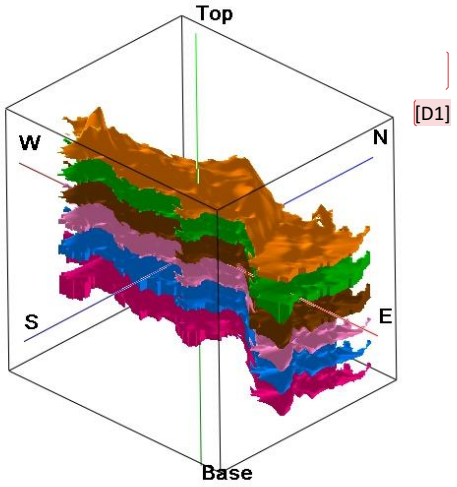
भारत सरकार

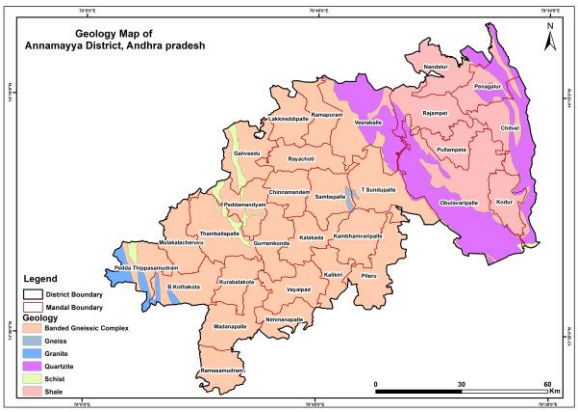
जल संसाधन नदी विकास एवम् गंगा संरक्षण मंत्रालय

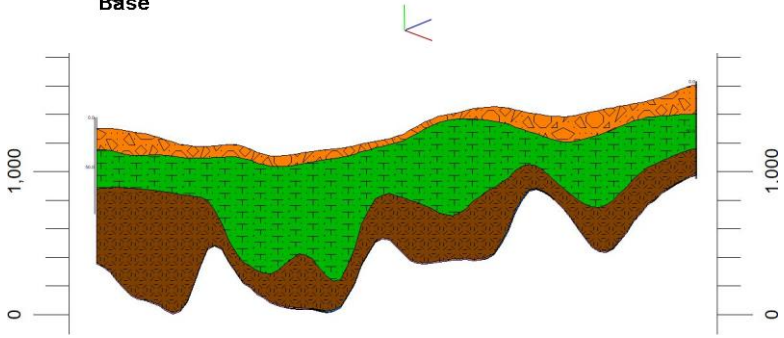
केंद्रीय भूमिजल बोर्ड

GOVERNMENT OF INDIA
MINISTRY OF WATER RESOURCES, RIVER DEVELOPMENT AND GANGA REJUVENATION

REPORT ON
AQUIFER MAPPING FOR SUSTAINABLE MANAGEMENT OF GROUND WATER RESOURCES IN HARD & SOFT ROCKS AREAS OF ANNAMAYYA DISTRICT, ANDHRA PRADESH STATE







CENTRAL GROUND WATER BOARD
SOUTHERN REGION
HYDERABAD
FEBRUARY 2025

REPORT ON
AQUIFER MAPPING FOR SUSTAINABLE MANAGEMENT OF GROUND WATER RESOURCES IN HARD & SOFT ROCKS AREAS OF ANNAMAYYA DISTRICT, ANDHRA PRADESH STATE

CONTRIBUTORS' PAGE

Name		Designation
Principal Authors		
Dr. M. Sudheer Kumar	**:**	**Scientist-D**

REPORT ON
AQUIFER MAPPING FOR SUSTAINABLE MANAGEMENT OF GROUND WATER RESOURCES IN HARD & SOFT ROCKS AREAS OF ANNAMAYYA DISTRICT, ANDHRA PRADESH STATE

Executive summary

Co n t e n t s

Figures

Table

REPORT ON
AQUIFER MAPPING FOR SUSTAINABLE MANAGEMENT OF GROUND WATER RESOURCES IN HARD & SOFT ROCKS AREAS OF ANNAMAYYA DISTRICT, ANDHRA PRADESH STATE

AT A GLANCE

S.No.	Item		Particulars
1	Districts	:	Annamayya
2	Revenue Divisions/ Mandals	:	3
3	Villages	:	463 Nos
4	Geographical area	:	7,951 km^2
5	Population (2011 Census)	:	~~16.97 lakh
6	Density of population (2011 Census)	:	213 persons/km^2.
7	Locations	:	North latitude: 13°19'50" and 14°42'32" East longitude: 78°18'55"and 79°20'26"
8	Rainfall (Normal)	:	~743.13 mm average annual rainfall (SW: 50.38 % & NE: 38.38%)
9	Geomorphology	:	Pediplain (47 %, pediment (22 %), Denudation hills (15 %), flood plains (8 %) and channel fill (5 %).
10	Major Rivers	:	Pennar
11	Watersheds	:	19 nos
12	Land Utilization (Ha)	:	Double cropped area occupies ~47% of the total geographical area, 34% of area is cultivated during kharif season. Forest: ~31%, wastelands ~ 15%, river sandy area is 0.03%, Water channel area 5%
13	Soils	:	Loamy soils (58 %) and Clayey soils (11 %)
14	Cropping Pattern (2019-2020) (Gross Area: 2.5 Lakh Ha)	:	Khariff: 46% paddy Oil seeds Cereals & Millets are also grown in other non –food crops are grown Rabi: 18% paddy Cotton oil seeds and other non-food crops etc.
15	Irrigation	:	**Major project:** Handri Neeva Sujala Sravanthi Phase-II (HNSS Phase-II) and Krishna Devaraya Galeru Nagari Sujala Sravanthi (GNSS). ayacut 1,55,350 Acres ayacut and 1,55,000 Acres **Medium Projects:** 6 medium irrigation projects i.e., Annamaya Project, Bahuda Reservoir Project, Pedderu Reservoir Project, Jerrikona Project, Pincha Project and Veligallu Project. **Minor** Lift Irrigation Schemes under APSIDC (2 Nos) 200 Acres ayacut, **MI Tanks** (181 Nos - above 100 acres ayacut) an extent of 64,837 Acres.

16	Prevailing Water Conservation/Recharge Practices	:	PT: 38 and CD: 54 and Farm ponds:1622 Micro irrigation: 78 Ha. additional
17	Geology	:	Banded Gneissic complex (70 %): and Sandstone/shale/limestone (20 %), and quartzite (3%) and ultramafic rocks.
18	Hydrogeological data points	:	67 hydrogeological data VES: 35
19	Number of ground water structures	:	As on 31/03/2020, CGWB drilled 28 bore wells
20	Ground water yield (lps)	:	0.1 to 7 lps
21	Water Levels (2023) Depth to water levels (m bgl)	: :	67 piezometers The average DTWL of 10 years (2013 to 2023) for pre-monsoon and post-monsoon were analysed, The avg. DTWL varies from 0.38 to 51.5 meter below ground level (m bgl) (average: 12.22 m bgl) and 0.98 – 80.25 m bgl (average: 14.01 m bgl) during pre and post-monsoon seasons. Pre-Monsoon WL below 10m 55% of the area, 10-20 m 24%, followed by 20-40 m bgl (20%). Deep water levels > 40 m.bgl occupy about 1% of Madanapalle mandal. Shallow water levels < 5 m.bgl occupy 29% of 22 mandals.. Post-monsoon: water levels 10-20 m 35% followed by 5-10 m bgl (37%), 20-40 m bgl 7%, > 40 m.bgl 7% of the area, falling in parts of Kalikiri, Chinna Mandem, Rajampet, Rajampet mandals (Fig.2.5). Shallow water level < 5 m.bgl occupy 14%
	Water Level Fluctuations (May vs. November 2023)	:	Fluctuations -15 to 25.72 m with average rise of 0.095 m, 62% (48 nos) of the wells show rise in water level and 38% (30 nos) of wells show fall in water level. Fall 9% rise 91% .Rise in water level range of 2 to 5 m covers majority of the area with 38% followed by 5 to 10 m, 0 to 2 m and 10 to 15 m in 19%, 33% and 08% of the areas respectively. Rise of water levels > 15 m. is observed only in 2% of area in parts of Chinna Mandem mandal..
23	Long term water level trends (2011-2023) (32 wells)	:	**Pre-monsoon:** 17 wells falling trend (0-1:10, 1-2 m: 2 and >2 m: 3 wells) (max fall: 1.5 m/yr) and 02 wells rising trend (0-1:2,) (max rise: 0.87 m/yr). **Post-monsoon:** 29 wells falling trend (0-1:18, 1-2 m: 2 and >2 m: 9 wells) (max fall: 1.5 m/yr) and 03 wells rising trend (0-1:2, > 2:1) (max rise: 1.2 m/yr)
24	Water level during **(2023-2023)** with average WL of last 10 years (2013-23)	:	**Pre-monsoon:** 27 wells show rise, 3 fall **Post-monsoon:** 7 wells shows fall and 23 rise.
25	Geophysical data (down to 200 m)	:	35 VES Top soil 0.1m and < 100 ohm (Ω) m for the weathered granite (1-30 m), 60-350 Ω m fractured granite 84 m and > 350 Ω m for massive granite. < 150 ohm (Ω) m for the weathered Meta-sediments (1-20 m), 50-300 Ω m fractured Meta-sediments (70-100m) and > 300 Ω m massive Meta-sedimentsm.

26	Hydrochemistry (2020)	:	Total 40 data Pre-monsoon (CGWB:40 nos,) Post-monsoon (CGWB:40)	
26.1	Electrical Conductivity (µ Siemens/cm)	:	Pre: 350-12100 (avg: 1687) µ Siemens/cm.In 68% of area EC is within 1500 µ Siemens/cm, in 22% area, it is 1500-3000 µ Siemens/cm and in 10% area, it is > 3000 µ Siemens/cm.	
26.2	Nitrate mg/l	:	Pre: 25% of samples is beyond permissible limits of 45 mg/L.	
26.3	Fluoride mg/l	:	Pre: 0.104-2.074 mg/L and 97.50 % within permissible beyond permissible 1.5 mg/L in Chinnamandem mandal of the district.	
27	Conceptualization		Weathered zone (~25 m).	Fractured zone (25 -196) m
27.1	Aquifer Characterization	:	Saprolite (~6 m) and lower sap rock (6-18) 10-20 m weathering occurs in 66% < 21 m in 26% deep 13% of area.	Majority of fractures ~43% occurs within 100 m depth. Deepest fracture at >150 m 29%
27.2	Aquifer wise Ground water yield	:	<0.1 to 11.72 lps. Lower yields (< 2 lps) occur in central part of study area and moderate yields (1-6 lps) occur in eastern part and higher yields (> 3 lps) occur in western,	0.01 to 11.72 lps.
27.3	Transmissivity (m^2/day)	:	1-14 m2/day granite 53 m2/day metasediment	1-910 m2/day
27.4	Specific Yield	:	< 1 to 2.3 %.(avg: 1 %).	-
27.5	Storativity	:	-	0.0001 to 0.00001
28	Ground water Resources (2023) MCM	:	MCM	
28.1	Net Dynamic groundwater availability	:	**846**	
28.2	Gross GW Draft	:	414	
28.3	Provision for Domestic &Industrial (2025)	:	34.10	
28.4	Average Stage of Ground water development (%)		49%	
28.5	Net GW Availability for future irrigation	:	419	
28.7	Categorization of mandals		Safe Mandal wise Min : 29% (Veeraballe) Max : 86% (Chinnamandem)	
29	Major Ground Water Issues Identified	:	• Ground water Pollution (Geogenic: Fluoride (2 % samples are unfit for human consumptions).(Anthropogenic: Nitrate 24 % samples are unfit for human consumptions). • Deep water levels (<10 m bgl) are observed during pre - monsoon season in 21 % of area. • Declining water levels: falling trend in the last 10 years (@- 0.02 to -3.3 m/yr and -0.04 to -3.8 m/yr)	

30	Management Strategies	:	**Supply side measures:** 604 MCM of unsaturated volume (below the depth of 5 m) is available during post-monsoon season, having 121 MCM of recharge potential (2%). **To be taken up (Artificial Recharge Structure)** **recommended water levels below 6 to 10 m Villages** • 142 ARS (CD: 00 and PT: 142) Calculated by considering for Recharge • ~78 MCM percolation tanks and ~ 1.715 MCM per and others sources etc. **Water Conservation measures (WCM) Farm Ponds** • The size of form ponds can be 10 x 10 x 3 m. In the district total 50230 farm ponds exist in 30 Mandals and additional 2778 farm ponds are recommended for 6 nos. in each village in 463 villages.
31	Expected Results and Out come	:	With the above interventions likely benefit would be the net saving of 78 MCM of ground water. This will bring down the stage of ground water development by 05 % (from 24 % to 81 %). The other benefits will be more distribution of income among farmer

ABBREVATIONS

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	:	Hector
Ha.m	:	Hector meter
ID	:	Irrigated dry
IMD	:	Indian 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
MSP	:	Minimum Support price
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

EXECUTIVE SUMMARY

The hard & soft rocks of Annamayya district covering 7,951 Km^2 area (, receives an average annual normal rainfall of 743.13 mm of which 80 % is contributed by SW monsoon and 20 % by north-east monsoon. During the year 2023, the district received 272.8 mm normal annual rainfall. Administratively, the area is governed by 30 revenue mandals with 463 villages. The population of the district is ~ 16.97 lakhs (2011 census) with average density of 213 persons/km^2.

Area is underlain by, granitic gneisses, Sandstone/Shale/limestone and Quartzite. Pediplains are major geomorphic features followed by pediment, denudation hills (15 %), flood plain and channel fill and residual hills. The area is drained by river Penner and Swarnamukhi and Palar rivers. The Pennar river flows towards north direction and its major tributaries are Cheyyeru, Papagni, Bahuda, Pincha and Pedderu. The gross cropped area (2019-20) during khariff season is 126845 ha and during rabi season is 2752 ha (Total 129597 ha). The Majority of the people in the district are depending on Agriculture only. The major crops in the district are Paddy, Groundnut, Sunflower, Cotton, Betel Leaves and Horticultural crops like Mango, Papaya, Banana, Lemon and Sweet Orange. The gross cropped area in the District is 126845 hectares, out of this, gross irrigated area is 66,281 hectares during 2019-20. The other crops are spices and oil seeds.

Two Major irrigation projects i.e., Handri Neeva Sujala Sravanthi Phase-II (HNSS Phase-II) of an extent of 1,55,350 Acres ayacut and Krishna Devaraya Galeru Nagari Sujala Sravanthi (GNSS) of an extent of 1,55,000 Acres. Six medium irrigation projects i.e., Annamaya Project, Bahuda Reservoir Project, Pedderu Reservoir Project, Jerrikona Project, Pincha Project and Veligallu Project with an ayacut 62353 acres. The Minor Lift Irrigation Schemes under APSIDC (2 Nos) covered in the district, an extent of 200 Acres ayacut, MI Tanks (181 Nos - above 100 acres ayacut) an extent of 64,837 Acres and Minor Irrigation anks (3,557Nos - bellow 100 acres ayacut) an extent of 57,062 Acres.

Exploratory results of CGWB 28 wells out of which 19 wells were drilled in metasedimentary area and 9 wells were drilled in granitic area and deepest depth 200m of that deepest fracture at 187m.bgl of Penagaluru mandal.

Ground water levels from 67 nos. of piezometers were monitored for pre-monsoon and post-monsoon season. The water-table elevation ranges from 97.41-794.62 and 102.09 to 794.02 meter above mean sea level (m amsl) respectively and general ground flow is

towards Pennar river i.e towards NE and from south to northern parts and from East to North eastern parts. The average DTWL of 10 years (2013 to 2023) for pre-monsoon and post-monsoon were analysed, the avg. DTWL varies from 0.38 to 51.5 meter below ground level (m bgl) (average: 12.22 m bgl) and 0.98 – 80.25 m bgl (average: 14.01 m bgl) during pre and post-monsoon seasons respectively. In pre-monsoon range DTWL below 10m was covering 55% of the area, 10-20 m covering 24% of the area, followed by 20-40 m bgl (20%). Deep water levels > 40 m.bgl occupy about 1% of the area falling in parts of Madanapalle mandal. Shallow water levels < 5 m.bgl occupy 29% of the area in parts of 22 mandals. In post-monsoon range of 10-20 m covering 35% of the area, followed by 5-10 m bgl (37%). Deep water levels in the range of 20-40 m bgl occupy about 7% of the area and Deep water levels > 40 m.bgl occupy about 7% of the area falling in parts of Kalikiri, Chinna Mandem, Rajampet, Rajampet mandals. Shallow water level < 5 m.bgl occupy 14% of the area in parts of Ramasamudram, Galiveedu, Lakkireddypalli, Nimnapalle, Kalikiri, Vayalpad, Veeraballe, B. Kothakota, T Sundupalle, Kodur mandals. water level fluctuations vary from -15 to 25.72 m with average rise of 0.095 m (Fig.2.6). 62% (48 nos) of the wells show rise in water level and 38% (30 nos) of wells show fall in water level. In general, it is observed has Fall in water level is recorded only in 9% of the area whereas rise in water levels is observed throughout the district covering 91% of area. Rise in water level range of 2 to 5 m covers majority of the area with 38% followed by 5 to 10 m, 0 to 2 m and 10 to 15 m in 19%, 33% and 08% of the areas respectively. Rise of water levels > 15 m. is observed only in 2% of area in parts of Chinna Mandem mandal. Trend analysis for the last 12 years (2011-2023) is studied from 32 hydrograph stations of CGWB and SGWD. It is observed that during pre-monsoon season 17 wells shows falling trend (0-1:10, 1-2 m: 2 and >2 m: 3 wells) (max fall: 1.5 m/yr) and 02 wells shows rising trend (0-1:2,) (max rise: 0.87 m/yr). During post-monsoon season 29 wells show falling trend (0-1:18, 1-2 m: 2 and >2 m: 9 wells) (max fall: 1.5 m/yr) and 03 wells shows rising trend (0-1:2, > 2:1) (max rise: 1.2 m/yr). The graphical representation of fall and rise.

Geophysical data of 35 VES is interpreted, which reveals resistivity < 100 ohm (Ω) m for the weathered granite (1-30 m), 60-350 Ω m for underlying fractured granite with maximum thickness of 84 m and > 350 Ω m for massive granite. Resistivity < 150 ohm (Ω) m for the weathered Meta-sediments (1-20 m), 50-300 Ω m for underlying fractured Meta-sediments (70-100m) and > 300 Ω m for massive Meta-sediments..

