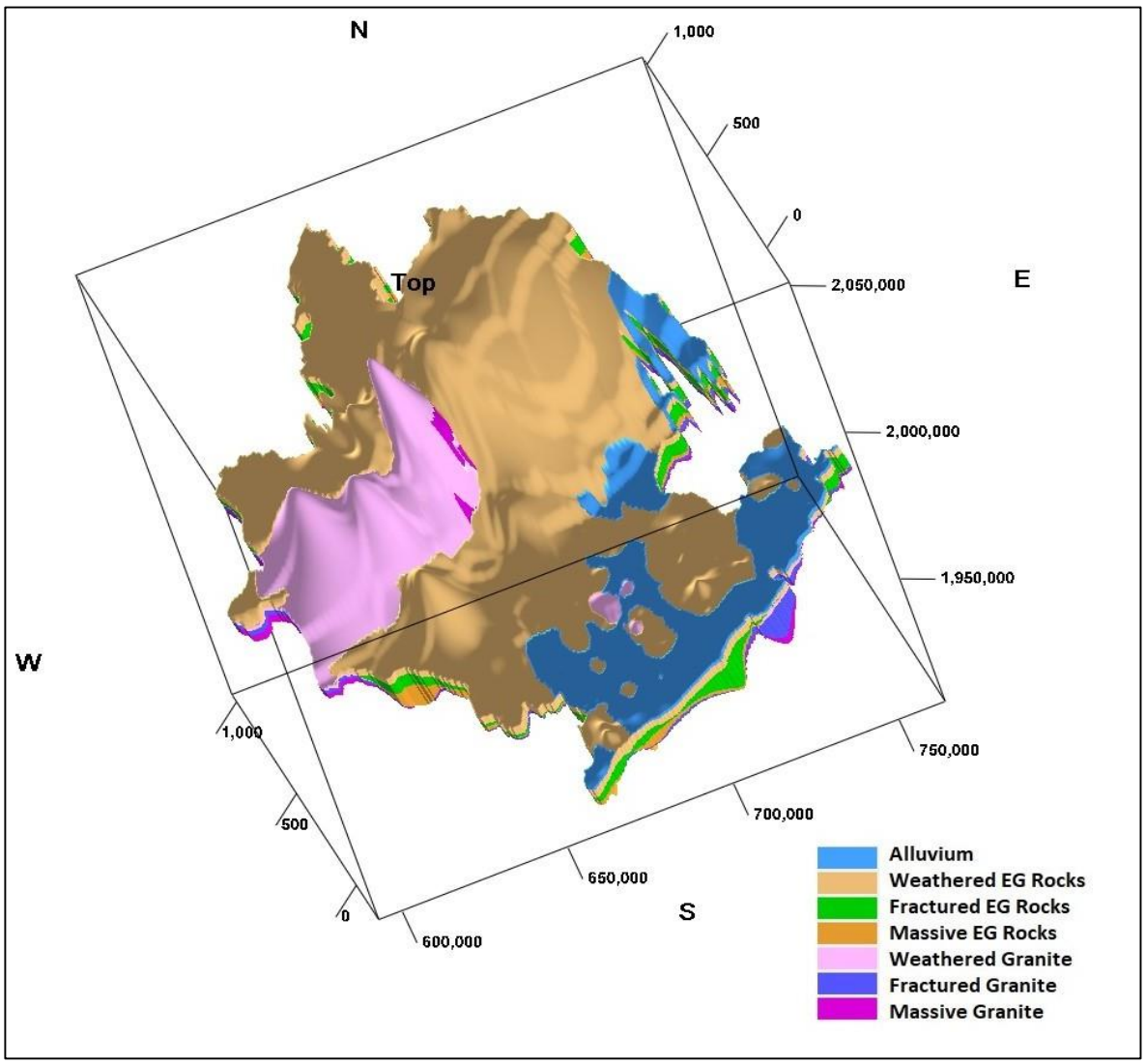


**Fig 3.1-3DModel of the study area**

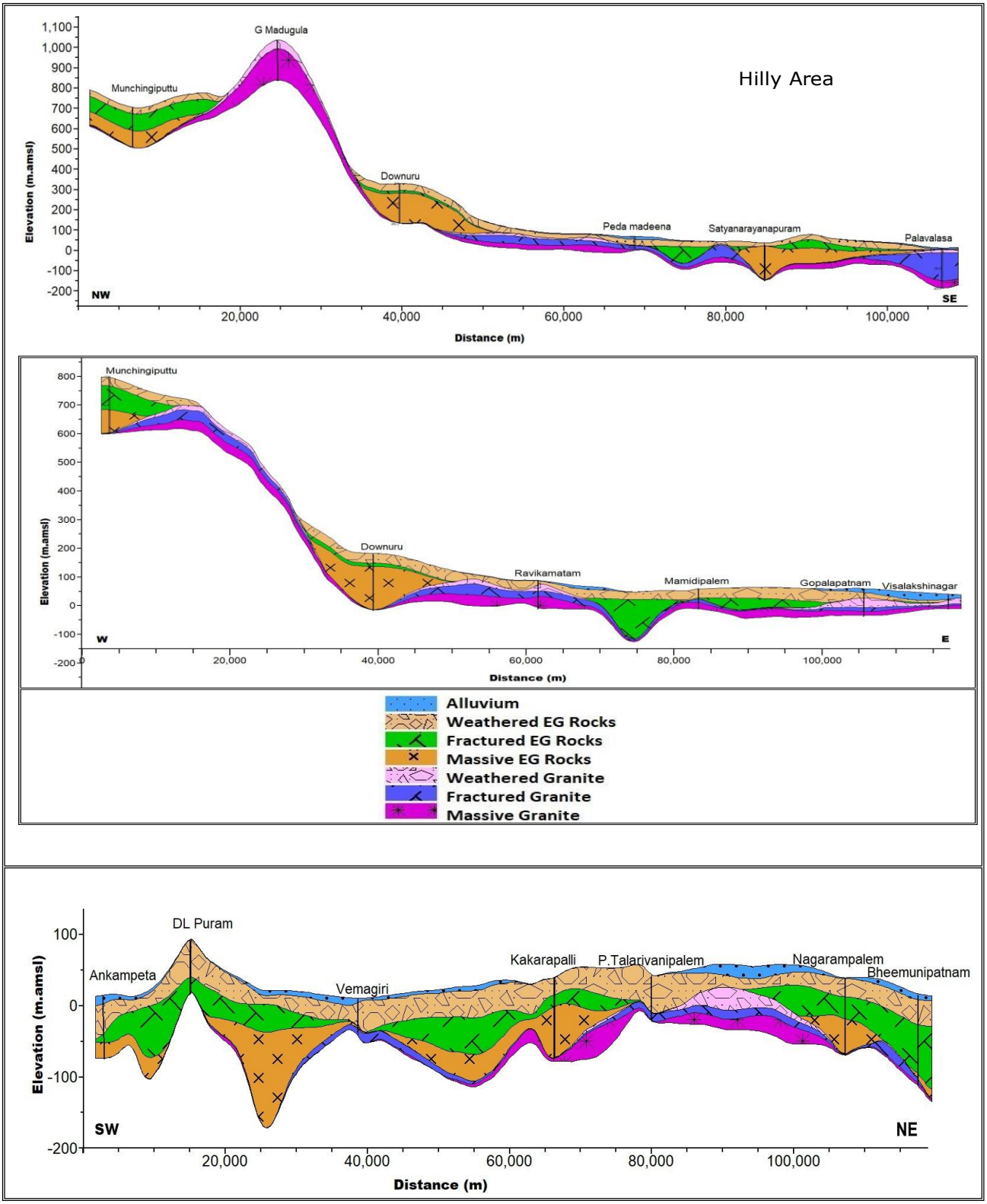


**Fig.3.1 (a-c): Hydrogeological profiles in different directions of Anakapalli district.**

### 3.3.1 Weathered zone:

The Thickness of weathered zone is varies from <10 m to 35 m. In most of the study area, the thickness of weathering is in between 10-25 m (75%) in most part of area followed by <30 m Deep weathering of the study area. The weathered thickness map is presented in (Fig.- 3.2)

### 3.3.2 Fractured zone:

The depth of fracturing varies from 10-180 m and deepest fracture is dechiphered through VES study is 109 m (Rayavaram, Yerragondapalem). The yield of the deepest fracture encountered at Giddaluru is 8 lps indicating the potential nature of Second aquifer in the study area. The depth of fracture map is presented in (Fig. 3.2). ~ All the exploratory wells drilled so far are less than 100 m and the potential fractures occur with in the depth range of 70 m (100%) The ground water yield varies from <1 to 32 lps.

