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भारत सरकार

Central Ground Water Board

Ministry of Water Resources, River Development and Ganga Rejuvenation

Government of India

AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES

Ananthpuram District, Andhra Pradesh

दक्षिणी क्षेत्र, हैदराबाद

Southern Region, Hyderabad

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

1.1 Objectives: In view of the above challenges, an integrated hydrogeological study was taken up to develop a 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 Ananthapuramuamu district, Andhra Pradesh having geographical area of 19,300 km^2, lies between north latitude 13°40´4"-15°14´46" and east longitude 76°47´12"-78°27´44" (**Fig.1.1**). Out of total area, the non-command area is 77 % and command area (13 %) and hilly area is 10 %. Administratively the district is governed by 63 revenue mandals and 964 revenue villages with a population of ~40.81 lakhs (2011 census) (urban: 26 %, rural: 74 %). The density of population is 213 persons/Km^2 and there is an increase in 12.1% growth rate over last 10 years (CPO**, Ananthapuramu, 2014**).

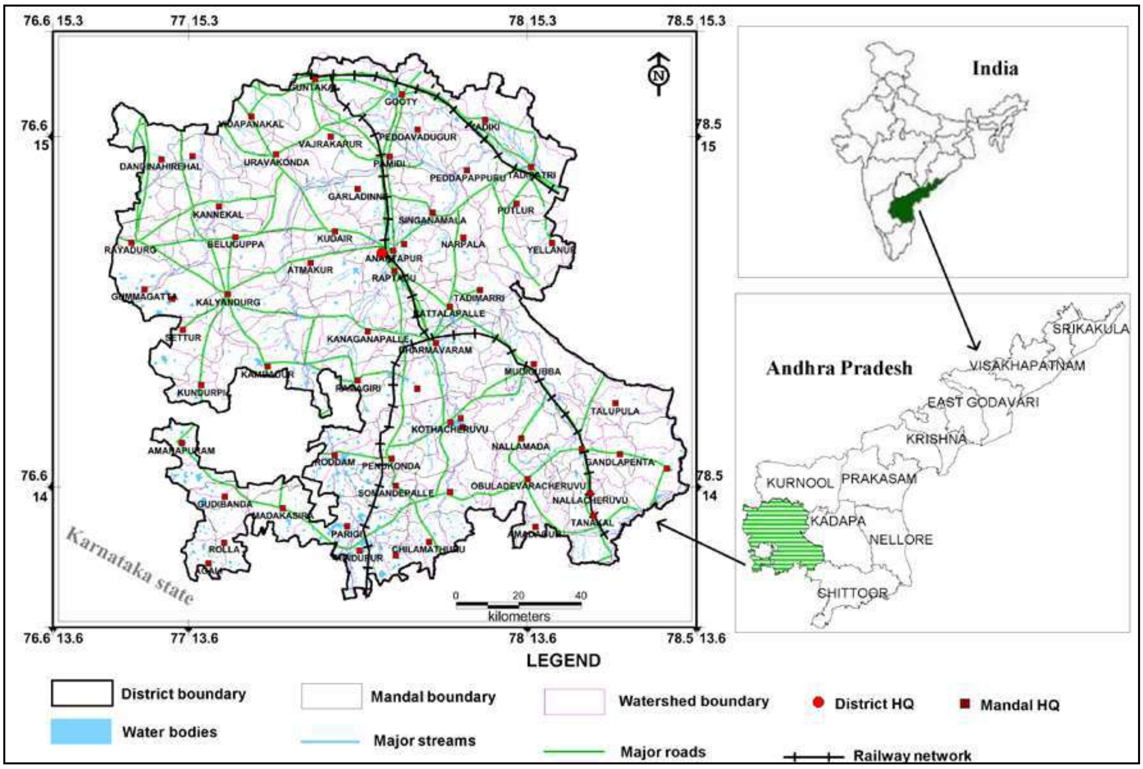


Fig.1.1: Location of Ananthapuramu district.

1.4 Climate and Rainfall: The climate of the district is characterised by hot summer and generally dry weather except during S-W monsoon season.The normal mean daily minimum and maximum temperature are 26 °C and 38.3 °C during May and 17.1°C and 30.2 °C during January. The normal annual rainfall of the district is 573 mm (Indian Meteorological Department). This varies between 341 mm (Atmakur) to 730 mm (Madakasira) (**Fig. 1.2**). The South west monsoon contributes ~56 %, North east monsoon contributes ~29%, and remaining by winter season. Rainfall increses from west to eastern part and low rainfall recorded in the central and northwestern parts. During the year 2013, 2014 and 2015 the district received rainfall of 501 mm (-13 % less), 438 mm (-24% less) and 706 mm (23 % more) rainfall respectively.