Total 40 piezometer wells data is utilized from chemical analysis from NHS monitoring wells of CGWB. pH in the range of 7.00-8.28 (Avg:7.46). Electrical conductivity varies

from 350-12100 (avg: 1687) µ Siemens/cm. In 68% of area EC is within 1500 µ Siemens/cm, in 22% area, it is 1500-3000 µ Siemens/cm and in 10% area, it is > 3000 µ Siemens/cm (Fig.2.9). Nitrate concentration in 25% of samples is beyond permissible limits of 45 mg/L (Fig.2.10). Fluoride concentration varies from 0.104-2.074 mg/L (Fig 2.11) and 97.50 % of samples are within permissible limits of BIS and rest is beyond permissible limit of 1.5 mg/L. High fluoride concentration is observed in Chinnamandem mandal of the district.

The Weathered zone (~25 m) consisting of upper saprolite (~6 m) and lower sap rock (6-18m.) with discharge varies from meagre to 2 m.bgl in granitic formation and meagre to 12 lps in metasediments rocks of quartzite, shale and limestone. Thickness of weathered zone is in the range of 10-20 m in most part of area covering ~66 % of area, shallow weathering (< 10 m) occurs in 21 % of the area and deep weathering (> 20 m) occurs in rest of the area.

Ground water yield from weathered granite/gneiss aquifer varies from <0.1 to 1 lps (avg: 0.18 lps) in granites and from 0.01 to 4 lps (avg: 1.0 lps) in meta-sediments. The transmissivity varies from 1-14 m2/day in granites and upto 53 m2/day in weathered meta-sediment aquifer.

CGWB exploration data it is inferred that fractures are range of < 100 m depth (43 % of the area), 100-150 fractures occur in 28 % and > 150 m. fractures occur in 29% and deep fractures are range of > 150m. Occur in Chitvel, Kodur, Penagaluru., Rajampet, Sambepalle and Chinnamandem mandals. Analysis of occurrence of fractures (from 28 wells) reveal that majority of fractures (~43 %) occur within 100 m depth.

Groundwater yield of fractured granite/gneiss varies from 0.01 to 2 lps (avg: 0.18 lps) and meta sediments (Quartzite, Shale and Limestone) varies from 0.01 to 11.72 lps (avg: 1 lps). Wells located in the command area have higher yield (1-6 lps) and sustains for more hours of pumping as compared to non-command area where yields are relatively low and sustains for 1-3 hrs. The transmissivity varies from 1-910 m2/day. Stotativity of the fracture zone varies from 0.0001 to 0.00001

As per GEC 2023, the net dynamic replenishable groundwater availability is 846 MCM, gross ground water draft for all uses 414 MCM, provision for drinking use for the year 2025 is 50 MCM and net annual ground water potential available for future use is 419 MCM. Stage of ground water extraction in the district is 49%. 02 mandals (Chitvel & Chinnamandem) fall in semi critical category and remaining 28 mandals fall in safe

category. Mandal wise stage of ground water development varies from 29% (Veeraballe mandal) to 89% (Chinnamandem mandal) with average of 51%.

Major issues identified are ground water Deep water levels (> 20 m bgl) are observed during pre as well as post-monsoon season in 21 % and 16% of the area respectively. Out of 64 wells analysed, 40 wells during pre-monsoon 39 wells during post-monsoon shown falling trend in the last 10 years (@-0.02 to -3.3 m/yr and -0.04 to -3.8 m/yr) respectively. Low yield. Chinnamandyam mandal show fluoride (geogenic) as high as 2.01 mg/L during pre-monsoon season is found in groundwater. The high fluoride concentration (>1.5 mg/L) occur in 2% of the samples during pre-monsoon season. 10 mandals show Nitrate (Anthropogenic) as high as 362 mg/L during pre-monsoon season is found in groundwater. The Nitrate concentration (>45 mg/L) occur in 24% of the samples during pre-monsoon season. The high concentration of EC (> 3000 micro-seimens/cm) in 10% of the area is observed during pre-monsoon season.<1 lps) occurs in ~53 % of area covering entire district.

Construction of 142 ARS of having storage potential and are recommended as supply side measures. Under Water conservation measures include, construction of 2778 nos of farm ponds of 6 nos. in each village in 463 villages.

Demand side measure includes bringing ~23,150 ha of additional land that can be brought under micro-irrigation @50 ha/village in 463 villages. With this 92 MCM of ground water can be conserved over the traditional irrigation practices.

Other measure includes providing good quality seeds, improved procurement facilities, mandatory artificial recharge at every Govt and industrial units. Capacity building in power supply regulation, application of laser levelling technology in irrigated land, providing proper sewerage system and participatory groundwater management (PGWM) are the other measures recommended.

With the above interventions likely benefit would be the net saving of 78 MCM of ground water. This will bring down the stage of ground water development by 05% (from 24% to 81%). The other benefits will be more distribution of income among farmers.

1. INTRODUCTION

Aquifer mapping is a multideciplinary 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. Capacity building in all aspects of ground water development and management through information, education and communication (IEC) activities, information dissemination, education, awareness and training.
6. Enhancement of coordination with concerned central/state govt. organizations and academic/research institutions for sustainable ground water management.

1.3 Area Details: The Annamayya district is the extreme south eastern district of Andhra Pradesh having geographical area of 7,951 km^2 and situated within the geographical co-ordinate of 13°19'50" and 14°42'32" of northern latitude and 78°18'55"and 79°20'26" Eastern longitude. The latitude varies from 269 to 3787 meters above sea level. The District is bounded on North by YSR Annamayya District, South by Chittoor District, West by Anantapur District and East by Nellore & Chittoor Districts. It is part of the River Pennar basin wherein Cheyyeru River joins Penneru at Gundlamada in Vontimitta mandal (**Fig.1.1**). Administratively the district is governed by 3 revenue Division, 30 mandals with 462 Gram Panchayats and 463 revenue villages and 5,673 habitations with a population of ~16.97 lakhs (2011 census). The density of population in the district is 213 per Sq.km.

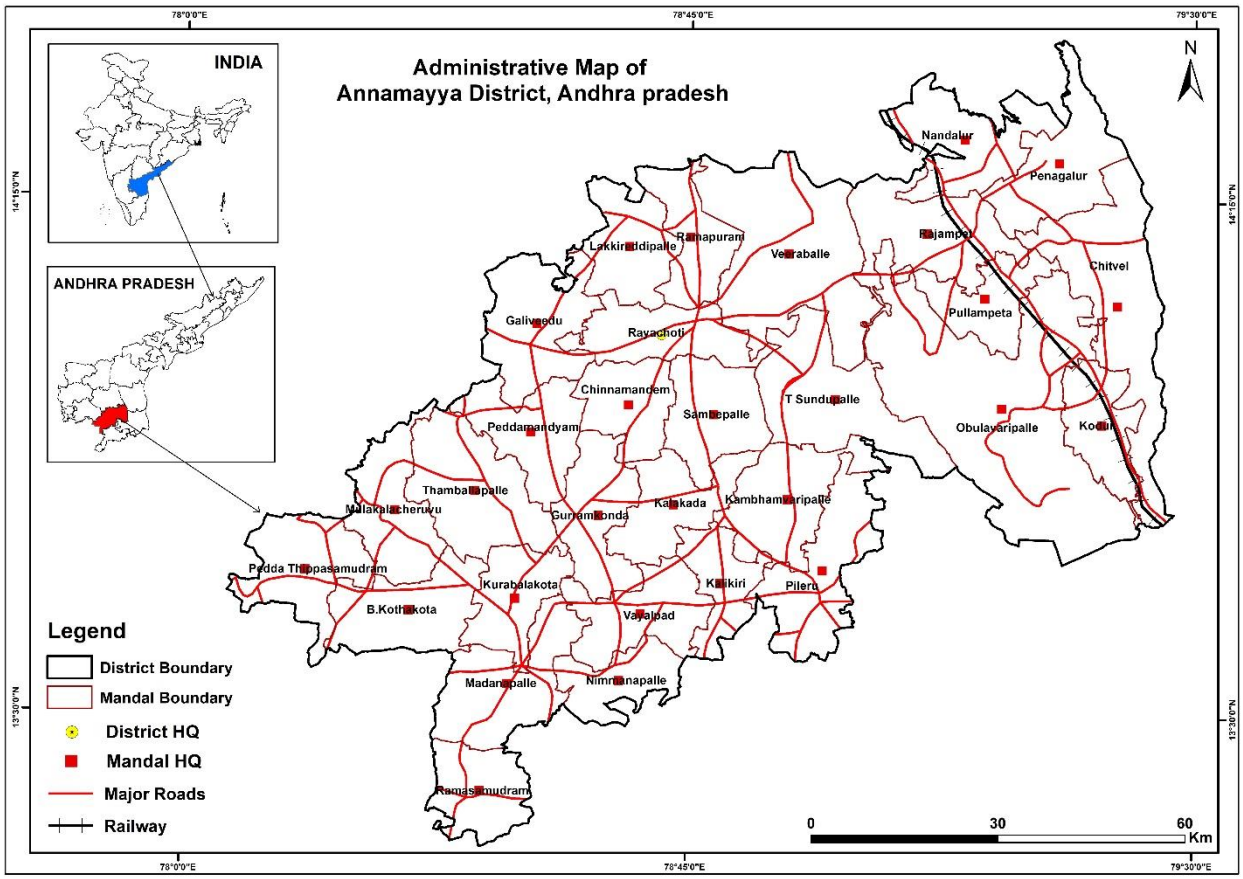


Fig.1.1: Location map of Annamayya district.

Physiography

1.3.1 Physiography

Physiographically, major part of district is occupied by pediplain landform. On the either sides of district is mostly covered by structural hills and valleys with dyke ridges and eastern part dominated by cuesta.

1.3.2 Relief

The slope distribution clearly shows that the district terrain is rugged hilly terrain, and the slope varies from nearly level to very steep slopes (Figure 1.1.1). The nearly level sloping areas are found in the eastern parts of the district along with very gently sloping areas. It is found in the areas of Penagluru, Nandaluru. Rajampet, etc and 7.54% land is under nearly level slopes. The very gently sloping area ranging from 1-3% are occupied 29% of the district geographical area. Most of the the district's land is gently sloping and is distributed along scrubs and forests, accounting for 29.40% of the district's land. The uplands and foothills have moderately to strongly sloping terrain. The slopes ranging from 510% and 10-15% contributed 11.05% and 11.16%, respectively. Moderately steep to steep sloping and very steep slopes are observed at the peak of the hills and are concentrated more in the east and central of the district.

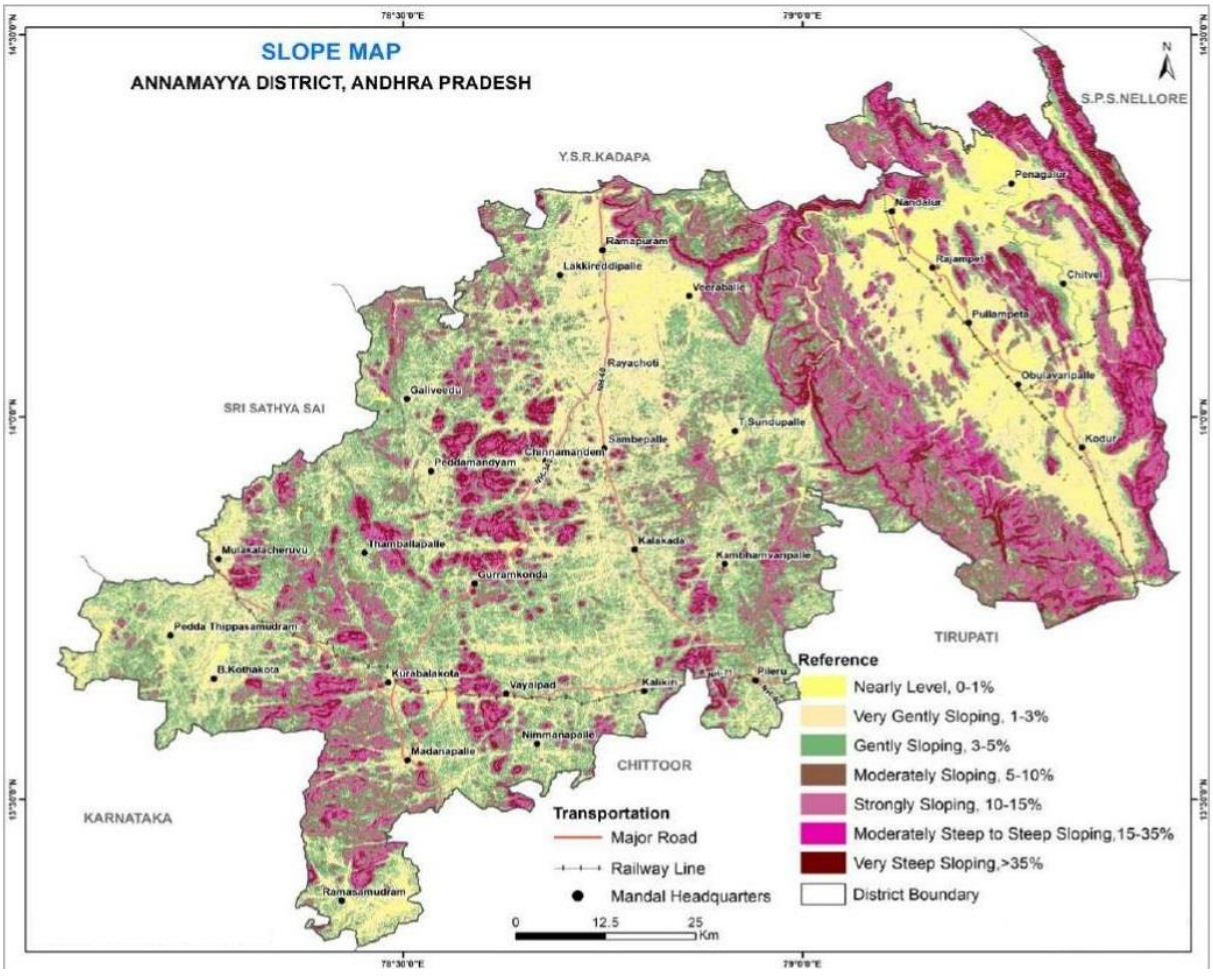


Fig.1.3.1: Slope map of Annamayya district

1.4 Climate and Rainfall: The climate of the district is characterised by tropical wet and dry climate, characterized by year round high temperatures. The District gets rainfall from both the South west monsoon as well as the North East Monsoon. June to October is usually the monsoon period. The average annual rainfall of the district is 743.13 mm, of which 373.41 mm falls as 50% South-West (June-September) monsoon and 285.2 mm as 38% North-East (October-December) monsoon. The mean minimum and maximum temperatures recorded in the district are 19°C in January and 40°C in May, respectively. The average rainfall for the last 25 years is used for the analysis. The Isohyetal map in Fig.1.2 and details is given in Table montly average annual rainfall.

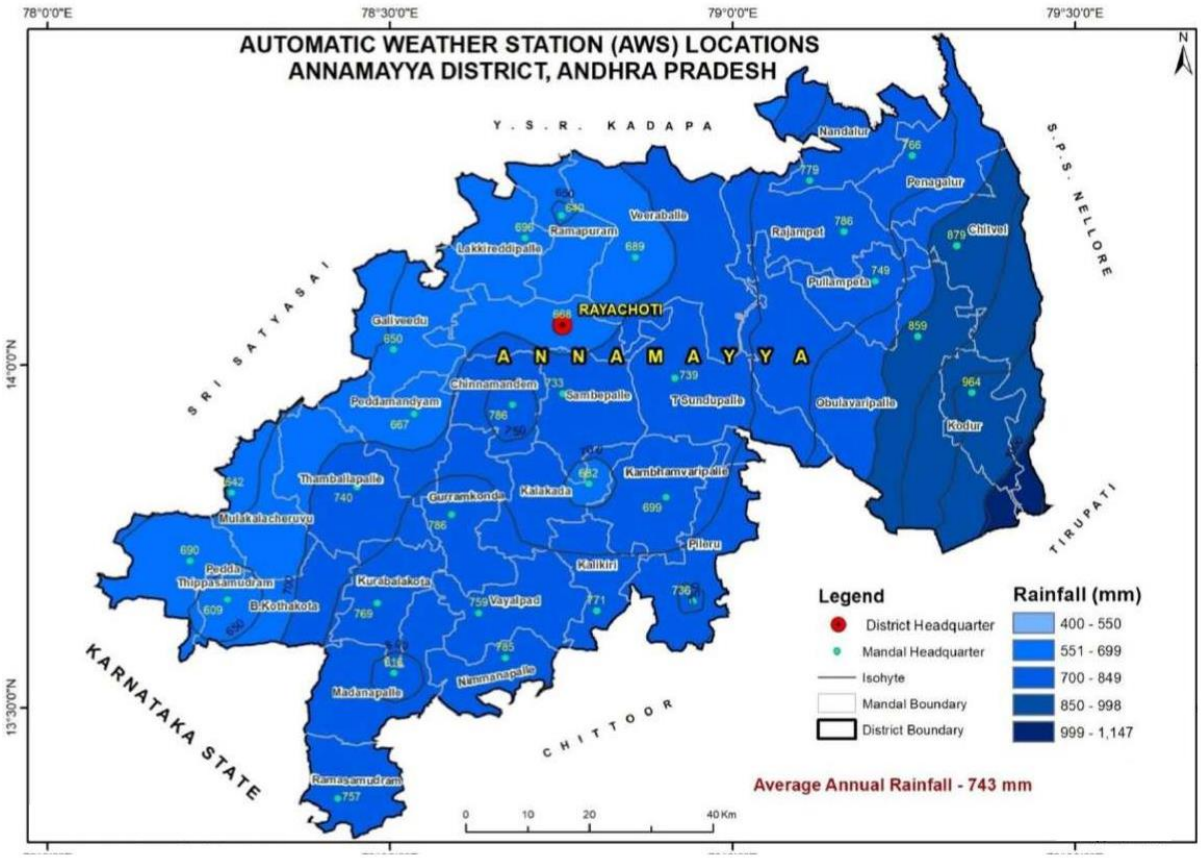


Fig.1.4: Isohyetal map of Annamayya district.

Table: Monthly Average Annual Rainfall (mm) in the district, during the year 1998-2021

S.No	Month	Average Annual Rainfall (mm)
1	January	3.66
2	February	5.73
3	March	9.59
4	April	18.35
5	May	47.38
6	June	68.48

7	**July**	**86.10**
8	**August**	**98.53**
9	**September**	**120.30**
10	**October**	**134.47**
11	**November**	**112.35**
12	**December**	**38.20**
	Total	**743.13**

1.5 Geomorphological Set-up:

The district exibits rolling topography with high and deep fronted hill ranges, valleys and plains. Physiographically, major part of district is occupied by pediplain landform. On the either sides of district is mostly covered by structural hills and valleys with dyke ridges and eastern part dominated by cuesta. (**Fig.1.5**).