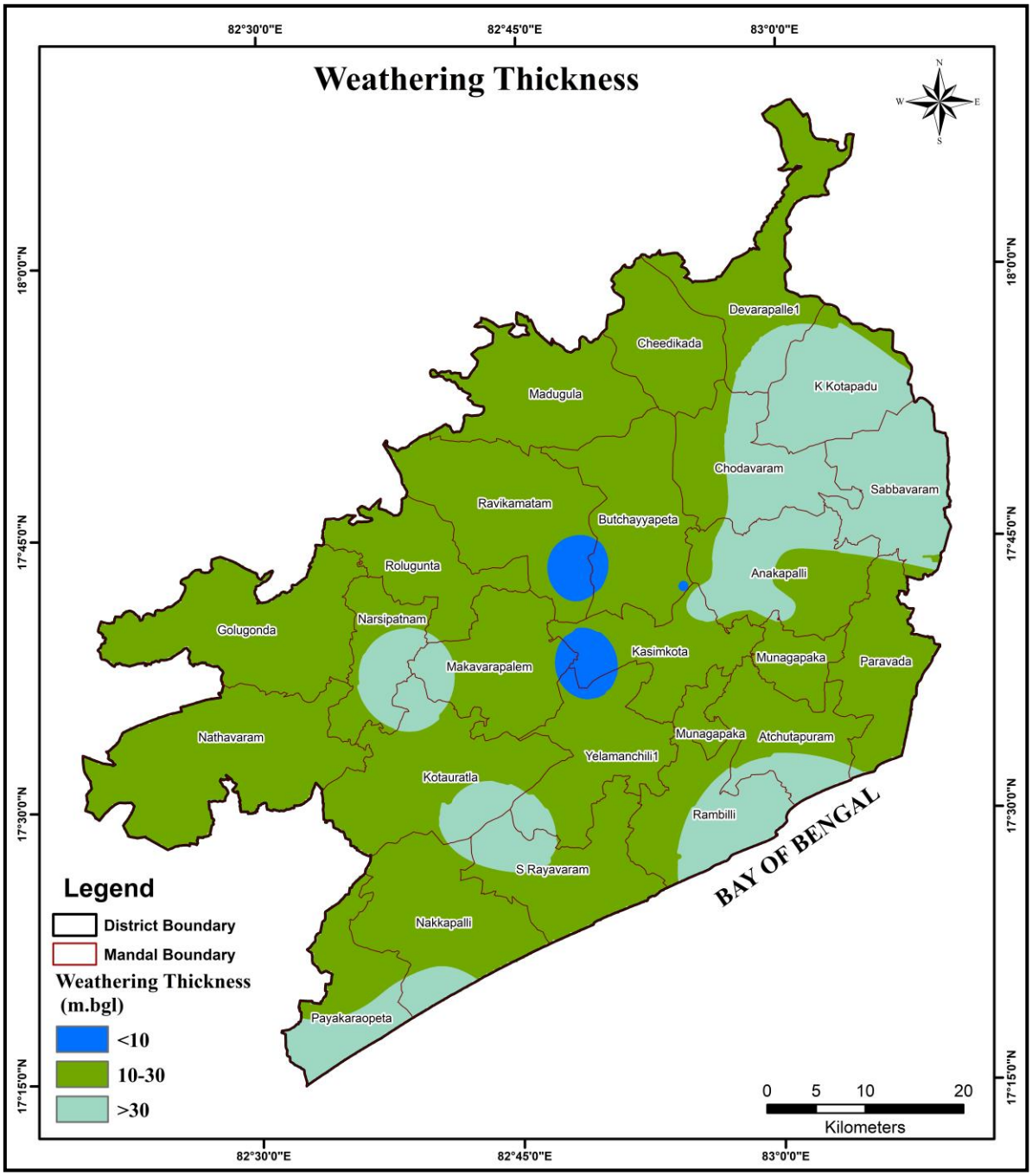


**Fig.3.2: Thickness of weathered zone- Study area**

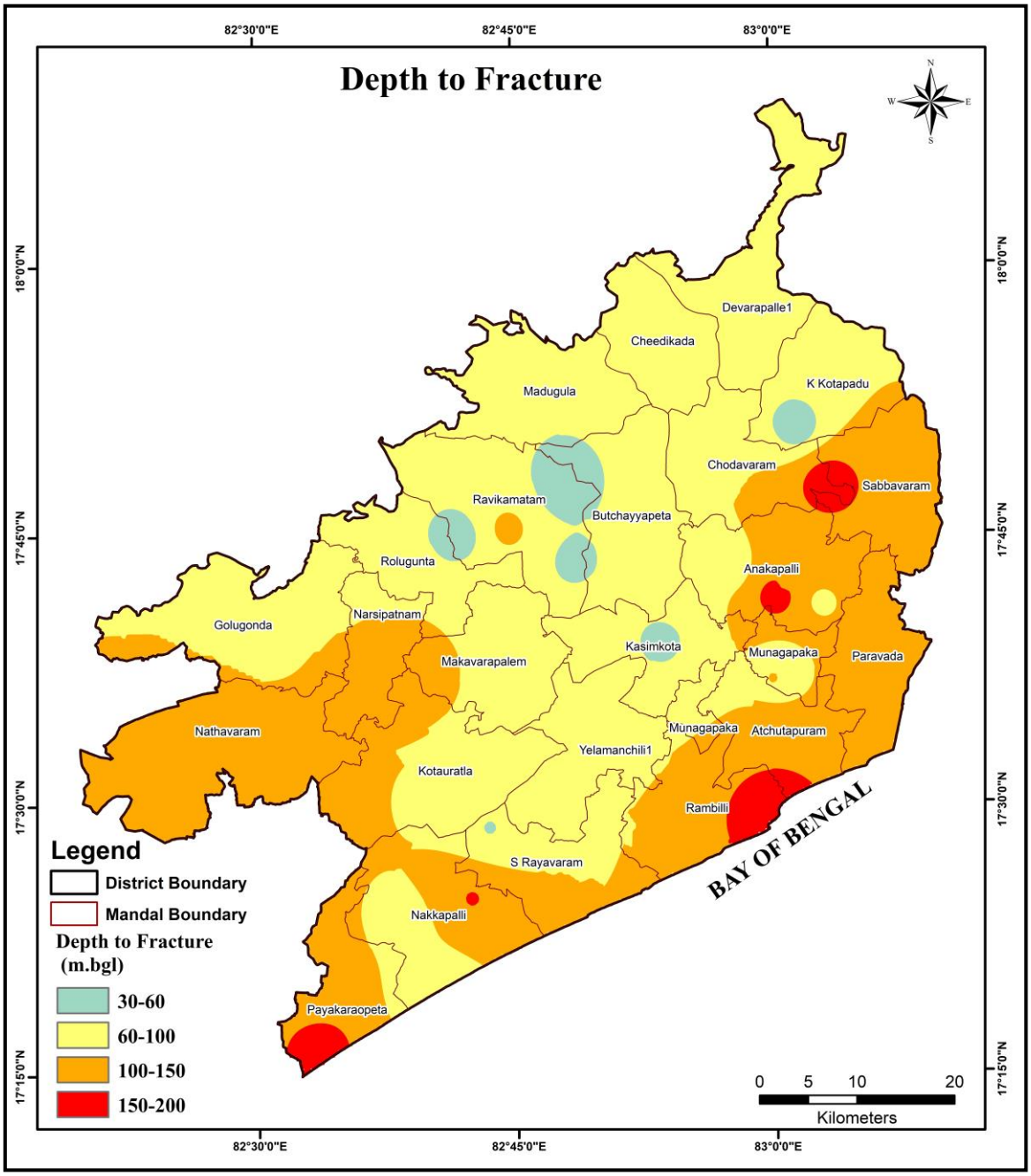


**Fig.-3.3: Depth of fractured zone (Maximum depth) (m bgl).**

## 4.0 GROUND WATER RESOURCES (2023)

In hard rocks, for practical purpose it is very difficult to compute zone wise (aquifer wise) ground water resources, because the weathered zone and fractured zone are inter-connected with fractures/joints and fractured zone gets recharged through weathered zone. Therefore, it is very difficult to demarcate the boundary between two aquifers; hence the resources are estimated considering entire area as a single aquifer system. Village wise dynamic and in-storage ground water resources are computed as per the guidelines laid down in GEC methodology.