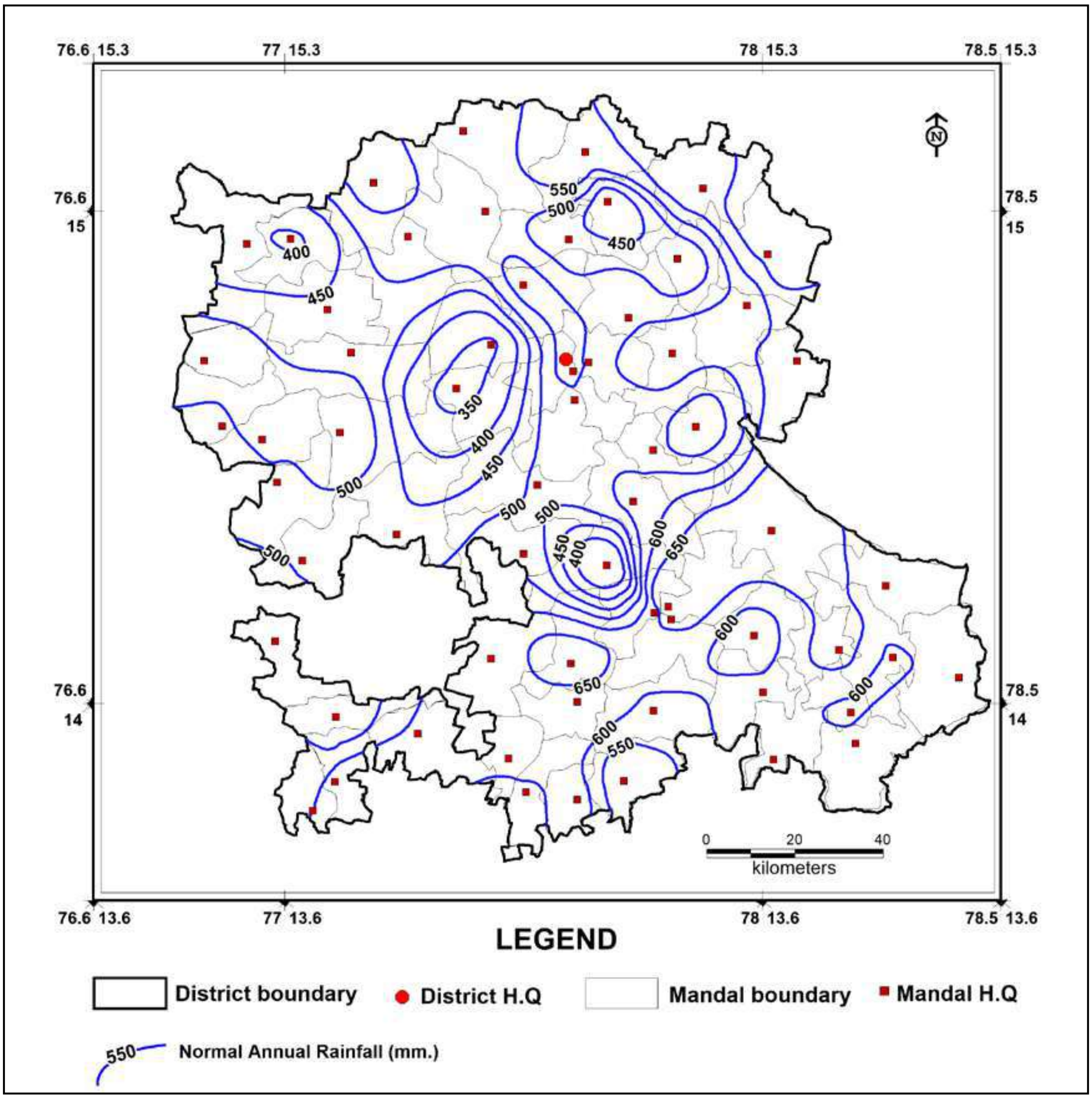


Fig.1.2: Isohyetal map of Ananthapuramu district.

1.5 Geomorphological Set up: Pediplain is the major landform covering about 10235 km^2 (53 %) area. The other landforms observed are pediment (17%), denudation hills (12%), flood plain, residual hill, channel fill, etc. (**Fig.1.3**).