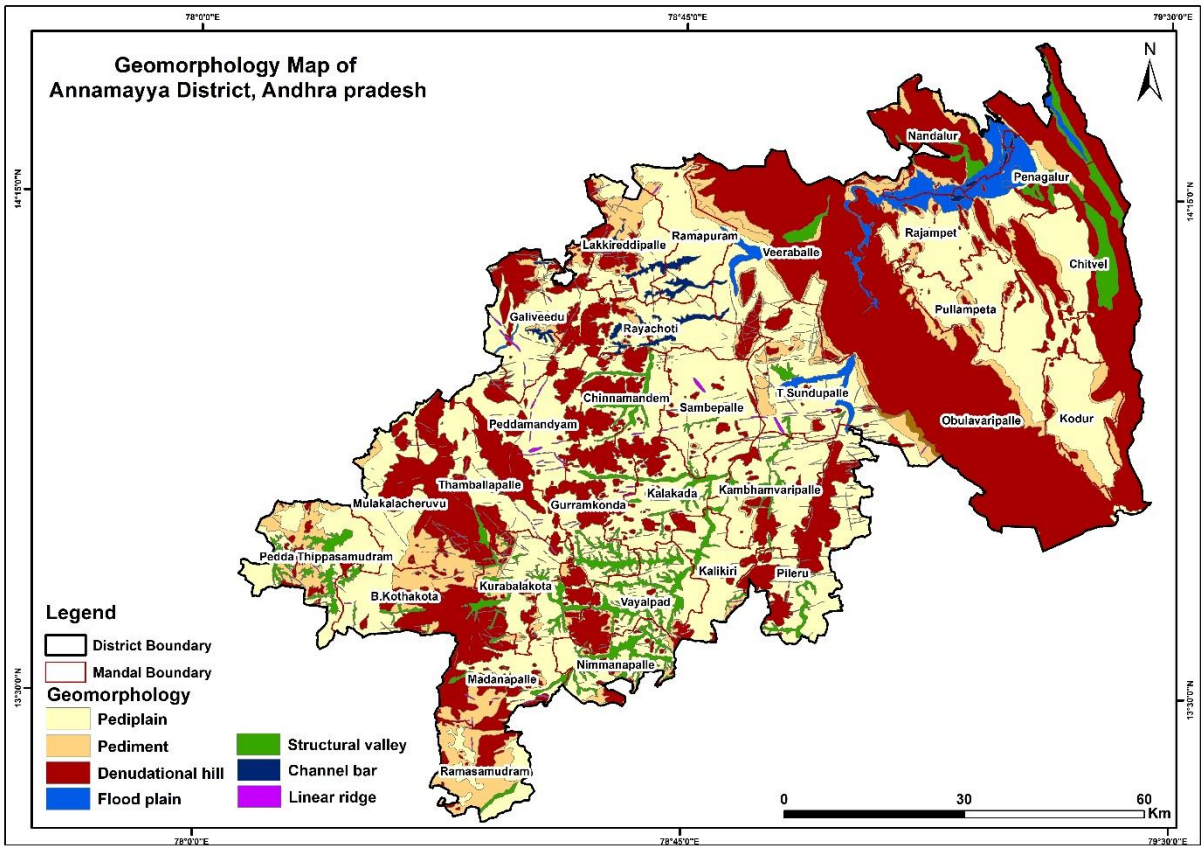


Fig.1.5: Geomorphology map of Annamayya district.

1.6 Drainage and Structures: The important river in the district is Pennar river and covered with 96% of the total area. The remaining part of the district partially covered with Swarnamukhi and Palar rivers. The Pennar river flows towards north direction and its major tributaries are Cheyyeru, Papagni, Bahuda, Pincha and Pedderu.

The Cheyyeru tributary rises in Horsely hills and flows through Chittoor district under the name of the Bahuda tributary and after being fed by several smaller streams the principal of which is the Pincha tributary follows through the Sheshachalam hills and merged into Pennar river near Rangayapalle village, Nandalur mandal in Annamayya district. The Papagni tributary of Pennar river rises near Nandi Hills of Chikkaballapur district in Karnataka State and enters into Andhra Pradesh near T.Sadum village in Peddatippasamudram mandal of Annamayya district. The tributary flows towards north to East direction through Thamalapalle, Rayachoti and leaves in the Northern of district near Talamudipi village in Galiveedu. The surface water bodies structure with minor antiforms and synforms. Many lineaments trend NE-SW and are sub-parallel to the trends of geological formations, other lineaments run either in a ENE-WSW or E-W direction. Map depicting drainage, water bodies, lineaments and watershed boundaries is presented in Fig.1.6**.**

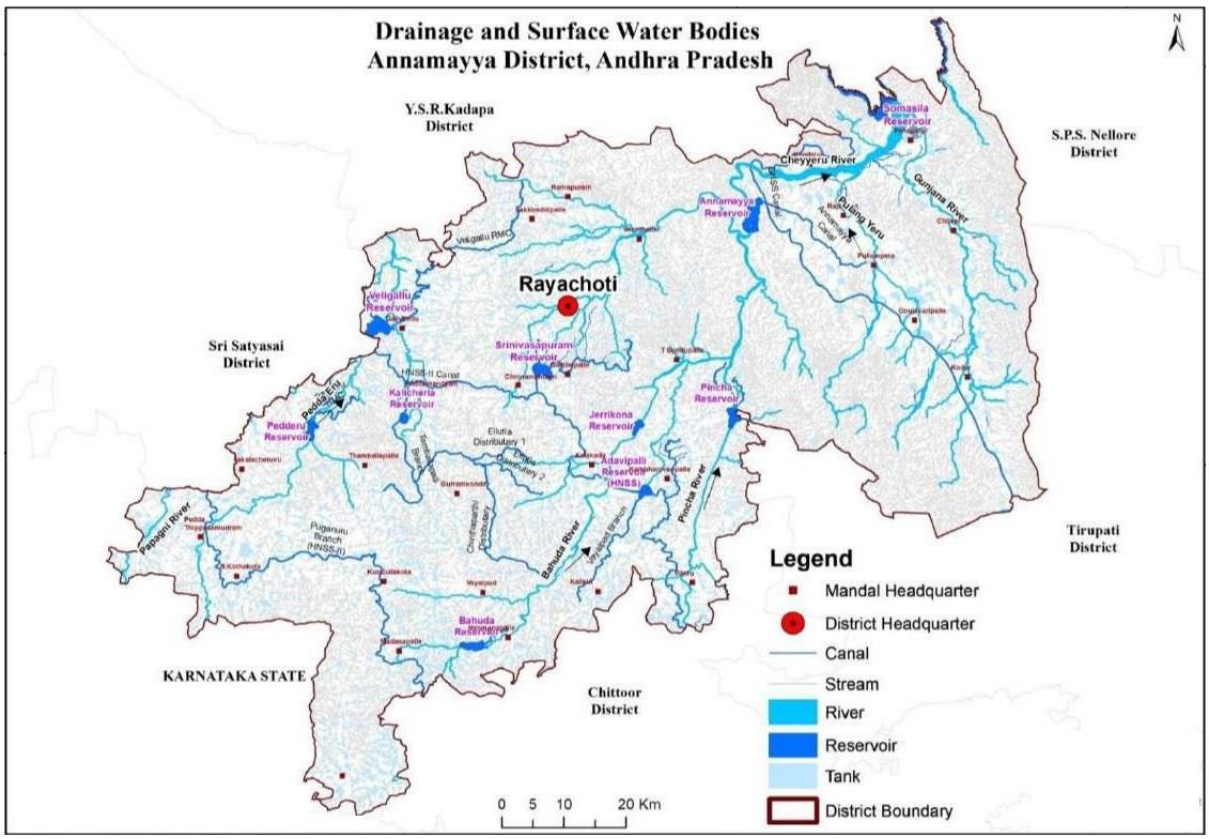


Fig.1.6.1: Drainage Network and Surface Water Bodies of the Annamayya District

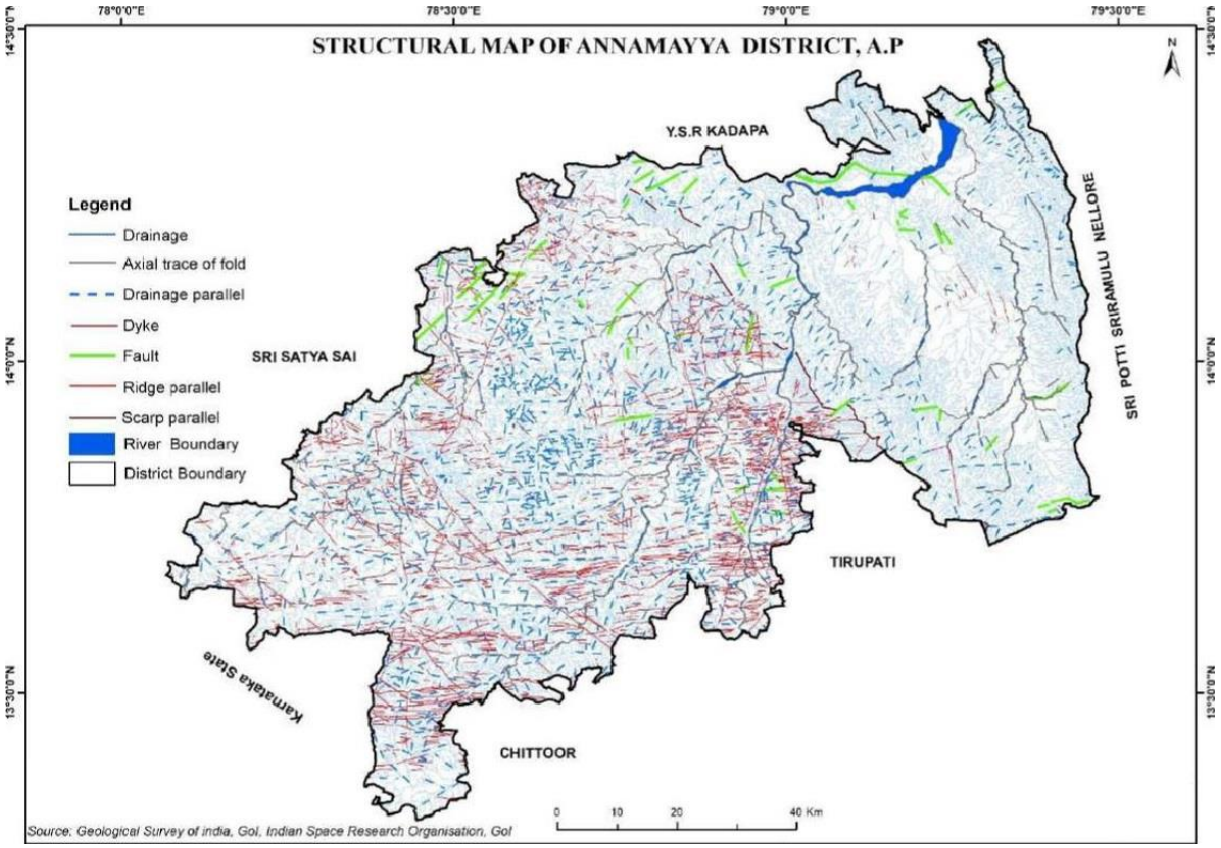


Fig. 1.6.2 : Structural Map of Annamayya District, Andhra Pradesh

1.7 Land use and cropping pattern (2019-20): In the area, major land use categories such as built up (162.81 sq. km), agriculture (3730.73sq.km), forest (2477.62 sq. km), wastelands (1211.71 sq. km), wetlands (2.61 sq. km) and water bodies (368.52 sq.km) were identified and mapped using on-screen interpretation techniques. The study area has been classified into 32 level-III land use / land cover classes. The predominant category is agriculture land followed by forest. The spatial distribution of land use / land cover map of Annamayya district is presented in (Fig. 1.5) and details are given in tabular form. In the area, Forest occupies ~31% of the total geographical area, Barren and uncultivable land 15.23%, land put to non-agricultural use is 9.93%. Nearly 2.5 lakh hectares are under cultivation, 46.90 % (1.4 lakh hectares) area is under double cropping, 18.16%.

Category-wise distributions of Land Use/Land Cover during -2019-2020

S. No	LULC categories	Area in sq. km	% to total
Built up		**162.81**	**2.05**
1	Compact (Continuous)	14.53	0.18
2	Sparse (Discontinuous)	6.08	0.08
3	Vegetated / Open Area	6.87	0.09

4	Rural	74.34	0.93
5	Industrial	2.74	0.03
6	Mining - Active	5.17	0.07
7	Quarry	53.08	0.67
Agricultural Land		**3730.73**	**46.90**
8	Kharif Crop	1268.45	15.95
9	Rabi Crop	27.52	0.35
10	Zaid Crop	6.48	0.08
11	Cropped in 2 seasons	1444.53	18.16
12	Cropped more in 2 seasons	0.34	0.00
13	Fallow	789.79	9.93
14	Plantation	193.62	2.43
Forest		**2477.62**	**31.15**
15	Deciduous (Dry/Moist/Thorn)-Dense/Closed	809.94	10.18
16	Deciduous (Dry/Moist/Thorn)-Open/Closed	852.73	10.72
17	Forest Plantation	0.26	0.00
18	Scrub Forest	715.59	9.00
19	Tree Clad Area-Dense	24.89	0.31
20	Tree Clad Area-Open	74.20	0.93
Wastelands		**1211.71**	**15.23**
21	Gullied Land	0.21	0.00
22	Salt affected land	17.76	0.22
23	Dense scrub	317.69	3.99
24	Open scrub	745.12	9.37
25	Sandy area-Riverine	0.08	0.00
26	Barren Rocky/Stony waste	130.84	1.64
Wetlands		**2.61**	**0.03**
27	Wetlands-Inland Natural	2.61	0.03
Water bodies		**368.52**	**4.63**
28	River/Stream-Perennial	6.09	0.08
29	River/Stream-Non Perennial	114.92	1.44
30	Canal/Drain	23.10	0.29
31	Reservoir/Tanks-Permanent	47.50	0.60
32	Reservoir/Tanks-Seasonal	176.91	2.22
Total		**7954**	**100.00**

The Majority of the people in the district are depending on Agriculture only. The major crops in the district are Paddy, Groundnut, Sunflower, Cotton, Betel Leaves and Horticultural crops like Mango, Papaya, Banana, Lemon and Sweet Orange. The gross cropped area in the District is 126845 hectares, out of this, gross irrigated area is 66,281 hectares during 2019-20.

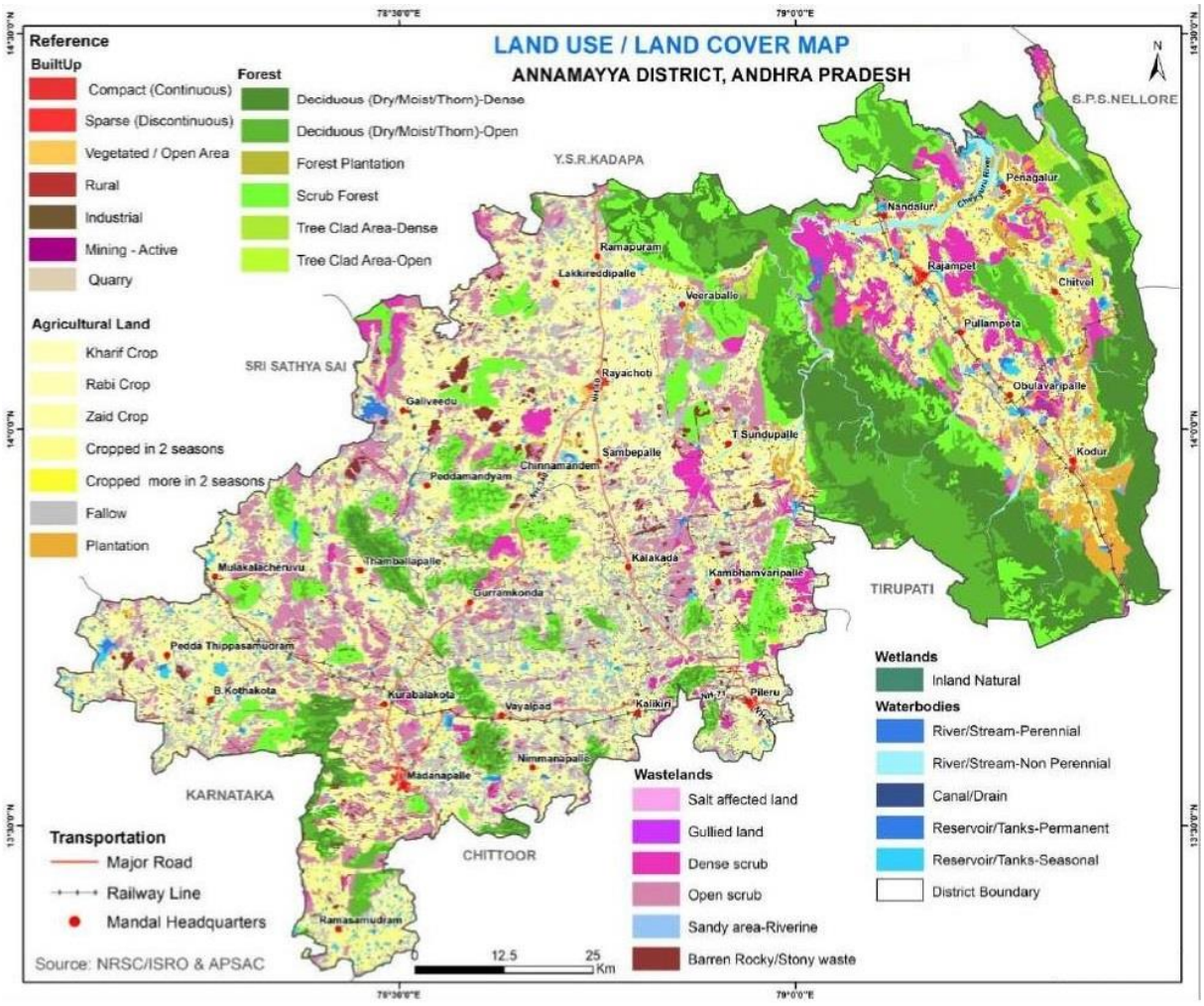


Fig.1.7: Land use and land cover of Annamayya district.