While computing the in-storage resources, the general depth of deepest fractures in the area, pre-monsoon water levels and 2 % of granular zone (depth below pre-monsoon water level and down to deepest fracture depth in the village) is considered. Summarized mandal wise resources are given in Table-4.1 and Annexure-1 respectively.

As per GEC report 2022, the net annual groundwater availability is **720.98** MCM, gross ground water draft for all uses **196.31** MCM, provision for drinking and industrial use for the year 2025 is 59.54 MCM and net annual ground water potential available for future irrigation needs is 518.94 MCM. The stage of ground water development varies from 12 % in Nathavaram mandal to 52 % in Munagapaka mandal with an average of 28%. All the 24 mandals fall under **Safe** category.

| Parameters | Total (MCM) |
|---|---|
| **Dynamic (Net GWR Availability)** | **557.62** |
| • Monsoon recharge from rainfall | 230.22 |
| • Monsoon recharge from other sources | 368.81 |
| • Non-monsoon recharge from rainfall | 140.99 |
| • Non-monsoon recharge from other sources | 61.39 |
| • Total Natural Discharge | 40.07 |
| **Gross GW Draft** | **203.25** |
| ✓ Irrigation | 149.53 |
| ✓ Domestic and Industrial use | 53.70 |
| Allocation of Ground Water Resource for Domestic Utilisation forprojected year 2025 | 42.64 |
| Net GW availability for future use | 57.64 |
| **Stage of GW Extraction (%)** | **28.18** |