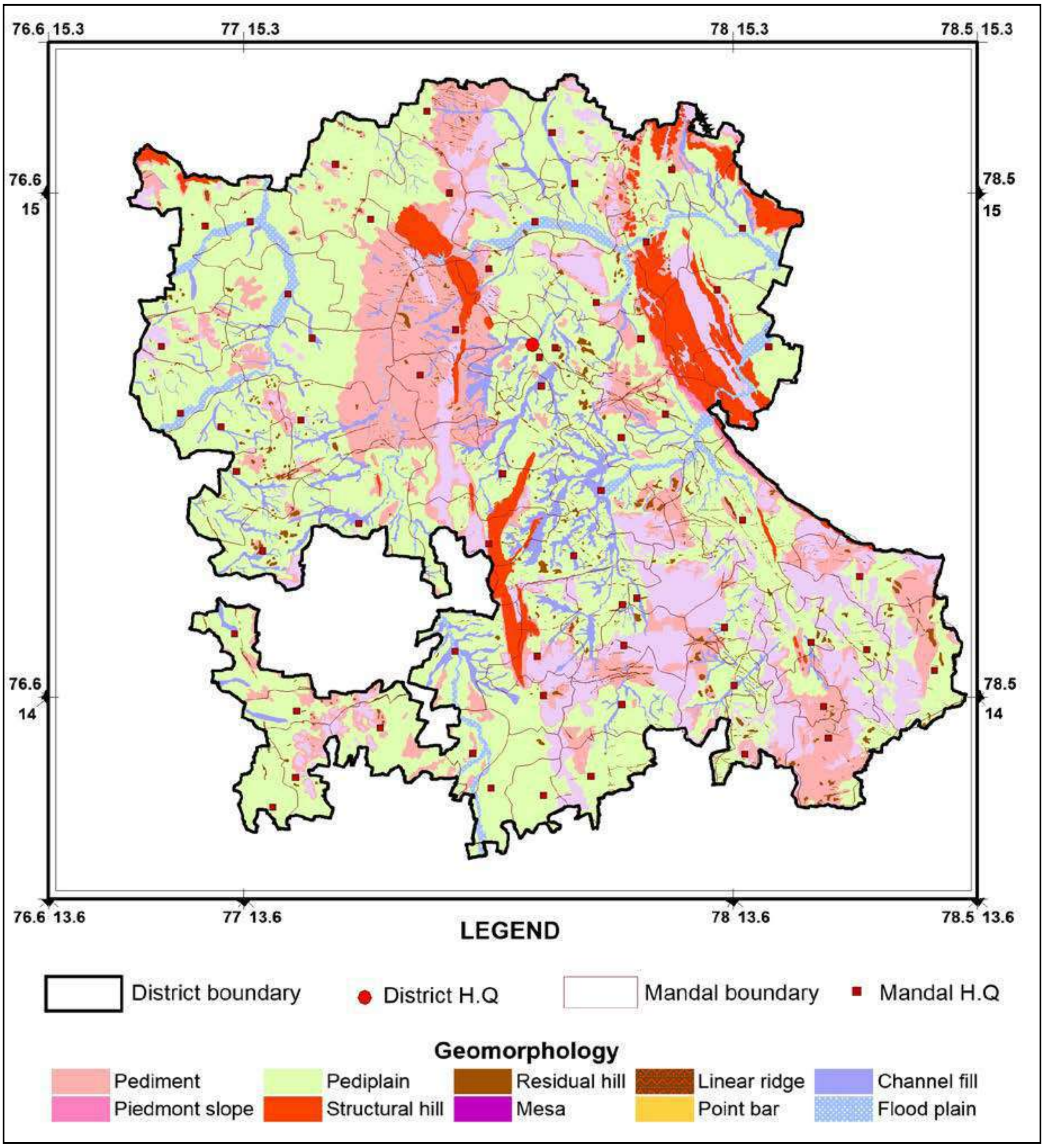


Fig.1.3: Geomorphology of Ananthapuramu district.

1.6 Drainage and Structures: The district is part of river Pennar (80%) and river Krishna basin (20%). It is mainly drained by the rivers Pennar and its tributararies Jayamangala, Chitravathi, Vedavathi and divided into 100 watersheds. During the year 2013-14 only 630 ha of area was irrigated through minor irrigation sources (1.4 %). Map depicting drainage, hills and water bodies is presented in **Fig.1.4**.

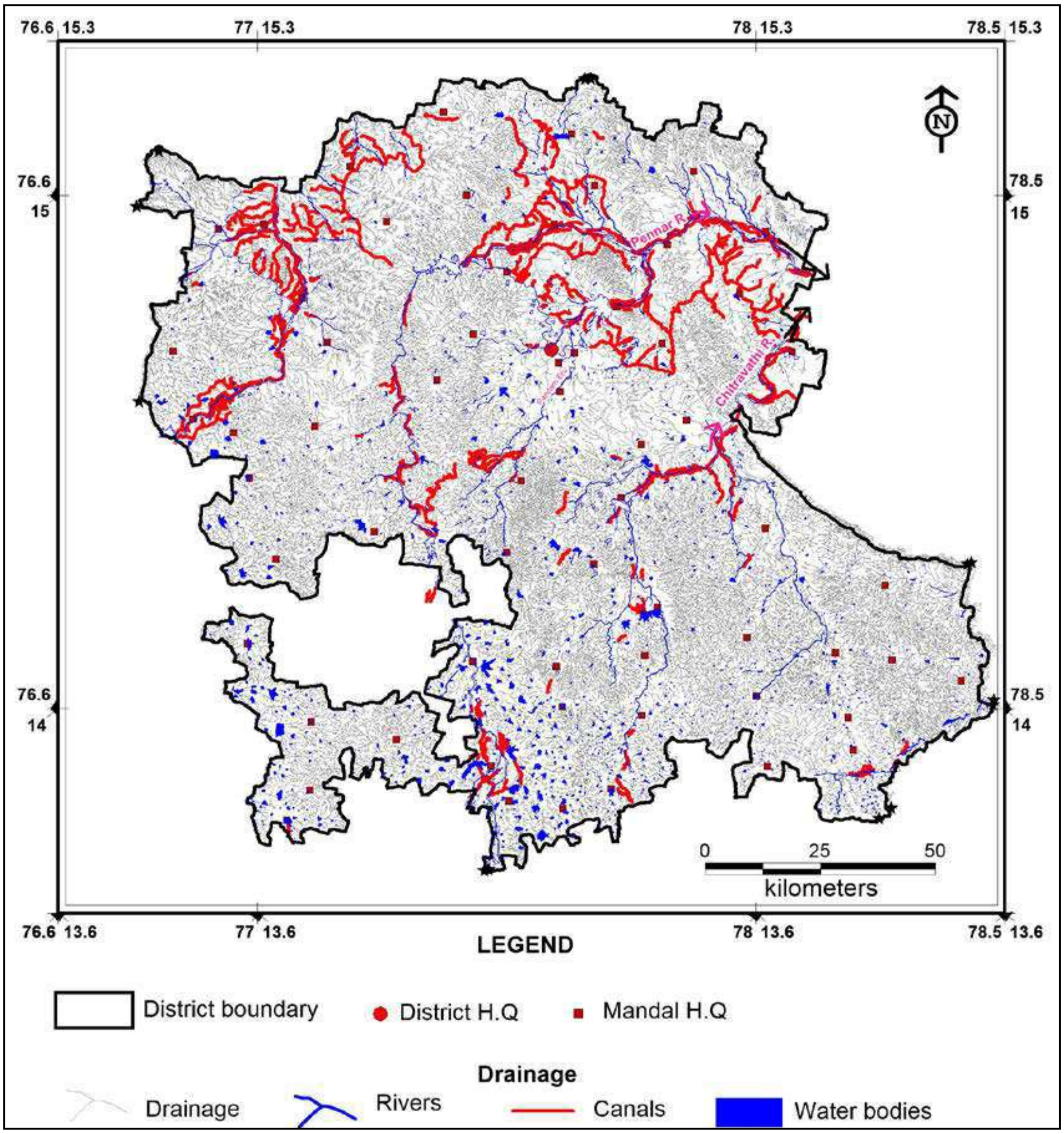


Fig.1.4: Drainage, lineaments, watershed boundaries and canal network.