1.8 Soils: The area is predominant soil types in the district are shallow gravelly red soils 4435.93 sq. km (56%), followed by loamy to clayey skeletal deep reddish brown soils 1182.74 sq. km (15%), clayey to gravelly clayey moderately deep dark brown soils 1029.35 sq .km, (13%), loamy to gravelly clay deep dark reddish brown soils 920.64 sq.km (12%) , gravelly clayey moderately deep red soils 461.3 sq. km, (6%) gravelly clayey shallow dark brown soils 457.75 sq.km (6%), gravelly loamy dark brown moderately deep soils 274.52 sq. km, (4%) moderately deep calcareous black soils 190.41 sq.km, (2.3%) deep black clayey soils 59.88 sq.km (0.8%) and moderately deep calcareous moist clayey soils 19.74 sq.km.(0.3%). The soil resource map of the district is shown in Fig. 1.8.

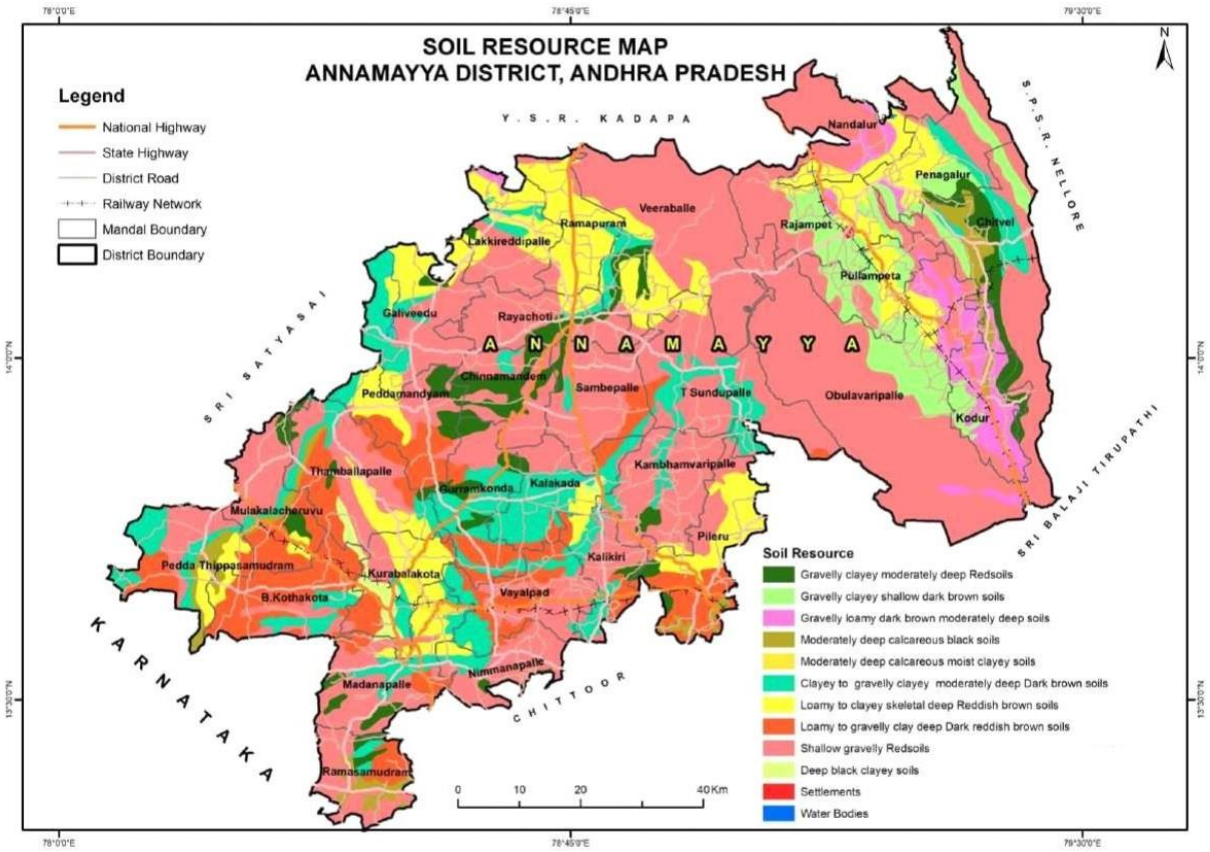


Fig.1.8: Soil map of Annamayya district.

1.9. Irrigation:

Irrigation has assumed an increasing significance in agriculture in the context of new technology, where high yielding varieties and multiple cropping is being practiced. The main reasons for low yields are inadequate rainfall, uneven and uncertain rains during the period of crop growth. It is generally found that the introduction of irrigation is associated with changes in the cropping pattern. The shift from traditional cropping pattern to the most advantageous cropping pattern is possible only in the presence of irrigation facilities. The new agricultural technology is highly based on sufficient moisture conditions. Thus, the development of irrigation is crucial for increasing agricultural production. The major and medium irrigation projects details are shown in Table and Fig.1.9

1.9.1 Major Irrigation Projects:

In Annamayya district there are two ongoing major irrigation projects i.e., Handri Neeva Sujala Sravanthi Phase-II (HNSS Phase-II) and Krishna Devaraya Galeru Nagari Sujala Sravanthi (GNSS). The project wise ayacut details are HNSS Phase-II project an extent

of 1,55,350 Acres ayacut and GNSS project an extent of 1,55,000 Acres in YSR and Annamayya combined district ayacut.

Medium Irrigation Projects:

In Annamayya district there are six medium irrigation projects i.e., Annamaya Project, Bahuda Reservoir Project, Pedderu Reservoir Project, Jerrikona Project, Pincha Project and Veligallu Project.

The Minor Lift Irrigation Schemes under APSIDC (2 Nos) covered in the district, an extent of 200 Acres ayacut, Minor Irrigation Tanks (181 Nos - above 100 acres ayacut) an extent of 64,837 Acres and Minor Irrigation.

Tanks (3,557Nos - bellow 100 acres ayacut) an extent of 57,062 Acres combined districts ayacut.

Major and Medium Irrigation Projects in Annamayya District

S. No	Project Type	Name of the Project	Status	Ayacut in Acres
1	Major	Ananta Venkata Reddy Handri Neeva Sujala Sravanthi (HNSS-II)	Ongoing	1,55,350
2		Krishna Devaraya Galeru Nagari Sujala Sravanthi (GNSS) *(Combined YSR Annamayya District)*		1,55,000
3	Medium	Annamaya Project	Completed	22,500
4		Bahuda Reservoir Project		2,880
5		Pedderu Reservoir Project		4,300
6		Jerrikona Project		4,900
7		Pincha Project		3,773
8		Veligallu Project	Ongoing	24,000
9	Minor	Minor Lift Irrigation Schemes under APSIDC (2 Nos)		200
10		Minor Irrigation Tanks - 181Nos *(Ayacut above 100 Acres)*	Completed	64,337
11		Minor Irrigation Tanks - 3557Nos *(Ayacut bellow 100 Acres)*		57,062
			Total:	4,94,302

Data source: WRD, APWRIMS, Govt. of A.P.

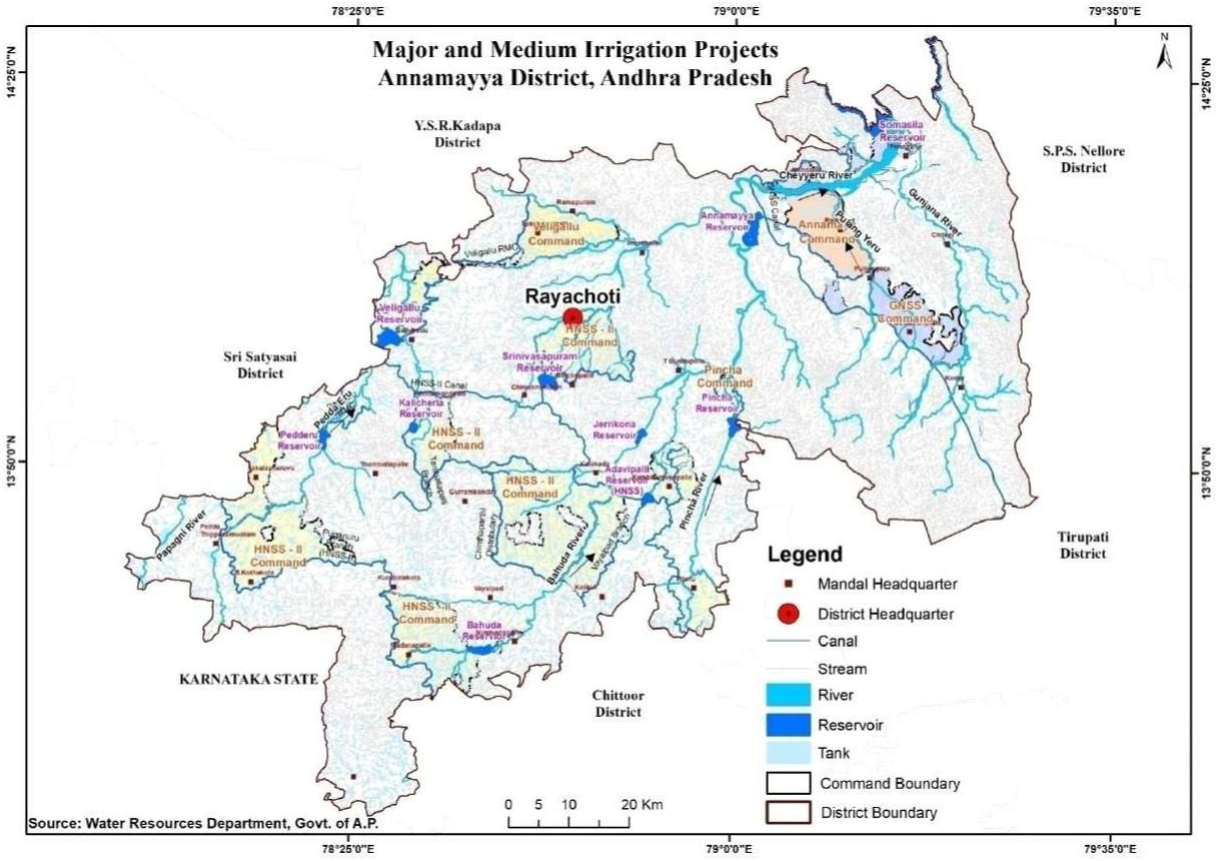


Fig. 1.9. Major and Medium Irrigation Projects of Annamayya District

1.9.2. Status of Groundwater development

The dug wells are generally circular or rectangular in shape and generally down to 10 m depth. The shallow bore wells for hand pumps are generally down to 60 m. Deep bore wells with 162 mm diameter were drilled down to 300 m in non-command areas and down to 100 m in command areas. The dug wells are fitted with centrifugal pumps of 5 to 7.5 HP whereas the shallow bore wells where water levels are shallow are fitted with hand pumps for drinking and domestic purposes. The irrigation bore wells are fitted with submersible pumps ranging from 5 to 20 HP. Most of the irrigation is through ground water in the district. Around 86% of the total irrigation is through ground water of which 81% is through bore wells and filter points and 5% through dug wells.

1.10 Prevailing Water Conservation/Recharge Practices: In the district there are **~70733** water conservation structures. 3089 Minor Irrigation Tanks, 1034 percolation tanks, 3938 Check dams, 50230 farm ponds and others 15531 exist in the district.

1.11 Geology: The Annamayya District is underlain by various rock types belong to Late Archaean or Early Proterozoic era which are succeeded by rocks of Dharwarian Age and both

are traversed by dolerite dykes. The older rocks are overlain by rocks of Cuddapah Super group and Kurnool Group belonging to Middle and Upper Proterozoic Age. The Cuddapah Sedimentary Basin, which is a huge depression formed over the denuded surfaces of older rocks extending into neighbouring districts occupies the major part of the district. The major rock types are quartzites, shales, limestones, phyllites, granites, granodiorites and granite gneiss. The Archaean comprises the Peninsular Gneissic Complex, represented by granite, granodiorite, granite-gneiss and migmatite. These rock types occur in the southwestern part of the district. Both the Archaean and Dharwar are traversed by dolerite dykes and quartz reefs. Alluvium consisting of gravel, sand, silt and clay occur along the river courses in the district shown in (**Fig1.11**).

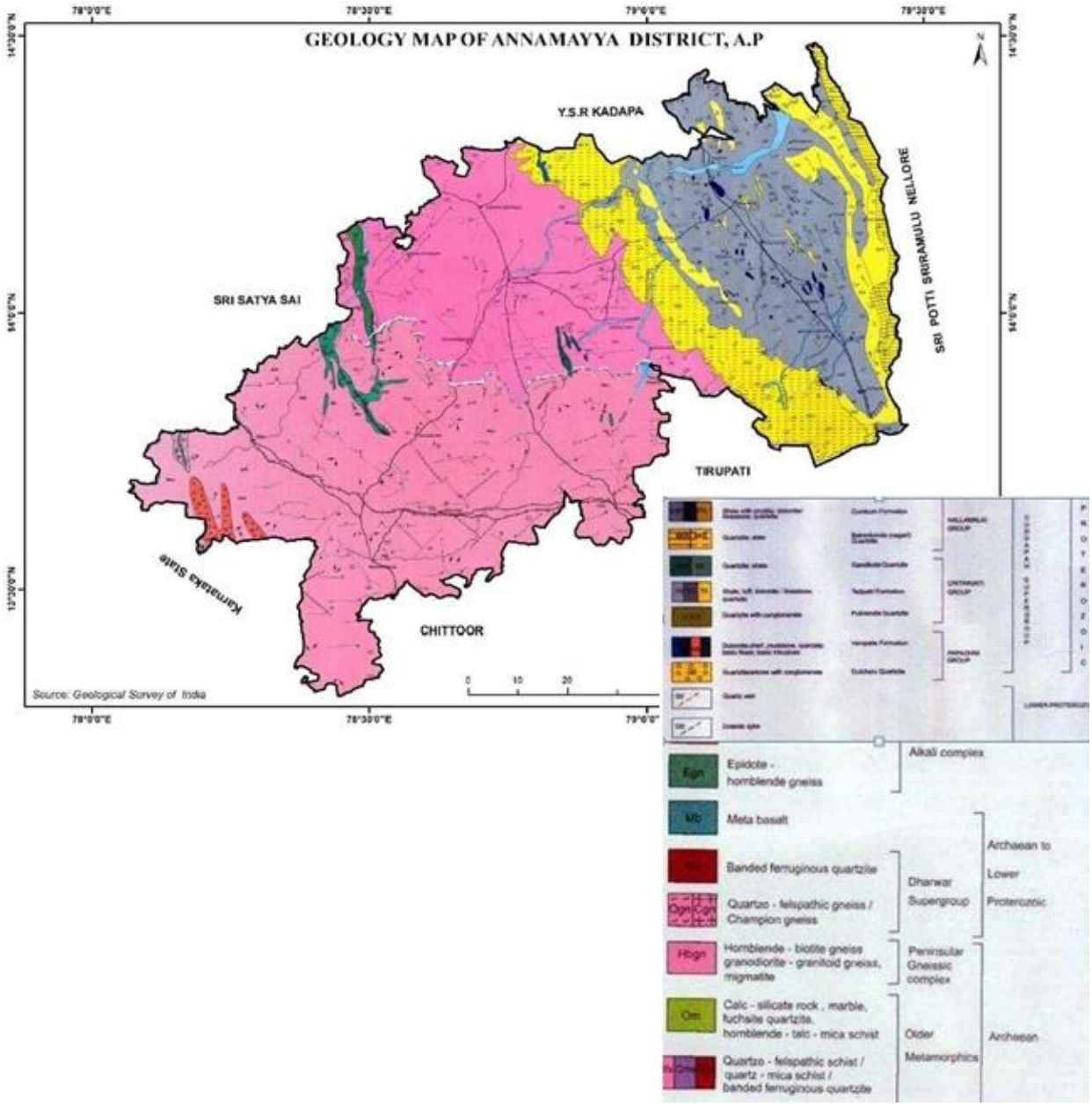


Fig.1.11: Geology map of Annamayya district

2. DATA COLLECTION AND GENERATION

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

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

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

2.1 Hydrogeological Studies

Hydrogeology is concerned primarily with mode of occurrence, distribution, movement and chemistry of ground water occurring in the subsurface in relation to the geological environment. The occurrence and movement of water in the subsurface is broadly governed by geological frameworks i.e., nature of rock formations including their porosity (primary and secondary) and permeability. The principal aquifer in the area is granites gneisses, 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 84 hydrogeological data points (**Fig.2.1)** hydrogeological map is prepared.

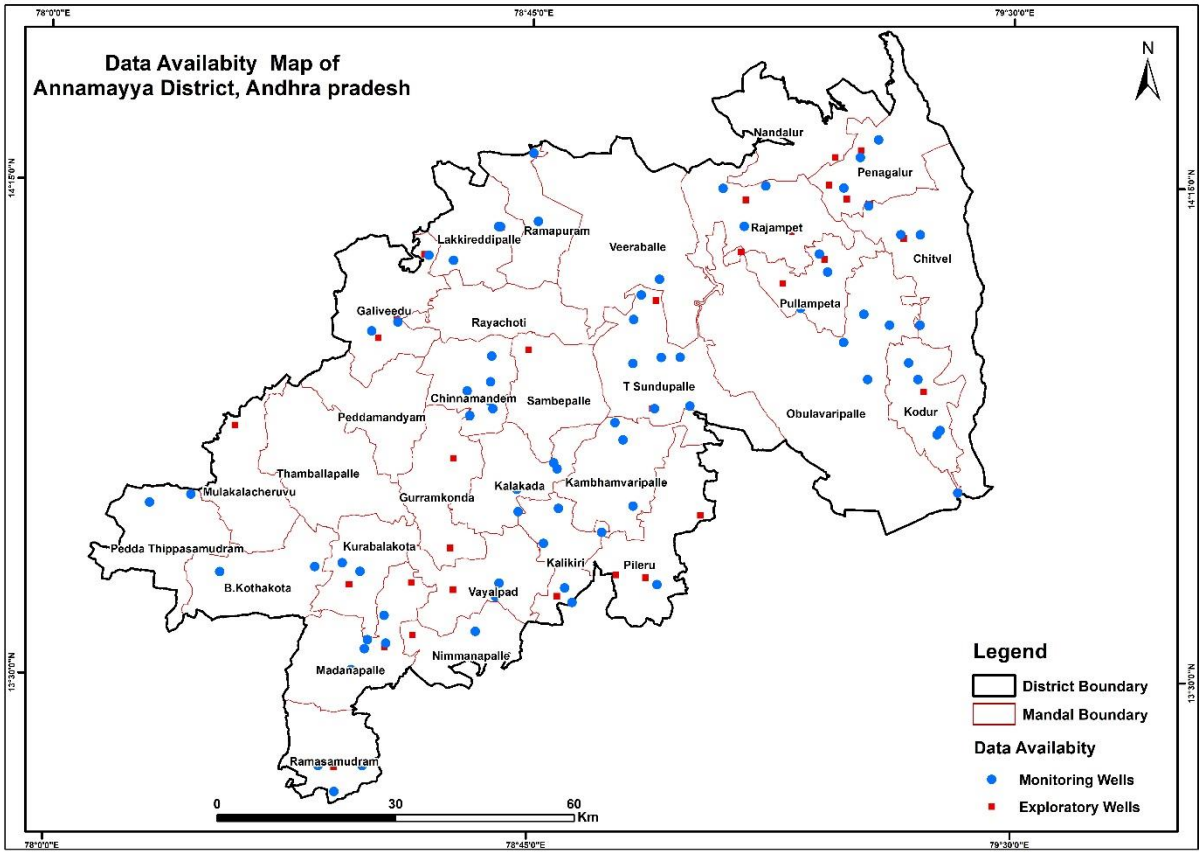


Fig. 2.1: Hydrogeological data availability.