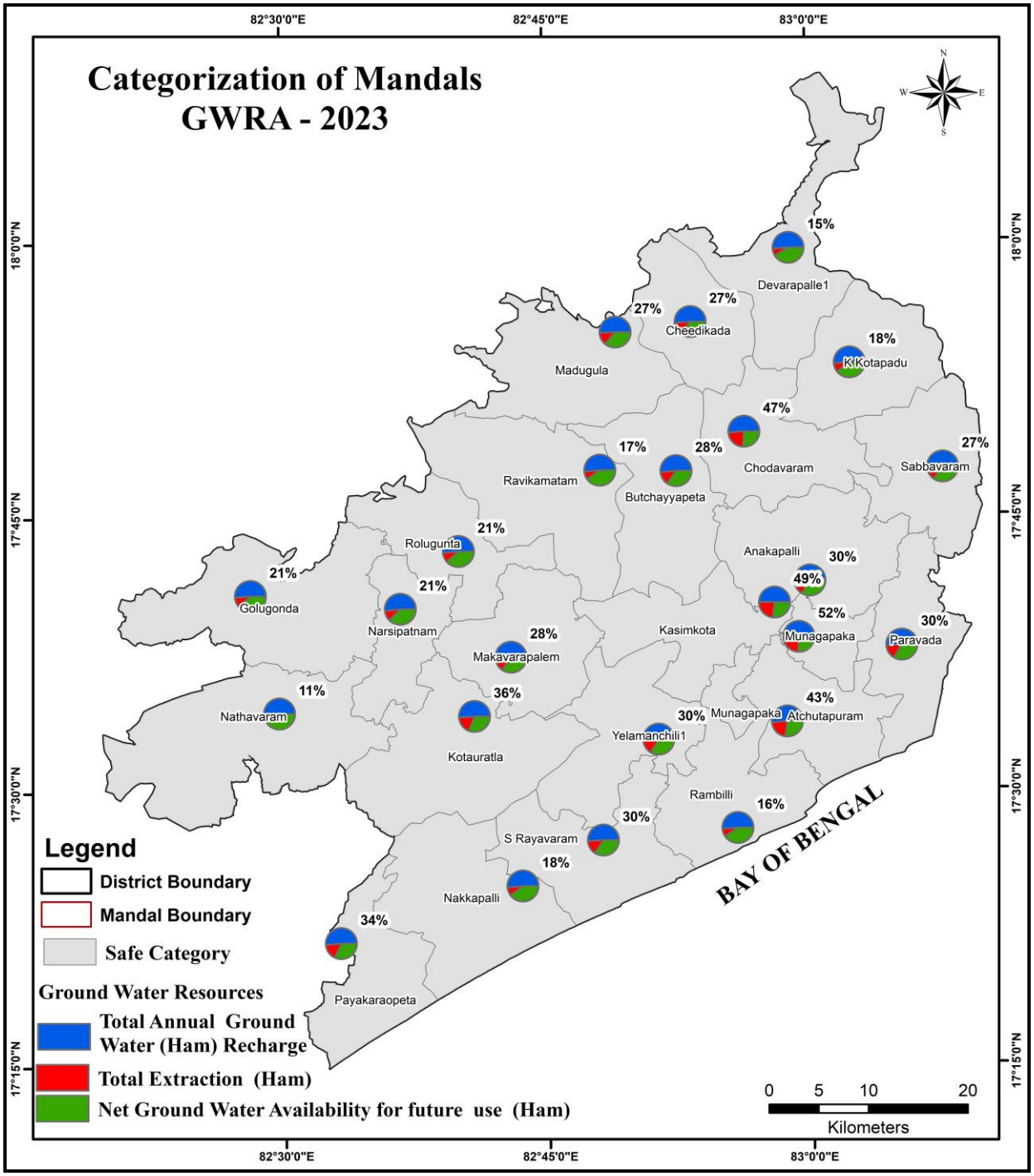


**Fig.4.1: Categorization of mandals (GEC 2023).**

# 5. GROUND WATER RELATED ISSUES AND REASONS

## 5.1 Issues and Resons

### Deep water levels

1. Deep water levels (> 20 m bgl) are observed during pre-monsoon season in 4 coastal mandals of the district.
2. Out of 25 wells analyzed, 12 wells (50%) shows fall in water levels (-0.03 to -13.13 m).

### Pollution (Geogenic and Anthropogenic)

1. Few mandals are fluorosis endemic where fluoride (geogenic) as high as 4 mg/L is found in groundwater. The high fluoride concentration (>1.5 mg/L) occur in 70 % of analyzed samples in the study area.
2. Higher concentration of fluoride in ground water is attributed due to source rock, rock water interaction where acid-soluble fluoride bearing minerals (fluorite, fluoro-apatite) gets dissolved under alkaline conditions and higher residence time of ground water in deeper aquifer.
3. High nitrate (> 45 mg/L) due to anthropogenic activities is observed in about 10 % samples. This is due to unscientific sewage disposal of treated and untreated effluents in urban and rural areas.Use of NPK fertilizers.
4. EC is < 3000 µ Siemens/cm covering Parts of Dornala, Markapuram, Tarlapadu and few parts of Ardhaveedu and Racherla mandals.
5. **Sustainability**

   Low yield (<1 lps) occurs in ~48 % of area covering entire district. The yield from bore wells have reduced over a period of time and some bore wells which used to yield sufficient quantity of water have gone dry due to low rainfall

## 5.2 Reasons for Issues

### Geo-genic pollution (Fluoride)

1. Higher concentration of fluoride in ground water is attributed due to source rock, rock water interaction where acid-soluble fluoride bearing minerals (fluorite, fluoro-apatite) gets dissolved under alkaline conditions.

2. Higher residence time of ground water in deeper aquifer.

### Anthropogenic pollution (Nitrate)

3. Higher concentration is due to unscientific sewage disposal of treated and untreated effluents in urban and rural areas. Use of NPK fertilizers and nitrogen fixation by leguminous crops.

### Over-exploitation and Deep water levels

4. Over-extraction, low rainfall and limited artificial measures etc.

### Sustainability

Absence of primary porosity, negligible development of secondary porosity, low rainfall, desaturation of weathered zone and urbanization

## 6. MANAGEMENT STRATEGIES

The lacking of assured irrigation facilities in the rural areas, the demand and gap in water supply in urban areas, the dependency of ground water is increasing day by day. The ground water development in hard rock aquifer system may led to a steady fall in water levels, pose sustainability issues which may pose challenges to food and drinking water security in future. The occurrence of fractures in hard rock aquifers are are very limited in extent, as the compression in the rock reduces the opening of fractures at depth and the majority of fractures occur within 100-150 m depth (40%). Though the general ground water scenario of the district is good, the uneven groundwater availability and its utilization indicates for requirement of integrated water resource management and sustainable practices for maintaining sustainable ground water scenario in the district.