1.7 Land use and cropping pattern (2013-14): Total cropped area is 1106371 ha (~58%), area sown more than once is 67391 ha (~3.5%), Forest occupies 196978 ha (~10%), Barren and cultivable land is 166425 ha (8.7%), land put to non-agricultural uses is 150140 ha (7.9%), Cultivable waste is 48533 ha (2.5%) etc. of the total geographical area. During Khariff season, main crops grown are Groundnut (71 %), pulses (mainly redgram) (13 %), Rice (3%) and Maize (3 %) etc. During Rabi season, main crops grown are Groundnut (26 %), Rice (17 %) and pulses etc.The other crops are onions, sunflower, chillies etc. Land use and land cover map of the district is depicted in **Fig. 1.5.**

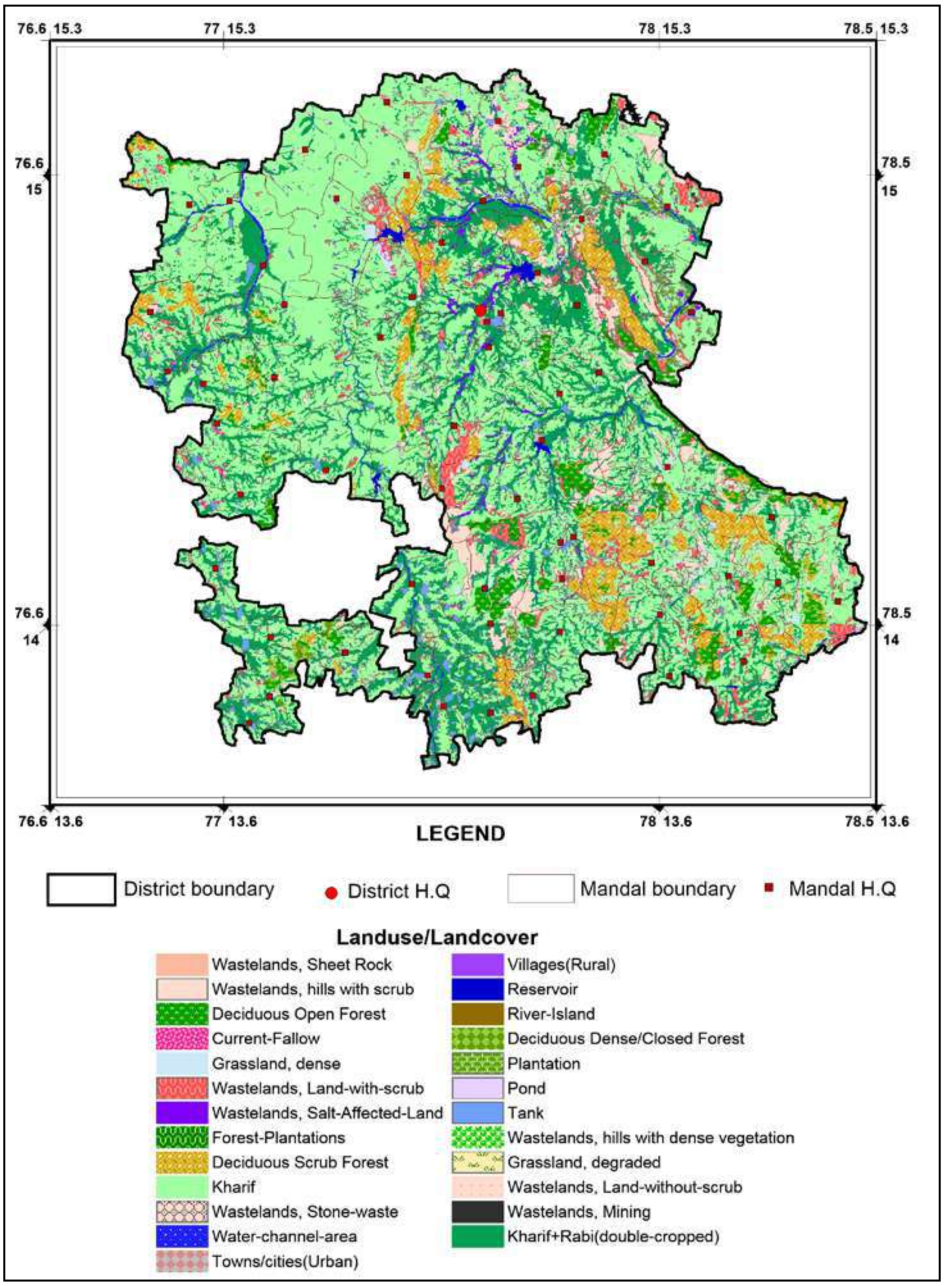


Fig.1.5: Land use and land cover of Ananthapuramu district.

In the district there are 258950 marginal farmers (<2.47 acres of land), 243528 small farmers (2.47-4.93 acres), 175194 semi-medium (4.94-9.87 acres), 45853 medium (9.88-24.7 acres) and 4426 large farmers (>24.71 acres).

1.8 Soils: The area is mainly occupied by clayey skeletal soils (36%), fine, mixed loamy soils (23%), loamy soils (17%) fine, montmorillonitic (10 %), and rock out crops (12 %) (**Fig.1.6**).