2.1.1 Ground water occurrences and movement: Ground water occurs under unconfined and semi-confined/confined conditions and flows downward from the weathered zone into the fracture zone. The main aquifers constitute the weathered zone at the top, followed by a discrete anisotropic fractured/fissured zone at the bottom, generally extending down to 200 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.The thickness of weathered zone generally extends upto 10m. in most of the granitic area. Ground water in fractured zone is developed through construction of shallow/deep bore wells. Ground water in metasediments occurs under water table conditions in weathered portion of the formation and the thickness of weathered portion is around 10 m.bgl. Ground water in fractured zone is developed through construction of deep bore wells down to a depth of 200 m.bgl.

At present, extraction is mainly through boreholes of 60-100 m depth, with yield between <0.2 and 7 litres/second (lps). ~ 87 % of fractures occur below 100m depth and deepest fracture is encountered in shales at the depth of 187 m (Penagaluru mandal) and in Granites at the depth of 191 m depth (Chinnamandem mandal). The hydrogeological & Aquiferwise map of the area is presented in **Fig. 2.2a** and **Fig 2.2b**.

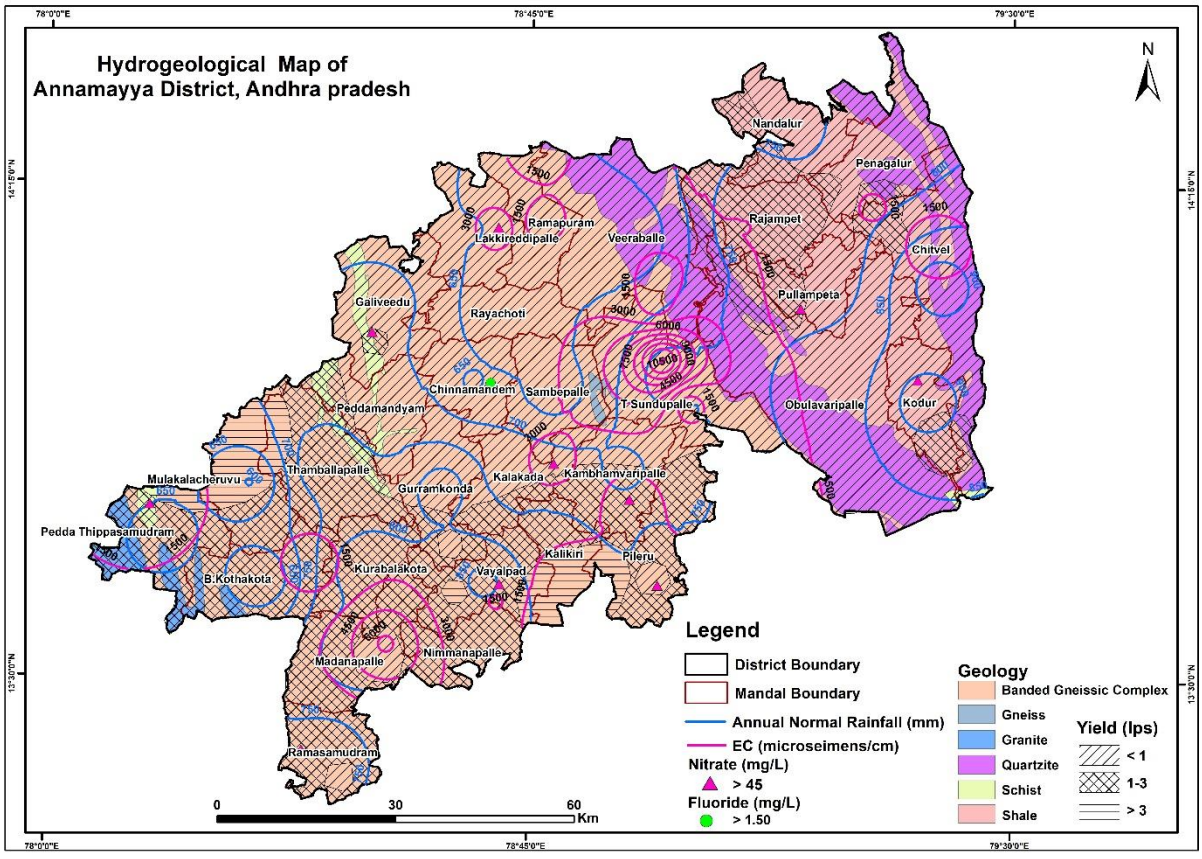


Fig.2.2a: Hydrogeological map of Annamayya district.

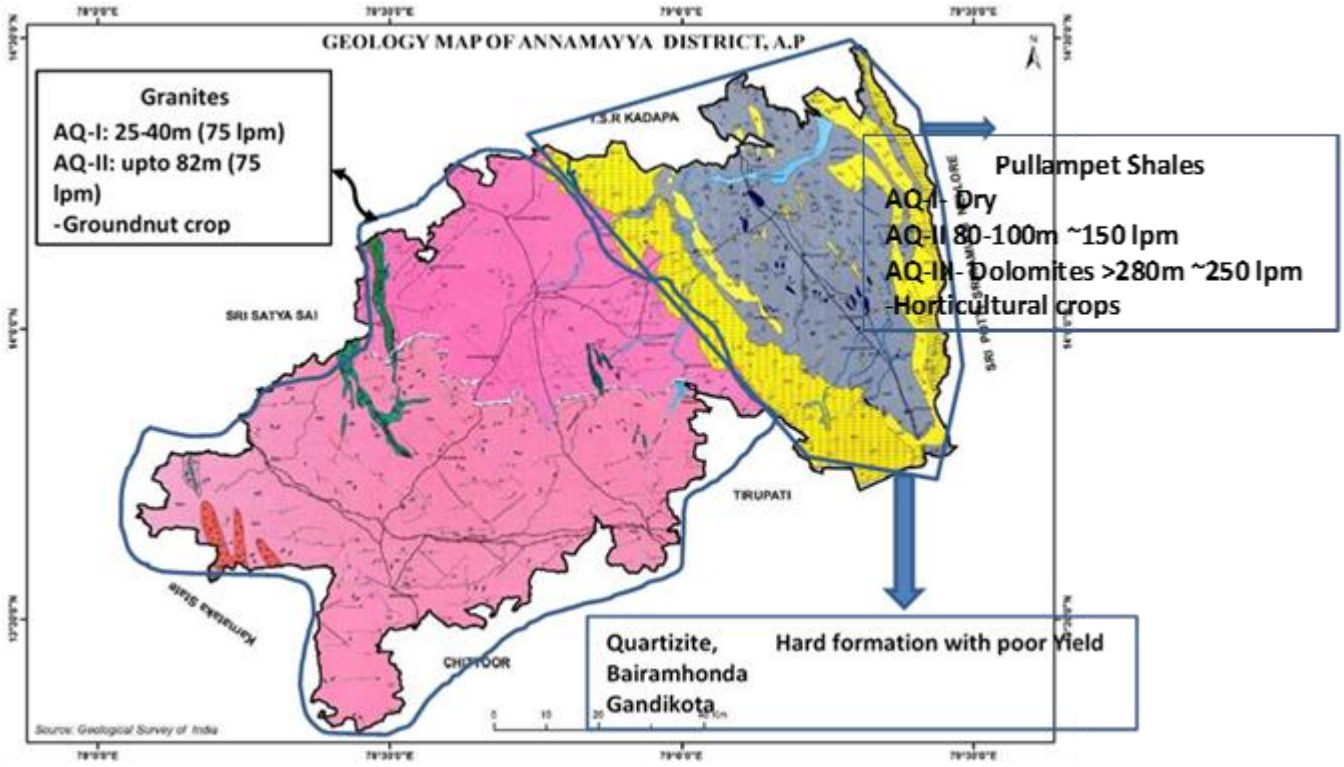


Fig. 2.2b: Geologically and Aquifer Wise discharge map

2.1.2 Exploratory Drilling: As on 31/03/2022, CGWB drilled 28 bore wells (exploratory, observation and piezometers), 19 wells were drilled in metasediment area and 9 wells were drilled in granitic area. 28 nos of wells data analysed from CGWB wells indicates that deepest depth (200m) within the deepest fracture encountered at 187m.bgl of Penagaluru mandal. 05 nos of exploratory borewells shows high yielding which was handed over to rural water supply (RWS) for drinking water supply to the village/mandal in the district. The details of Exploration borewells drilled by CGWB are given in Annexure-III. **2.1.2.2**

Ground Water Exploration in Pincha Basin: Total 22 nos of exploratory borewells were constructed by State Govt & CGWB in the basin down to a maximum depth of 200 m bgl. The yield of bore wells ranges from 0.01 to 7 lps. The specific capacity of the bore wells ranges from 5-79 lpm/m/dd. The transmissivity and storativity ranges from 2 to 166 m^2/day and1.37 x 10^{-4} to 1.58 x 10^{-3} respectively. Out of 22 exploratory wells, 7 wells yielded <1 lps, 5 yielded 1 to 3 lps, 5 wells yielded 3 to 5 lps and 4 wells more than 5 lps discharge. In the basin deep fractures rarely occur.

Ground Water Exploration in Bahuda Basin: Total 29 nos. exploratory borewells were constructed by State Govt. Department and CGWB down to a maximum depth of 200 m with 0.2 to 8.4 lps yield. The specific capacity ranges from 7 to 45 lpm/m/dd. The transmissivity and storativity ranges from 1 to 489 m^2/day and 1.4 x 10^{-4} to 2.7 x 10^{-3} respectively. In this basin deeper fractures rarely occur.

2.1.3 Ground water Yield: Ground water yield of granitic aquifers varies varies from <0.01 to 2 lps (avg: < 0.2 lps) and metasediment aquifers varies from <0.1 to 11 lps (avg: 1.5 lps). Wells located in the non-command area where yields are relatively low with sustainability for 2-3 hrs (**Fig.2.2).**

2.2 Water Levels: Ground water levels from 67 nos. of piezometers were monitored for pre-monsoon and post-monsoon season.

2.2.1 Water Table Elevations: During pre and post-monsoon season (May and November), the water-table elevation ranges from 97.41-794.62 and 102.09 to 794.02 meter above mean sea level (m amsl) respectively and general ground flow is towards Pennar river i.e towards NE and from south to northern parts and from East to North eastern parts of the district (**Fig.2.3**).

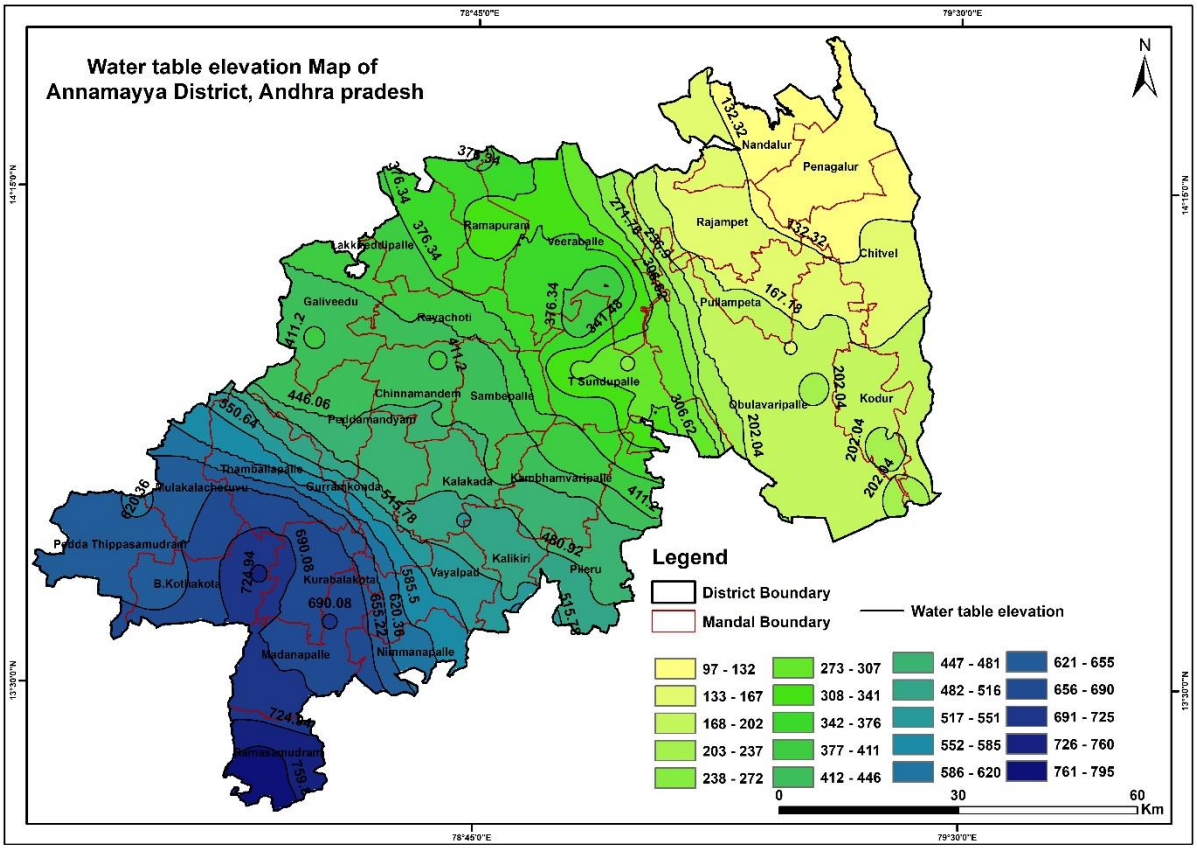


Fig.2.3: Water table elevations (m amsl) during pre and post-monsoon seasons.

2.2.2 Depth to Water Levels (DTWL): The average DTWL of 10 years (2013 to 2023) for pre-monsoon and post-monsoon were analysed, The avg. DTWL varies from 0.38 to 51.5 meter below ground level (m bgl) (average: 12.22 m bgl) and 0.98 – 80.25 m bgl (average: 14.01 m bgl) during pre and post-monsoon seasons respectively.

Pre-monsoon season: Majority of the water levels during this season are in the range below 10m was covering 55% of the area, 10-20 m covering 24% of the area, followed by 20-40 m bgl (20%). Deep water levels > 40 m.bgl occupy about 1% of the area falling in parts of Madanapalle mandal (**Fig.2.4**). Shallow water levels < 5 m.bgl occupy 29% of the area in parts of 22 mandals.

Post-monsoon season: Majority of the water levels during this season are in the range of 10-20 m covering 35% of the area, followed by 5-10 m bgl (37%). Deep water levels in the range of 20-40 m bgl occupy about 7% of the area and Deep water levels > 40 m.bgl occupy about 7% of the area falling in parts of Kalikiri, Chinna Mandem, Rajampet, Rajampet mandals (**Fig.2.5**). Shallow water level < 5 m.bgl occupy 14% of the area in parts of Ramasamudram, Galiveedu, Lakkireddypalli, Nimnapalle, Kalikiri, Vayalpad, Veeraballe, B. Kothakota, T Sundupalle, Kodur mandals.

2.2.3 Water Level Fluctuations (May vs. November): The water level fluctuations vary from -15 to 25.72 m with average rise of 0.095 m (**Fig.2.6**). 62% (48 nos) of the wells show rise in water level and 38% (30 nos) of wells show fall in water level. In general, it is observed has Fall in water level is recorded only in 9% of the area whereas rise in water levels is observed throughout the district covering 91% of area. Rise in water level range of 2 to 5 m covers majority of the area with 38% followed by 5 to 10 m, 0 to 2 m and 10 to 15 m in 19%, 33% and 08% of the areas respectively. Rise of water levels > 15 m. is observed only in 2% of area in parts of Chinna Mandem mandal.

2.2.4 Long term water level trends: Trend analysis for the last 12 years (2011-2023) is studied from 32 hydrograph stations of CGWB. It is observed that during pre-monsoon season 17 wells shows falling trend (0-1:10, 1-2 m: 2 and >2 m: 3 wells) (max fall: 1.5 m/yr) and 02 wells shows rising trend (0-1:2,) (max rise: 0.87 m/yr). During post-monsoon season 29 wells show falling trend (0-1:18, 1-2 m: 2 and >2 m: 9 wells) (max fall: 1.5 m/yr) and 03 wells shows rising trend (0-1:2, > 2:1) (max rise: 1.2 m/yr). The graphical representation of fall and rise is shown in **Fig 2.7** and spatial distribution map is shown in **Fig 2.8**.

2.3 Geophysical Studies A total of 35 VES data is interpreted, which reveals resistivity < 100 ohm (Ω) m for the weathered granite (1-30 m), 60-350 Ω m for underlying fractured granite with maximum thickness of 84 m and > 350 Ω m for massive granite. Resistivity < 150 ohm (Ω) m for the weathered Meta-sediments (1-20 m), 50-300 Ω m for underlying fractured Meta-sediments (70-100m) and > 300 Ω m for massive Meta-sediments.