Management plan

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

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

### 7.1 Supply side measures:

**7.1.1** Repair, Renovation and Restoration of existing tanks (Competed): De-silting of 5.3 MCM of silt from existing (minor irrigation tanks and Percolation tanks) tanks are completed under State Govt. sponsored NEERU- CHETTU programme and created additional surface storage in stabilization of ayacut in acres i.e 1925 acres. This will contribute ~0.54 MCM to groundwater (considering 25% of recharge) and with this additional ~780 ha land can be brought under irrigated dry (ID) crops in tank ayacut.

### 7.1.2 Artificial Recharge structures:

In the district 286 MCM of recharge potential volume is vaialble in the aquifers. This can be utilized for implementing artificial recharge structures. Govt. of AP under IWMP and MNREGS constructed a total of 1091 Check dams and 301 percolation tanks in the district. The details of ARS have been provided in the figure and table.

It is recommended for desiltation of all existing artificial recharge structures and water conservation structures for effective utilization of existing structures and storage created through these structures. In addition, there is a scope for construction of 2340 artificial recharge structures (1151 CDS and 1189 PTS), which can be taken up as per requirement in the districts (Fig-7.2). With this 82 MCM of ground water can be recharged.

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

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

### 7.1.3 Water Conservation Measures (WCM) (Farm Ponds):

The farm ponds are the ideal water conservation structures, which are constructed in the low-lying areas of the farm. The Govt. of Andhra Pradesh had constructed around 16276 no. of farm ponds in the district. It is recommended for desilting of existing farm ponds. Further, it is recommended to construct 17060 farm ponds (20 in each village in 853 villages).