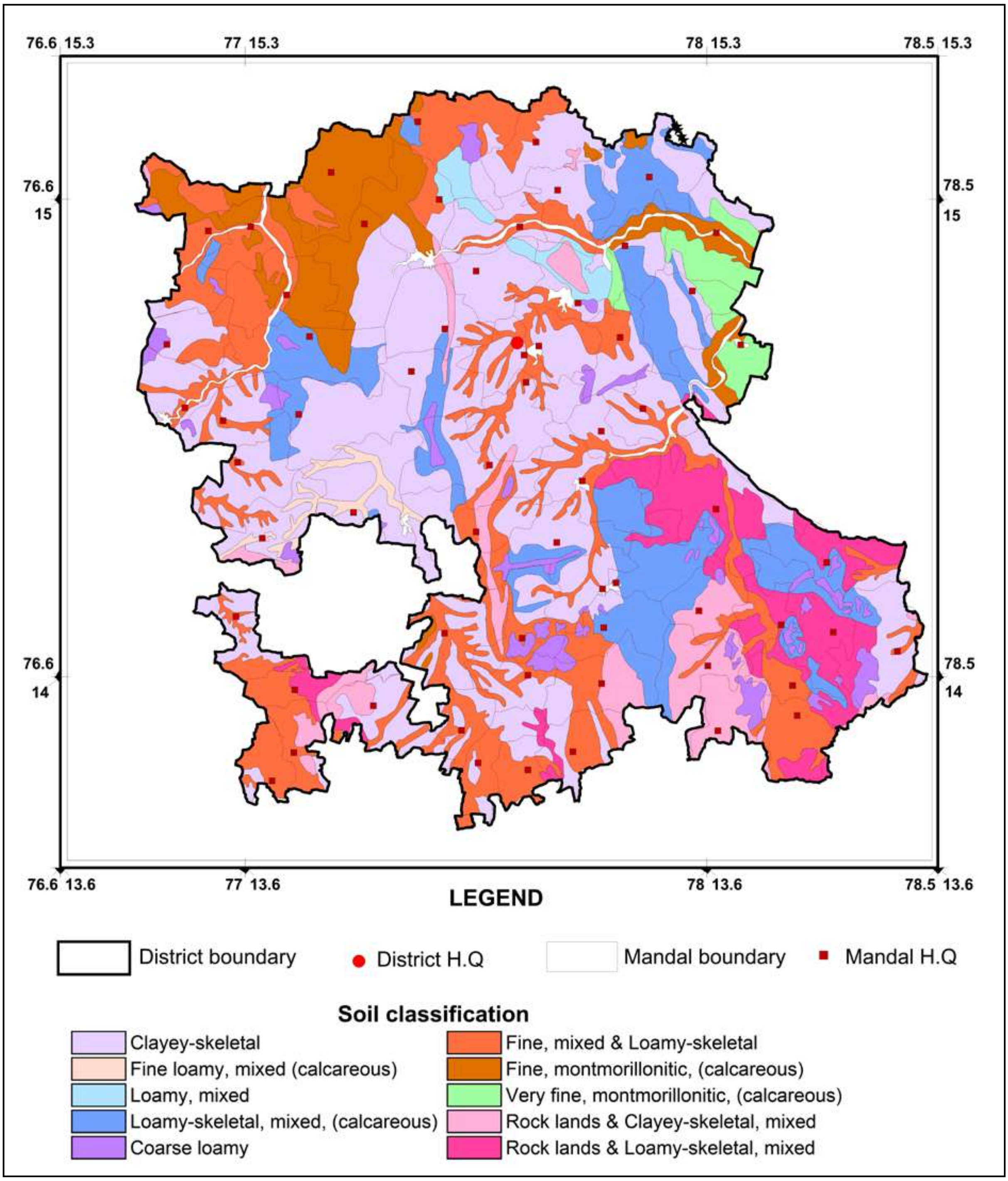


Fig.1.6: Soil map of Ananthapuramu district.

1.9 Irrigation:

The two major irrigation projects are 1) Tungabhadra Project High level Canal - I and 2) Tungabhadra Project High level Canal - II on Tungabhadra River. There are 6 medium irrigation projects (Upper Pennar, Bhairavani Thippa, Chennaraya Swami Gudi, Pennar

Kumdvathi, Yogi Vemana Reservoir and Pedaballi). The ayacut created by these two projects are 113173 ha and 32063 ha respectively. The actual area irrigated as on 2013-14 is only 33528 ha and 10459 ha respectively under these projects. The gross irrigated area is 161675 ha, area irrigated more than once is 31187 ha and net area irrigated is 130488 ha. There are ~ 1263 minor irrigation tanks with 47593 ha of registered ayacut and 280 MCM capacities.

The area irrigated by ground water is 134803 ha (83%) where as 26872 ha of area are mainly irrigated by surface water sources (17%). The salient features of irrigation are given in **Table-1.1**. In the irrigation sector there are ~192983 bore wells and in domestic sector there are 7059 bore wells (2789 fitted with power pump and 4270 fitted with hand pumps) and 56 dug wells.

Table-1: Salient Features of Irrigation during Khariff and Rabi season.

Source of Irrigation	Irrigation Structures	Khariff (ha)	%	Rabi (ha)	%	Total (ha)	Total (ha)
Ground Water	Bore wells	91545	69	41601	31	133146	**134803**
	Dug wells	1233	74	424	26	1657	
Surface Water	Canals	19160	90	2188	10	21348	**26872**
	Tanks	449	12	3442	88	3891	
	Lift Irrigation	40	35	75	65	115	
Others	Others	758	50	760	50	1518	

1.10 Prevailing water conservation/Recharge practices: In the district there are ~2376 percolation tanks, 7473 Check dams with combine capacity of 242 MCM. Till 2015-16 ~ 2.03 lakh ha area is brought under micro-irrigation practices (Drip and Sprinklers). In the district (2013-14) there are 308 water user associations

1.11 Geology: ~ 92 % of the area is underlain by crystalline rocks, namely Banded gneissic complex (66%), granites (21%) of Archaean to Proterozoic age and remaining 8 % of the area in the northeastern parts of the district is underlain by metasediments of Cuddapah supergroup of Proterozoic age, namely shales (6%), limestone (2%) (**Fig1.7**).