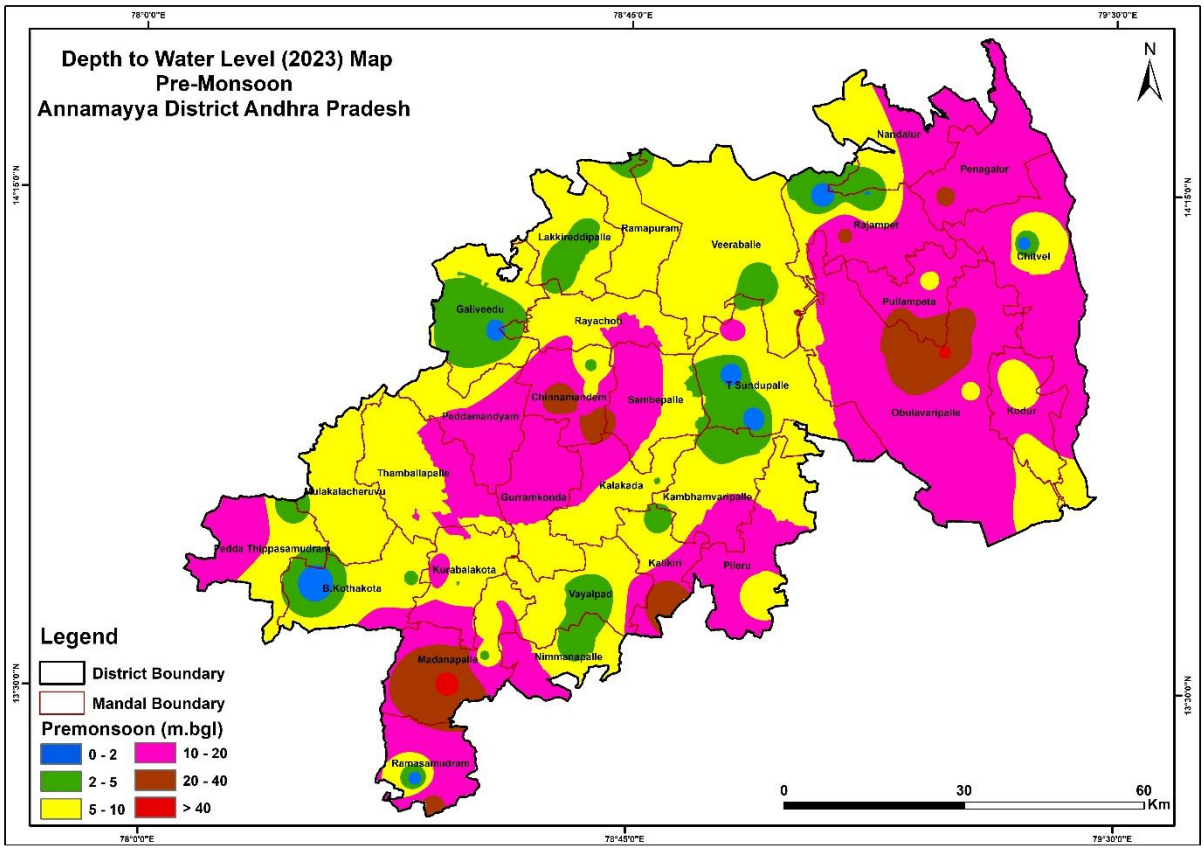


Fig.2.4: Depth to water levels Pre-monsoon (Average).

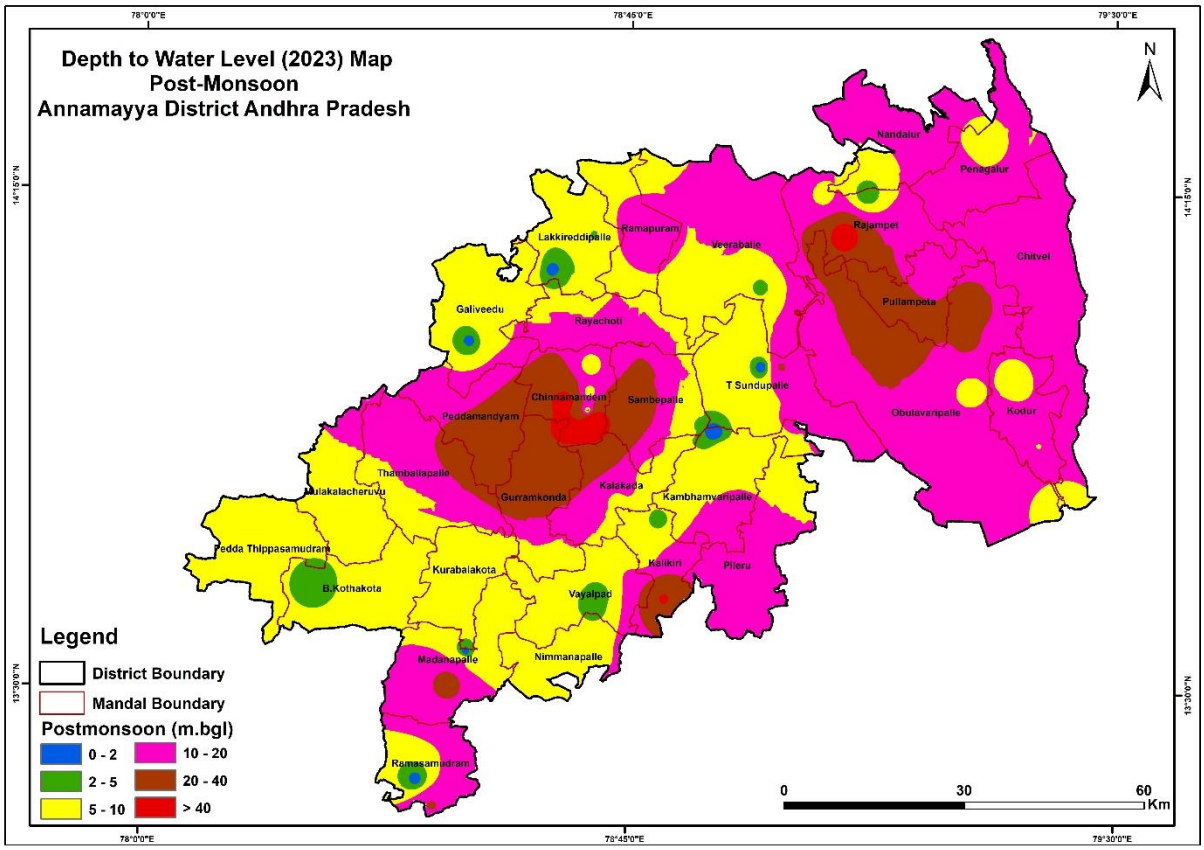


Fig.2.5: Depth to water levels Post-monsoon (Average).

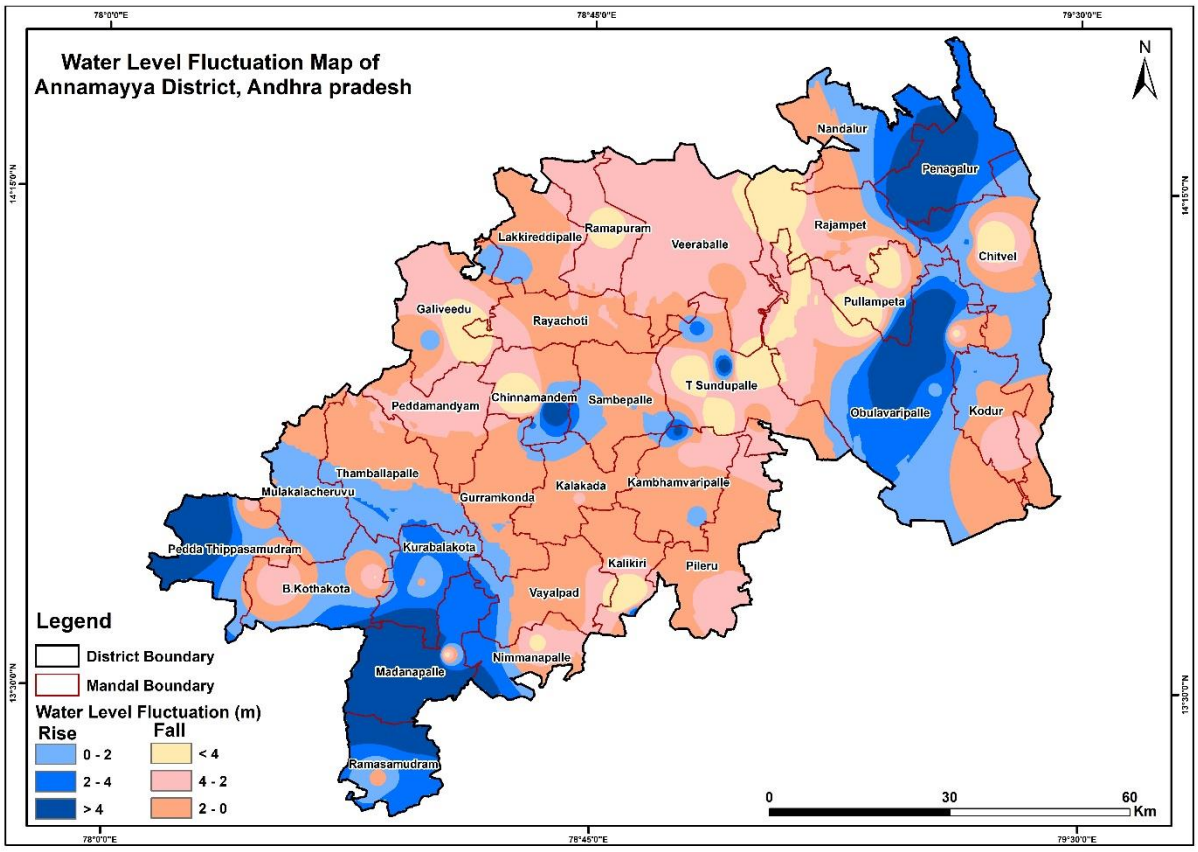


Fig.2.6: Water Level Fluctuations (m) (Nov with respect to May).

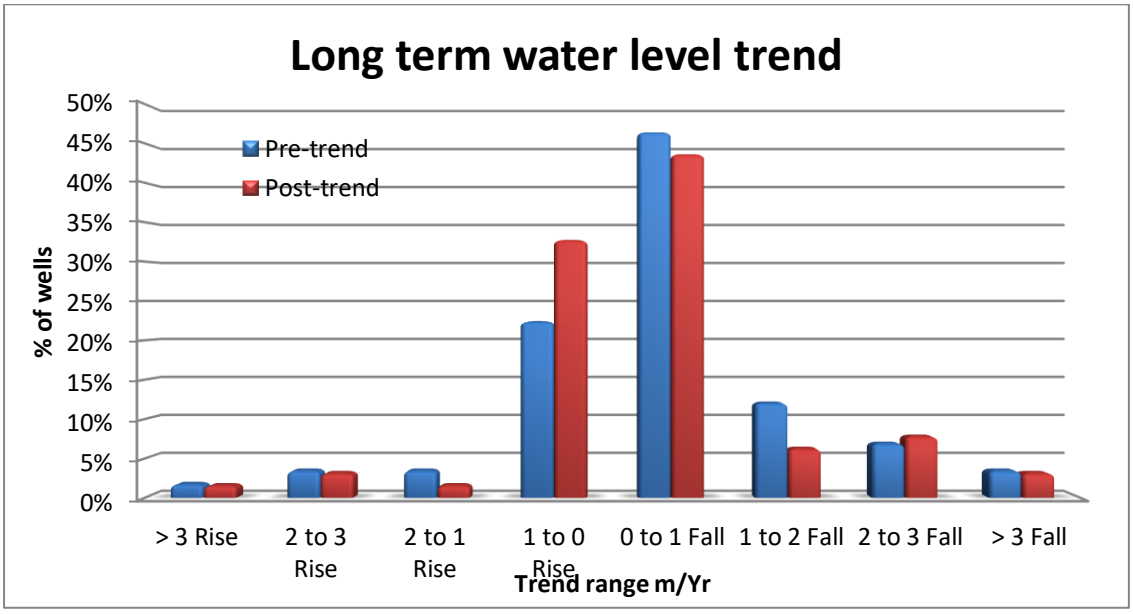


Fig. 2.7: Graphical representation of water level trends (2009-2018).

2.4 Hydro chemical Studies

To understand chemical nature of groundwater, 40 water sample data is utilized from ground water monitoring wells of CGWB (Pre-monsoon:40), these wells are mostly tapping combined aquifers Aq-1 and aq-2. During the pre-monsoon season of 13 parameters which comprises of pH, EC (in µS/cm at 25° C), TH, Ca, Mg, Na, K, CO_3, HCO_3, Cl, SO_4, NO_3 and F were analyzed.

2.4.1 Pre-monsoon: (Total 40 samples were analyzed of CGWB):

Groundwater from the area is neutral to alkaline in nature with pH in the range of 7.00-8.28 (Avg:7.46). Electrical conductivity varies from 350-12100 (avg: 1687) µ Siemens/cm**.** In 68% of area EC is within 1500 µ Siemens/cm, in 22% area, it is 1500-3000 µ Siemens/cm and in 10% area, it is > 3000 µ Siemens/cm (**Fig.2.9).** Nitrate concentration in 25% of samples is beyond permissible limits of 45 mg/L (**Fig.2.10**). Fluoride concentration varies from 0.104-2.074 mg/L (**Fig 2.11**) and 97.50 % of samples are within permissible limits of BIS and rest is beyond permissible limit of 1.5 mg/L. High fluoride concentration is observed in Chinnamandem mandal of the district.

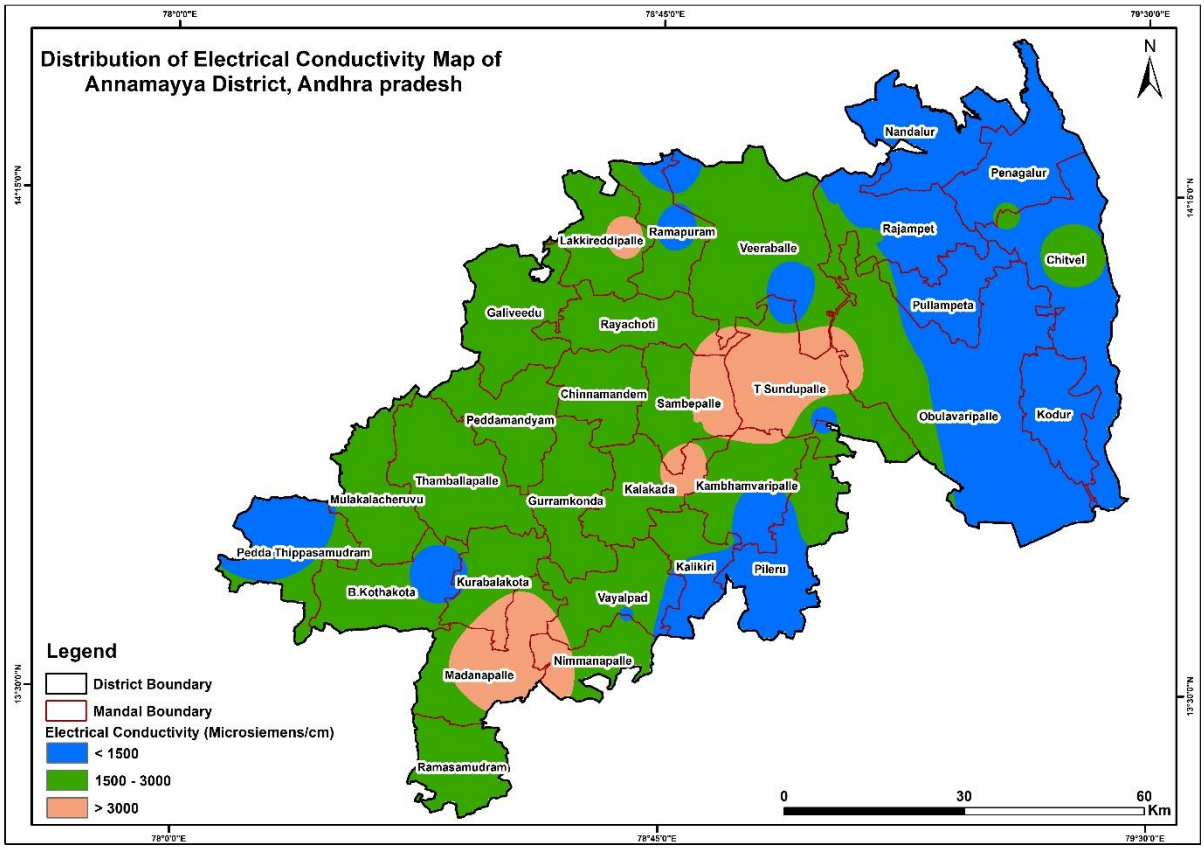


Fig.2.9: Distribution of Electrical conductivity (Pre-monsoon).

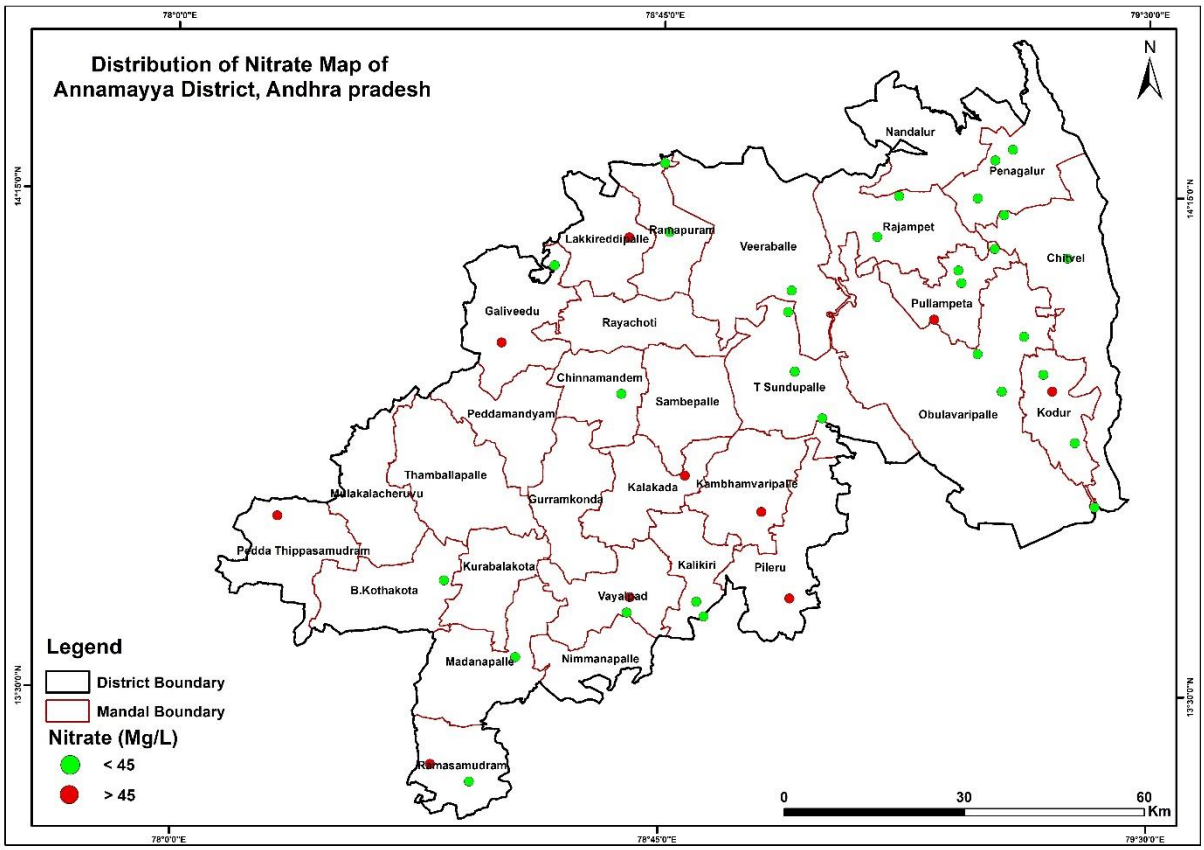


Fig.2.10: Distribution of Nitrate (Pre-monsoon).