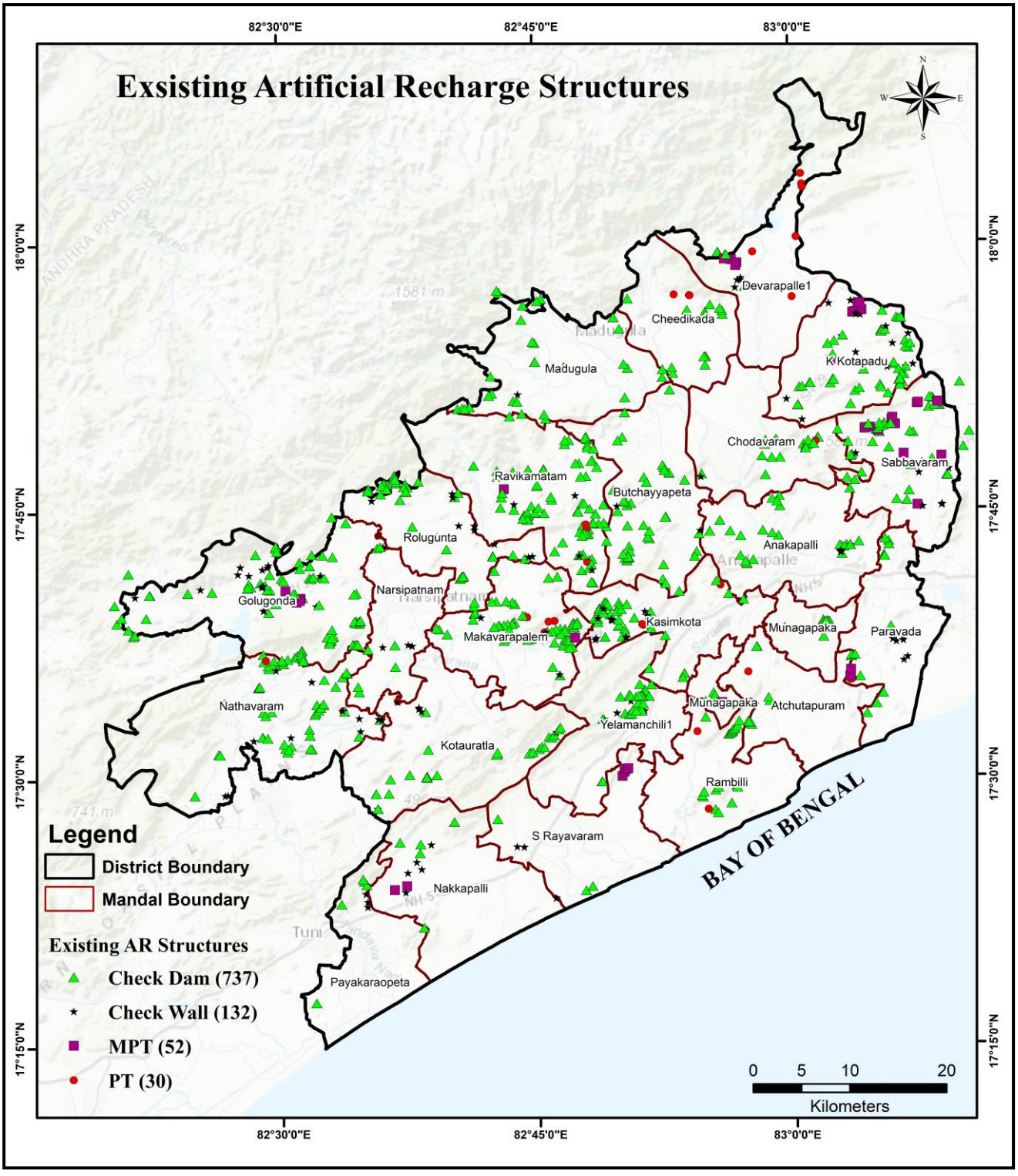


**Fig- 7.1 Map showing existing and proposed AR Strctures in Anakapalli district**

**7.2 Demand side measures**: In order to manage the available resources, more effectively the following measures are recommended.

### 7.2.1 Ongoing Works

- In the district till date a total number of 811 no's drip and sprinklers are sanctioned which has irrigated ~1533 ha of land saving ~2.30 MCM of groundwater from the district considering 30% of net savings as compared to traditional practice of flood irrigation. (MI Census data 2013-14).

### 7.2.2 Proposed Work

- ~42,650 ha of additional land that can be brought under micro-irrigation (@50 ha/village in 853 villages) considering 1 unit/ha @0.6 lakh/ha. With this

85 MCM of ground water can be conserved over the traditional irrigation practices (considering 0.004 MCM/ha for ID crops against 0.006 MCM/ha).

### 7.3 Other measures

- Change in cropping pattern from water intensive paddy to irrigated dry crops like pulses and oil seeds are recommended, particularly in water stress/ Over-exploited/ Critical areas. If necessary, some regulatory rules may be framed and implemented. Whereas water intensive crops are also recommended in water logged areas.

  As a mandatory measure, every groundwater user should harvest and recharge rainwater through artificial recharge structures in proportionate to the extraction. This mechanism will be helped in rejuvenating ground water vulnerability zones into fresh water zones.

- A Participatory Groundwater Management (PGWM) approach in sharing of groundwater and monitoring resources on a constant basis along with effective implementation of the existing 'Water, Land and Trees Act' of 2002 (WALTA-2002) are the other measures suggested. Subsidy/ incentives on cost involved in sharing of groundwater may be given to the

concerned farmers.

- In urban and rural areas, the sewerage line should be constructed to arrest leaching of nitrate into ground water system. GVMC must adopt proper treatment of sewerage water treatment plants by installing STPs in urban area before it reaches to ocean (otherwise which will a creat major damage in ocean bio-diversity).

**Acknowledgment**

- I would like to express my sincere thanks to Dr. Sunil Kumar Ambast (Chairman CGWB), G.Krishnamurthy (Regional Director CGWB), Shri Ravi Kumar Gumma (Scientist-D) for encouragement, guidance and support. I am grateful to all officers and officials of CGWB Hyderabad, Andhra Pradesh Water Department, Ground Water and Water Audit Department, Rural Development Department, Rural Water Supply Department, Directorate of Economics and Statistics, Minor Irrigation, Govt of Andhra Pradesh for providing the data for the preparation of report.

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