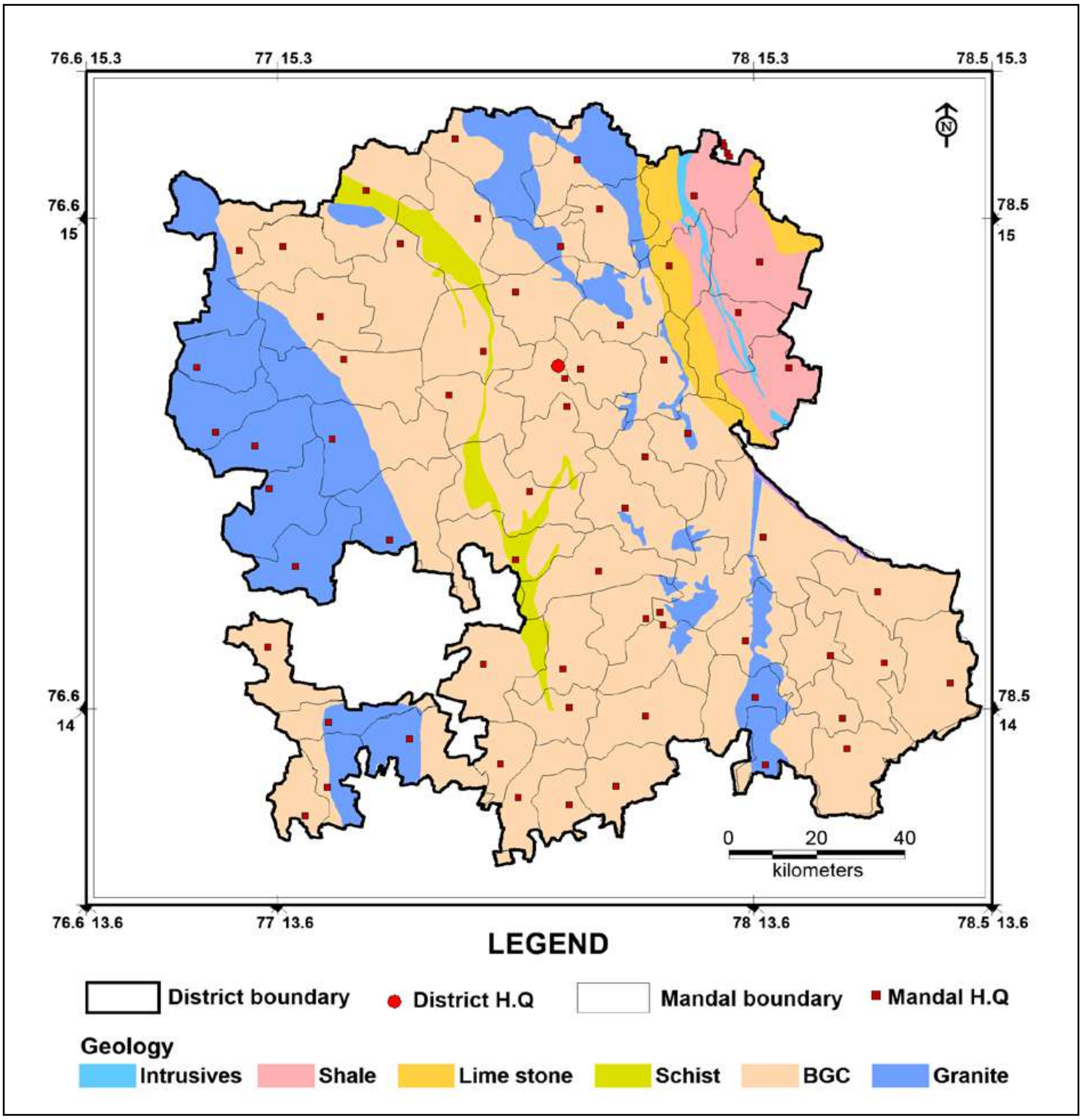


Fig.1.7: Geology of Ananthapuramu district.

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 and gneisses 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 651 hydrogeological data points (Exploration: 108, Geophysical: 213 and well inventory: 330) **(Fig.2.1)** hydrogeological map is prepared.