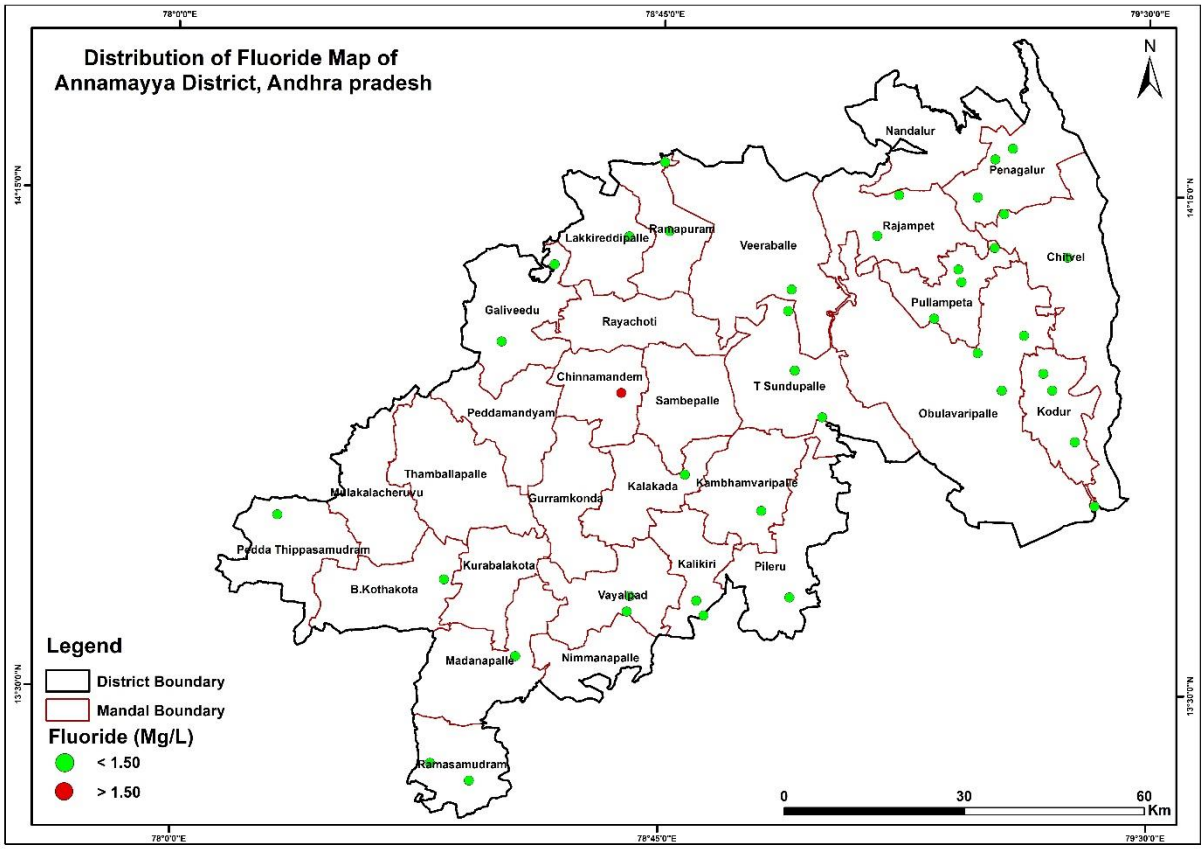


Fig.2.11: Distribution of Fluoride (Pre-monsoon).

3. DATA INTERPRETATION, INTEGRATION AND AQUIFER MAPPING

Conceptualization of 3-D hydrogeological model was carried out by interpreting and integrating representative 78 data points (both hydrogeological and geophysical down to 200 m) for preparation of 3D map, panel diagram 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-16 software and generated 3-D map for Annamayya district (**Fig.3.1)** and hydrogeological sections.

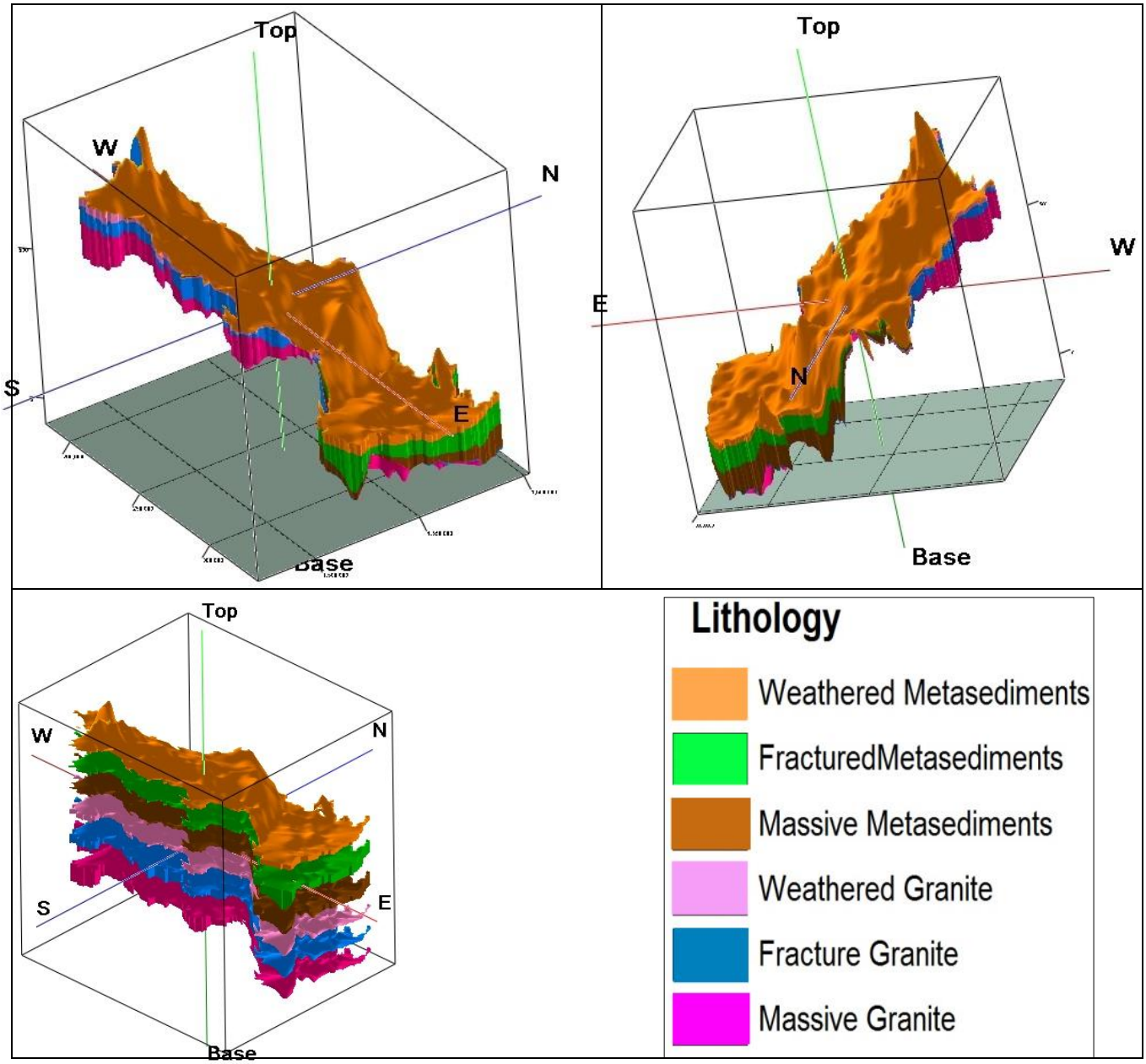


Fig.-3.1:3D Model for study area.

3.1 Conceptualization of aquifer system in 3D

Aquifers were characterized in terms of potential and quality based on integrated hydrogeological data and various thematic maps. Weathered zone is considered up to the maximum depth of weathering and first fracture encountered (below weathered depth) generally down to ~25 m depth and the fractured zone (fractured granite) is considered up to the depth of deepest fracture below weathered zone (~25-196 m).

3.2 Hydrogeological Sections

Hydrogeological sections are prepared in NW-SE, SW-NE and W-E directions (**Fig. 3.2**).

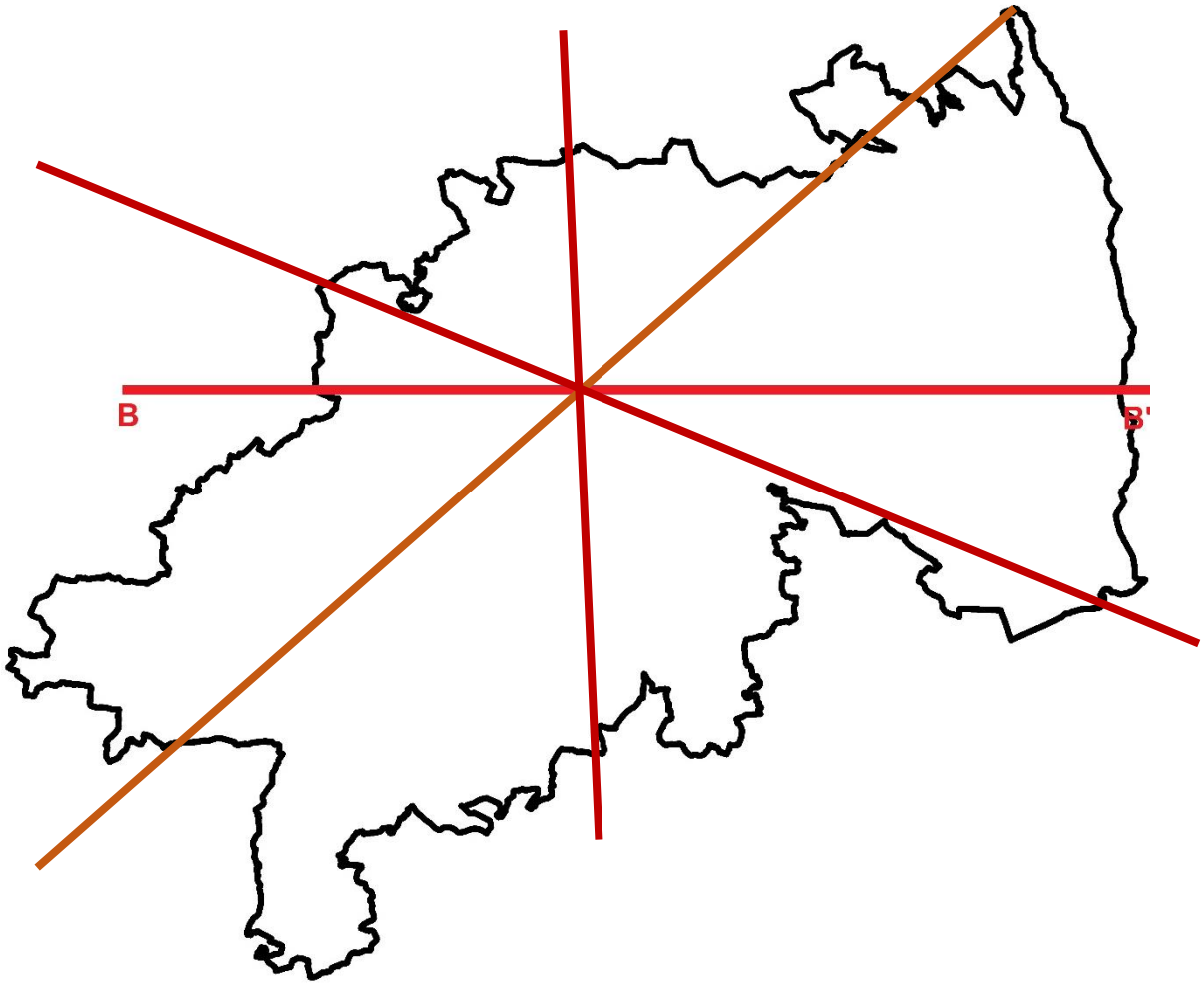


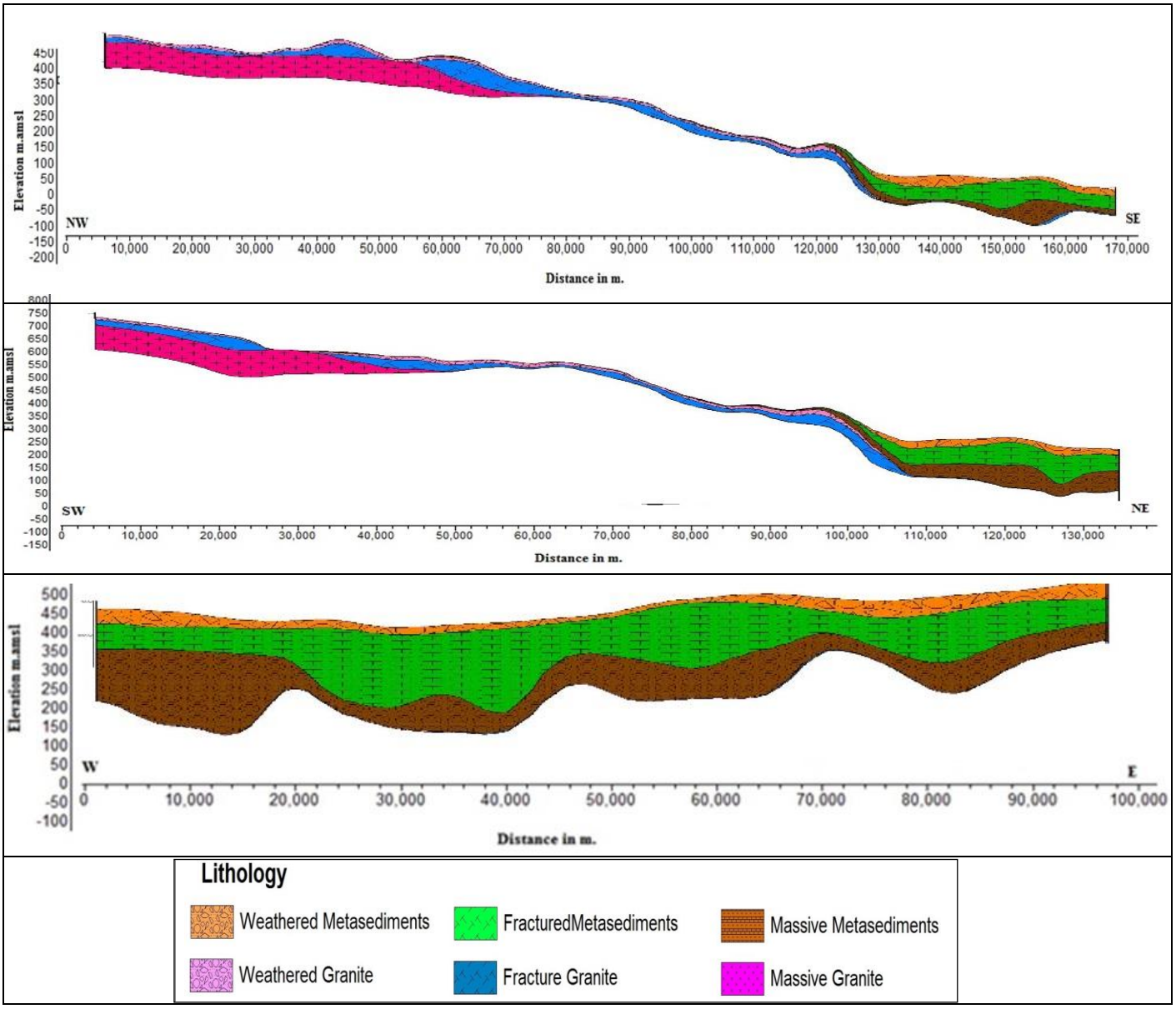
Fig.-3.2: Map showing orientation of hydro geological Sections

3.2.1 South-West and North-East Section: The section drawn along the SW-NE direction covering distance of ~140 kms (**Fig.3.3a**). It depicts thick fractured zone overlaid by thin weathering zone in granites extending upto ~45 Km from SW. Thick fractured zone in metasediments is seen in central part of the section averlaid by thick weathering zone.

3.2.2 North-West and South-East Section: The section drawn along the N-S parts covering distance of ~175 kms (**Fig.3.3b**). It depicts thick weathered zone in the NW and SW part along with thick fracture zones and in the central part with thin fractured zone on no much weathered rock.

3.2.3 West-East Section: The section drawn horizontally along the W-E direction covering distance of ~100 kms (**Fig.3.3c**).It depicts thick weathered zone in South and North part. Thin fractured zone in seen cental part of section and thin fracture zones in the central and eastern part.

Fig.3.3 (a-c): Hydrogeological profile in different directions in Annamayya district.



3.3 Aquifer Characterization

3.3.1 Weathered zone: The Weathered zone (~25 m) consisting of upper saprolite (~6 m) and lower sap rock (6-18m.) with discharge varies from meagre to 2 m.bgl in granitic formation and meagre to 12 lps in metasediments rocks of quartzite, shale and limestone. At certain parts of the area considerably discharge decreases to dry due to over exploitation and no recharge. Spatial distribution of weathering depth zone map is given in **Fig.3.4**. Thickness of weathered zone is in the range of 10-20 m in most part of area covering ~66 % of area, shallow weathering (< 10 m) occurs in 21 % of the area and deep weathering (> 20 m) occurs in rest of the area (**Fig.3.5**). Shallow weathering mostly seen in granitic areas along the SW boundary of the district.

Ground water yield from weathered granite/gneiss aquifer varies from <0.1 to 1 lps (avg: 0.18 lps) in granites and from 0.01 to 4 lps (avg: 1.0 lps) in metasediments. The transmissivity varies from 1-14 m^2/day in granites and upto 53 m^2/day in weathered metasediment aquifer.