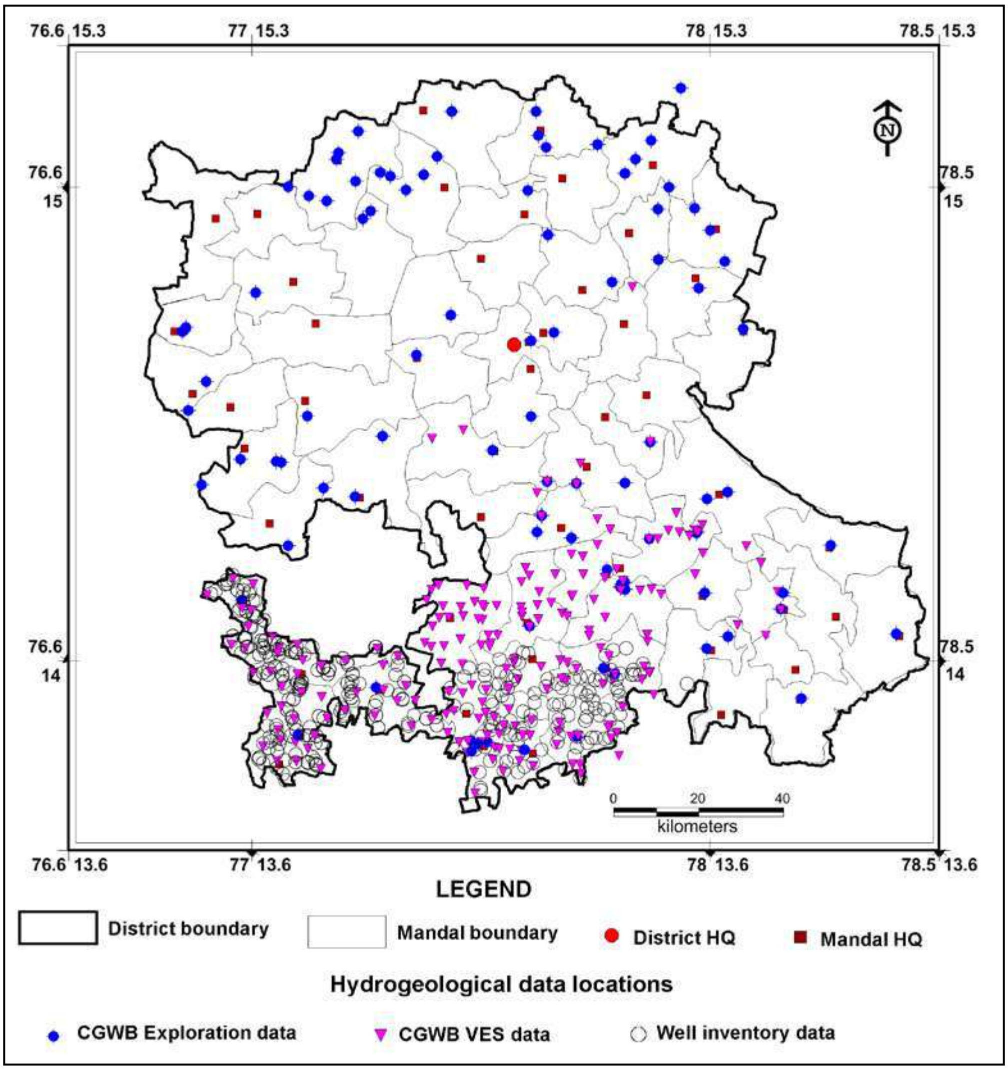


Fig. 2.1: Hydrogeological data availability.

2.1.1 Ground water occurrences and movement: Ground water occurs under unconfined and semi-confined conditions and flows downward from the weathered zone (saprolite and sap rock) 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 300 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 60-300 m depth, with yield between <0.2 and 7.43 litres/second (lps). Majority of fractures occur within 100 m depth and deepest fracture is encountered at the depth of 199 m depth (Nimmakampalle). The hydrogeological map of the area is presented in **Fig. 2.2**.

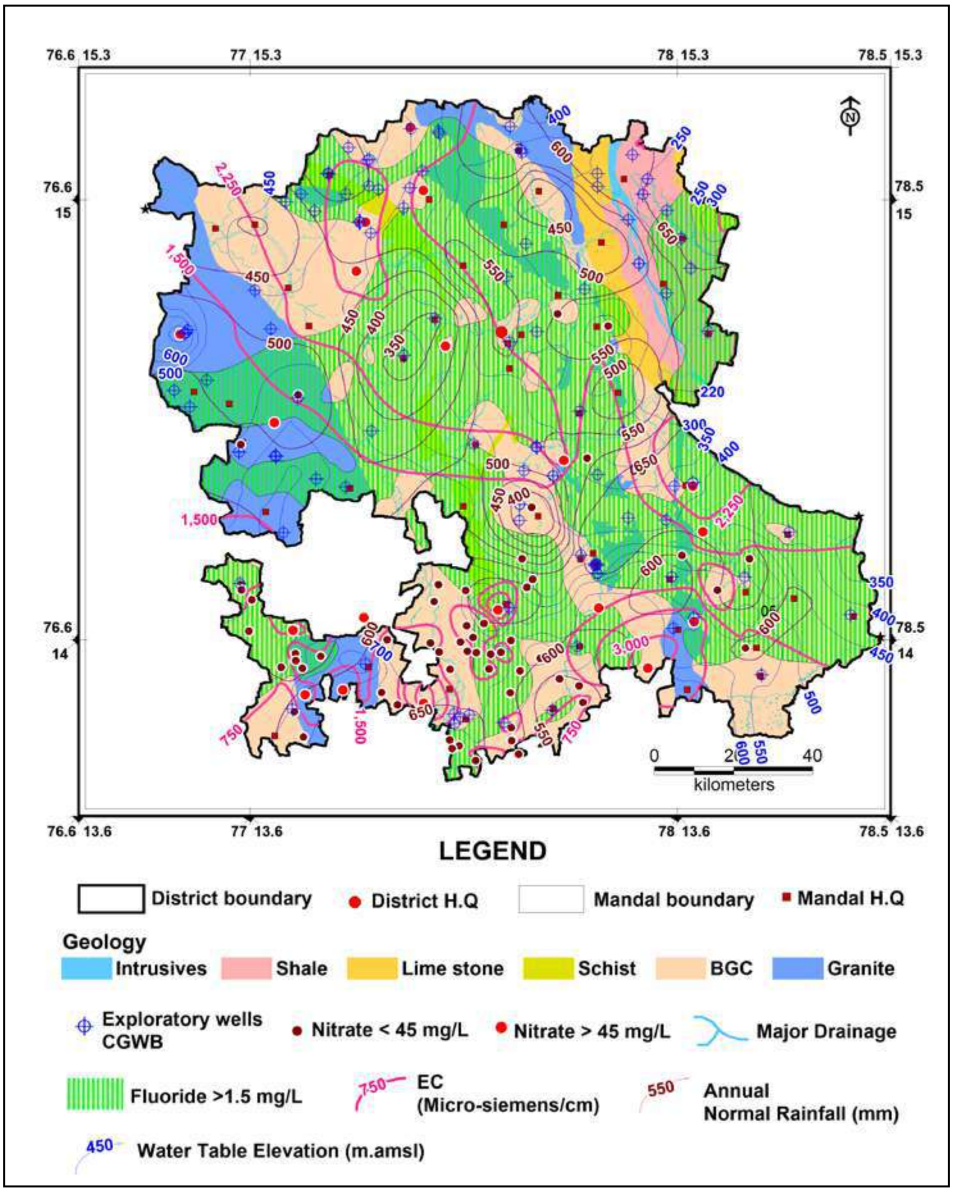


Fig.2.2: Hydrogeological map of Ananthapuramu district.

2.1.2 Exploratory Drilling: As on 31/03/2016, CGWB drilled 146 bore wells (exploratory, observation and piezometers) and SGWD drilled 89 wells in the district. Data analysed from CGWB wells indicates, 14 wells are of shallow depth (30 m), 28 nos are of 30-60 m, 15 nos are of 60-100 m, 17 nos are of 100-150 m, 68 nos are of 150-200 m and 4 nos are of 200-305 m depth**.** In the district, there are 7059 existing wells in domestic sector (BW fitted with power pump: 2789; HP: 4270 and DW: 56).