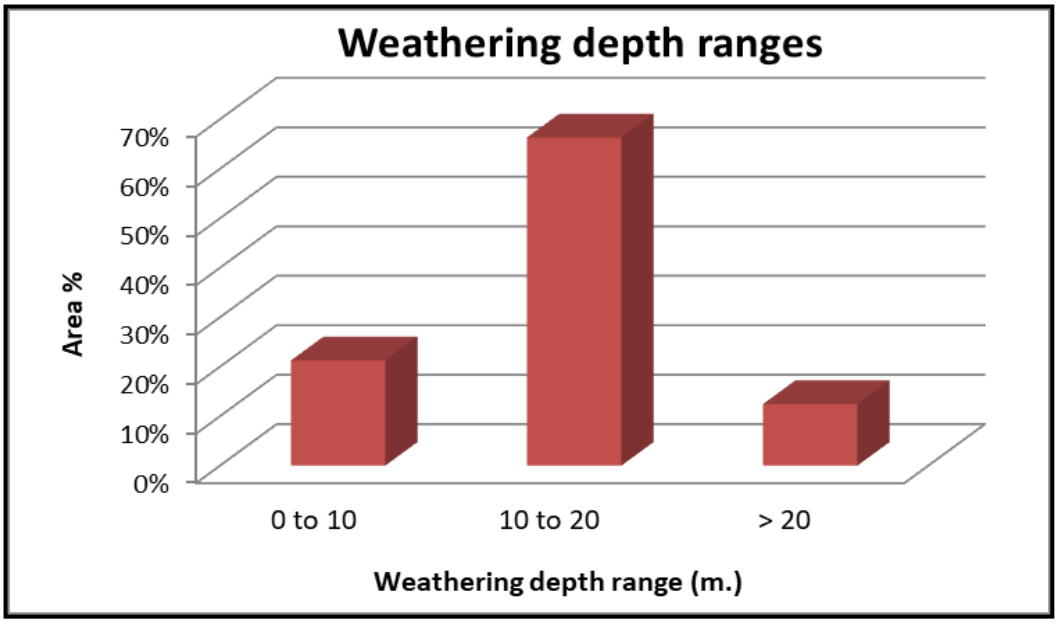


Fig.3.5: Depth wise weathered zone distribution

3.3.2 Fractured zone: Ground water is extracted mainly through bore wells of upto 200 m depth from fractured zone (~9 to 192 m). CGWB data, it is inferred that fractures in the range of < 100 m depth are more predominant (43 % of the area), 100-150 fractures occur in 28 % and > 150 m. fractures occur in 29% of area respectively and deep fractures in the range of > 150m. Occur in Chitvel, Kodur, Penagaluru., Rajampet, Sambepalle and Chinnamandem mandals. Analysis of occurrence of fractures (from 28 wells) reveal that majority of fractures (~43 %) occur within 100 m depth.

Groundwater yield of fractured granite/gneiss varies from 0.01 to 2 lps (avg: 0.18 lps) and meta sediments (Quartzite, Shale and Limestone) varies from 0.01 to 11.72 lps (avg: 1 lps). Wells located in the command area have higher yield (1-6 lps) and sustains for more hours of pumping as compared to non-command area where yields are relatively low and sustains for 1-3 hrs. The transmissivity varies from 1-910 m^2/day. Stotativity of the fracture zone varies from 0.0001 to 0.00001.

4. 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 (WZ) and fractured zone (FZ) 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 command/ non-command area and mandal wise resources are given in ***Table-4.1***.

As per 2023 GEC report, the net dynamic replenishable groundwater availability is 846 MCM, gross ground water draft for all uses 414 MCM, provision for drinking use for the year 2025 is 50 MCM and net annual ground water potential available for future use is 419 MCM. Stage of ground water extraction in the district is 49%. 02 mandals (Chitvel & Chinnamandem) fall in semi critical category and remaining 28 mandals fall in safe category. Mandal wise stage of ground water development varies from 29% (Veeraballe mandal) to 89% (Chinnamandem mandal) with average of 51%. Based on 2023 resources, mandal categorization map is given in **Fig. 4.1.**

.

Table-4.1: Computed Dynamic ground water resources.

As per GEC 2023	MCM
Dynamic (Net GWR Availability)	**846**
• Monsoon recharge from rainfall	465.44
• Monsoon recharge from other sources	204.48
• Non-Monsoon recharge from rainfall	7.13
• Non-monsoon recharge from other sources	213.47
Gross GW Draft	**414**
• Irrigation	379.18
• Domestic and Industrial use	34.10
Provision for Drinking use for the year 2025	50
Net GW availability for future irrigation	419
Stage of GW development (%)	**49%** Min : 29% (Veeraballe) Max : 86% (Chinnamandem)

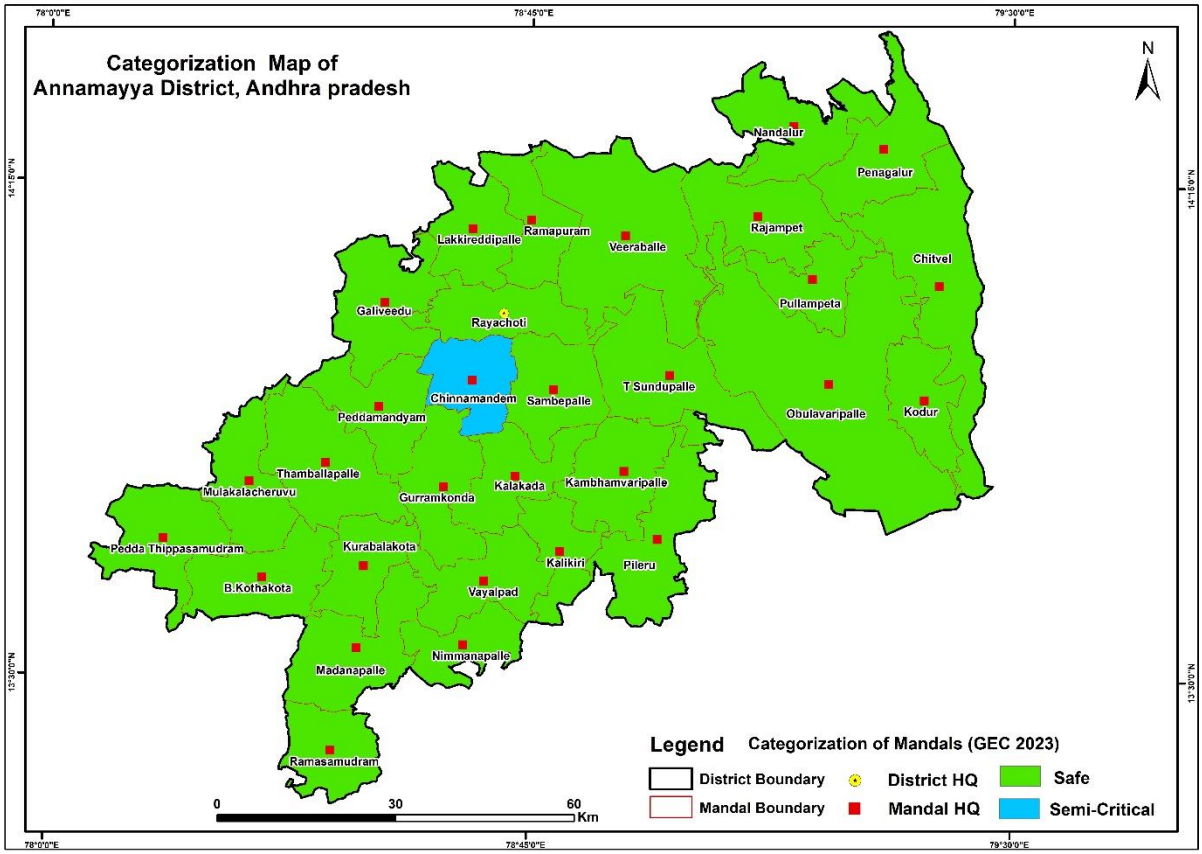


Fig.4.1: Categorization of mandals (GEC 2023).

5. GROUND WATER RELATED ISSUES AND REASONS FOR ISSUES

5.1 Issues

Deep water levels

1. Deep water levels (> 20 m bgl) are observed during pre as well as post-monsoon season in 21 % and 16% of the area respectively.

2. Out of 64 wells analysed, 40 wells during pre-monsoon 39 wells during post-monsoon shown falling trend in the last 10 years (@-0.02 to -3.3 m/yr and -0.04 to -3.8 m/yr) respectively.

Sustainability

4. Low yield (<1 lps) occurs in ~53 % 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.

Pollution (Geogenic and Anthropogenic)

5. Chinnamandyam mandal show fluoride (geogenic) as high as 2.01 mg/L during pre-monsoon season is found in groundwater. The high fluoride concentration (>1.5 mg/L) occur in 2% of the samples during pre-monsoon season.

6. 10 mandals show Nitrate (Anthropogenic) as high as 362 mg/L during pre-monsoon season is found in groundwater. The Nitrate concentration (>45 mg/L) occur in 24% of the samples during pre-monsoon season.

7. The high concentration of EC (> 3000 micro-seimens/cm) in 10% of the area is observed during pre-monsoon season.

5.2 Reasons for Issues

Deep water levels

1. Low rainfall and limited artificial measures etc.

Sustainability

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

Geo-genic pollution (Fluoride)

3. 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.

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

6. MANAGEMENT STRATEGIES

More and more dependence on groundwater coupled with absence of augmentation measures has led to a steady fall in water levels and desaturation of phreatic aquifer (weathered zone) in some parts, raising questions on sustainability of existing groundwater structures (Borewells) for food and drinking water security. The occurrence of fractures in hard rocks are very limited in extent, as the low disintegration of the rocks in deeper depth reduces opening of fractures. The majority of fractures occur within 100 m depth (43%) (**Fig.3.7**). Higher NO_3^- concentrations (> 45 mg/L) in weathered zone is due to sewage contamination and higher concentration of F^- (>1.5 mg/L) in weathered zone and fractured zone is due to local geology (granite/gneiss rock), high weathering, longer residence time and alkaline nature of groundwater.

6.1 Management plan

The uneven distribution of groundwater availability and its utilization indicates that a single management strategy cannot be adopted and requires integrated hydrogeological aspects along with socio-economic conditions to develop appropriate management strategy.

In the district 604 MCM of unsaturated volume (below the depth of 5 m) is available during post-monsoon season, having 121 MCM of recharge potential (2%). This can be utilized for implementing management strategy.

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

6.1.1 Supply side measures:

Ongoing Projects

6.1.1.1 Repair, Renovation and Restoration of existing tanks (Competed):

De-silting of 0.55 MCM of silt from existing 906 (minor irrigation tanks and Percolation tanks) tanks are completed under state Govt. sponsored NEERU-CHETTU programme and created additional surface storage. This will contribute ~ 0.14 MCM to groundwater

(considering 25 % of recharge) and with this additional ~78 ha land can be brought under irrigated dry (ID) crops in tank ayacut.

6.1.1.2 Artificial Recharge structures:

To be taken up

Construction of 142 artificial recharge structures (ARS) in unsaturated zone of safe and critical mandals are suggested by following standard methodology.

While formulating the village wise groundwater management plan, the unsaturated volume of aquifer is estimated by multiplying the area with specific yield and unsaturated thickness (post-monsoon water levels below 5 m). Initially village wise dynamic groundwater resources of 2017 are considered (**Fig.4.1**). Potential surface run off is estimated by following standard procedures. On conservative side 20% run off yield is considered as non-committed yield for recommending artificial recharge structures, in intermittent areas 50% of yield is considered and remaining 50% is recommended for implementing water conservation measures in recharge areas through MGNREGS.

The pre-monsoon groundwater quality is considered for categorising contaminated area (F >1.5 mg/l & EC >3000 µ S/cm). Nitrate is not considered here because it is point source pollution and localized. Based on above criteria, the area which is having unsaturated zone needs to be intervention. Based on hydrogeological characteristics, the area is further sub-divided into following 8 categories (**Table-6.1**).

Table-6.1: Hydrogeological characteristics of area.

Category	Hydrogeologic characterizations
1	High EC with additional scope for artificial recharge.
2	High EC with no additional scope for artificial recharge.
3	High F with additional scope for artificial recharge.
4	High F with no additional scope for artificial recharge.
5	High EC and F with additional scope for artificial recharge.
6	High EC and F with no additional scope for artificial recharge.
7	Groundwater quality within permissible limits for drinking and irrigation with scope for artificial recharge.
8	Groundwater quality within permissible limits for drinking and irrigation with no scope for artificial recharge.

A**rea where groundwater development <100 %**

Area consisting of 463 villages with ~ 5354 Sq. Km rechargable areas (**Fig.6.1**) are considered where 121 MCM recharge potential and 78 MCM utilizable yield is avaialable. The area is again further divided into 8 categories based on hydrogeological characteristics as mentioned above (**Table-6.1)**. For sustainable development and management of groundwater resources, the recommendations are made and summarised in **Annexure-II**.

- 142 artificial recharge structures (0 CD's and 142 mini PT's (good and minor repair structures) exist in the area.
- In addition to the existing structures, 4972 artificial recharge structures (ARS) (0 CD's with shafts and 142 mini PT's with shafts) can be taken up.
- After effective utilization of this yield, there will be 78 MCM of ground water recharge with new structures.
- All existing artificial recharge structures are to be desilted and maintained properly.
- Roof top rainwater harvesting structures should be made mandatory to all Government buildings.

6.1.1.3 Other supply side measures:

- Existing ARS like percolation tanks and check dams categorized under major repair by the state Govt. need to be repaired.
- Existing ARS like percolation tanks and check dams and dried dug wells can be de-silted involving people's participation through the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) (NREGA 2005). This will also help in sustainable management of groundwater resources.

6.1.1.4 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 size of form ponds can be 10 x 10 x 3 m. In the district total 50230 farm ponds exist in 30 Mandals and additional 2778 farm ponds are recommended for 6 nos. in each village in 463 villages.

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

6.1.1.1 Proposed Work

- ~23,150 ha of additional land that can be brought under micro-irrigation @50 ha/village in 463 villages. With this 92 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).

- 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.

- To avoid the interference of cone of depression between the productive wells, intermittent pumping of bore wells is recommended through regulatory mechanism.

- Power supply should be regulated by giving power in 4 hour spells two times a day in the morning and evening by the concerned department so that pumping of the bore well is carried out in phased manner to allow recuperations of the aquifer and increase sustainability of the bore wells.

- As a mandatory measure, every groundwater user should recharge rainwater through artificial recharge structures in proportionate to the extraction.

6.1.3 Other measures

- 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.

6.2 Expected Results and Out come

With the above interventions likely benefit would be the net saving of 78 MCM of ground water. This will bring down the stage of ground water development by 05 % (from 24 % to 81 %). The other benefits will be more distribution of income among farmers.

Acknowledgment

The authors thank Chairman and Regional Director of the Central Ground Water Board, Goverment of India and RODC section and out-sourcing Sri Sai for preparation of maps. The authors acknowledge State Ground Water Department and Rural Water Supply department, Govt of Telangana for making available of field data.

Exploratory well details of deep wells (200m.) in Annamayya district *Annexure-III*

S.No.	Site	Mandal	Well type	Total depth	Weathered depth (m.bgl)	Deepest fracture (m.bgl)	Yield (lps)	Geology
1	Vishwanathpuram	CHINNAMANDEM	EW Aq-II	200	17.5	165.6	0.78	shale
2	Kesshapuram	CHINNAMANDEM	EW OF AQ-II	200	5.5	19.9	0.78	Granite
3	Padamaiona	CHINNAMANDEM	EW OF AQ-II	200	15	59	0.01	Granite
4	Besthapalli	CHINNAMANDEM	EW OF AQ-II	200	5.5	105.3	0.07	Granite & Dolerite
5	Kayalwandlapalli	CHINNAMANDEM	EW OF AQ-II	200	8.7	192	0.07	Granite
6	M.Rachepalli	CHITVEL	EW-II of AQ-II	200	25.6	166.2	0.58	Shale
7	Nakkalavandlapalli	GALIVEEDU	EW OF AQ-II	200	10	62.6	1.19	Granite & Dolerite
8	Gangarajupuram	KODUR	EW Aq-2	200	35.5	163.6	0.78	Shale/Limestone
9	Kokaladoddi	KODUR	EW of AQ-II	200	31	175.3	2.43	Shale
10	Somalavandlapalli	LAKKIREDDIPALLE	EW OF AQ-II	200	5.5	68	0.01	Granite
11	Lakkireddypalli	LAKKIREDDIPALLE	EW OF AQ-II	200	10.5	69	0.01	Granite
12	Kothachoparavaripalli	NANDALUR	EW Aq-II	200	23.5	74.1	4.25	Shale
13	Pulapatru	NANDALUR	EW Aq-II	200	11.5	86.3	6.71	shale/carbonaceous shale
14	Kothachoparavaripalli	NANDALUR	OW Aq-II	200	20	137.1	2.43	Shale
15	Erraguntlakota	OBULAVARIPALLE	EW of AQ-II	200	8.5	139.7	0.58	Shale
16	Kislampalle	OBULAVARIPALLE	OW	200	8	36.5	2.11	Shales
17	Penagalur	PENAGALURU	EW	200	20.8	133.3	2.9	Shale
18	Peramvaripalle	PENAGALURU	EW	208	17.5	187.3	0.59	Shales
19	Pullampet	PULLAMPETA	EW	200	11	66	0.08	Shale/Limestone
20	Annamayya	RAJAMPET	EW	200	16	141	11.72	Shale/Limestone

S.No.	Site	Mandal	Well type	Total depth	Weathered depth (m.bgl)	Deepest fracture (m.bgl)	Yield (lps)	Geology
21	Gundlur	RAJAMPET	OW 2	200.05	29.3	159.95	11.72	Shale/Limestone
22	Bramhanapalle	RAJAMPET	EW	200	2.1	134	0.01	Shales
23	Mannur	RAJAMPET	EW	200	11.85	137.2	6.2	Shales
24	Waddipalli	SAMBEPALLE	EW OF AQ-II	200	11.5	111.4	0.04	Granite
25	OW Of Aq-II At Machupally	SAMBEPALLE	OW Aq-II	200	17.5	178.8	6.71	Shale
26	Rayavaram	T SUNDUPALLE	EW OF AQ-II	200	17.7	18.7	0.01	Granite
27	Gundlapalli	T SUNDUPALLE	EW OF AQ-II	200	11.15	62.1	0.02	Granite
28	Appayagaripalli	T SUNDUPALLE	EW OF AQ-II	200	7.5	8.5	0.01	Granite