Depth of exploratory wells in Cuddapah group of rocks varies from 20-289 m and deepest fractured encountered is at 188.3 m (Konnappalapadu). In granite rocks the depth of bore wells ranges from 20-305 m and deepest fracture is encountered at 199 m (Nimmakampalle). In Gniesses the depth of exploratory wells ranges from 20-200 m and deepest fracture is encountered at 169 m (Gollapalle).

2.1.3 Ground water Yield: Ground water yield from weathered and fractured granite/gneiss aquifer varies from <0.1 to 12 lps. Based on exploratory data of CGWB, yield map is prepared and shown in **Fig.2.3**. In most of the area in deeper wells yields are in the range of 1-3 lps and, in south western parts of Anantapur town and south-eastern part of the district low yields (< 1lps) are observed and in western and northern part high yields (> 3 lps) are observed. Wells located in the command area have higher yield (1-3 lps) and sustain for more hours of pumping as compared to non-command area where yields are relatively low with sustainability for 2-3 hrs**.**

2.2 Water Levels (2015): Ground water levels from 203 wells (CGWB: 52 and SGWD: 151) consisting of dug wells and 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) of 2015, the water-table elevation ranges from 220.5-882.6 and 220.8-884.7 meter above mean sea level (m amsl) respectively and general ground flow is towards NE direction (Pennar River) (**Fig.2.4**).

2.2.2 Depth to Water Levels (DTW): The DTW varies from 0.3 to 89.4 meter below ground level (m bgl) (average: 19.2 m bgl) and 0.3-69.6 m bgl (average: 13.5) during pre and post-monsoon season of 2015 respectively.

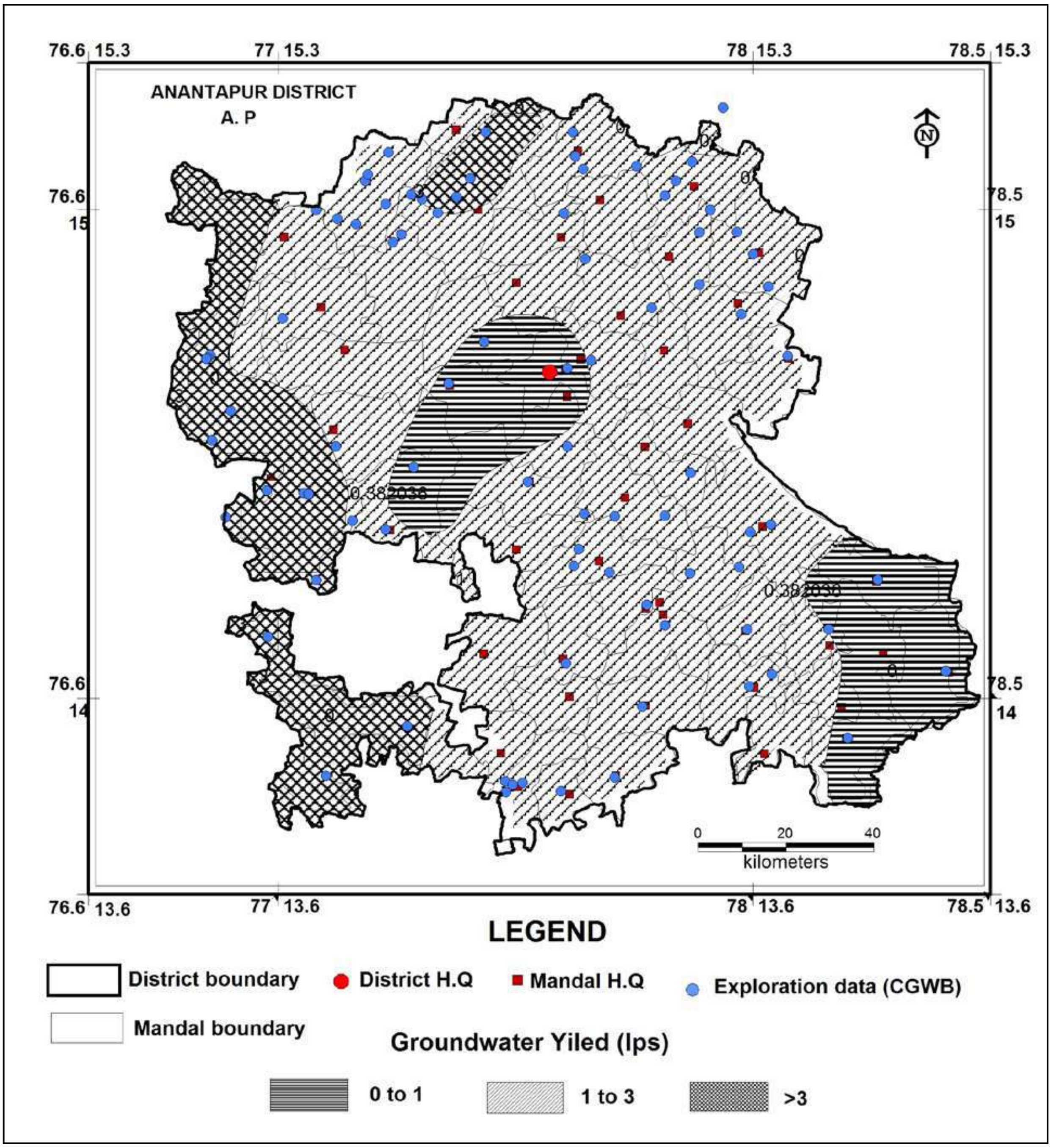


Fig.2.3: Ground water yield, Anantapur District, A.P.

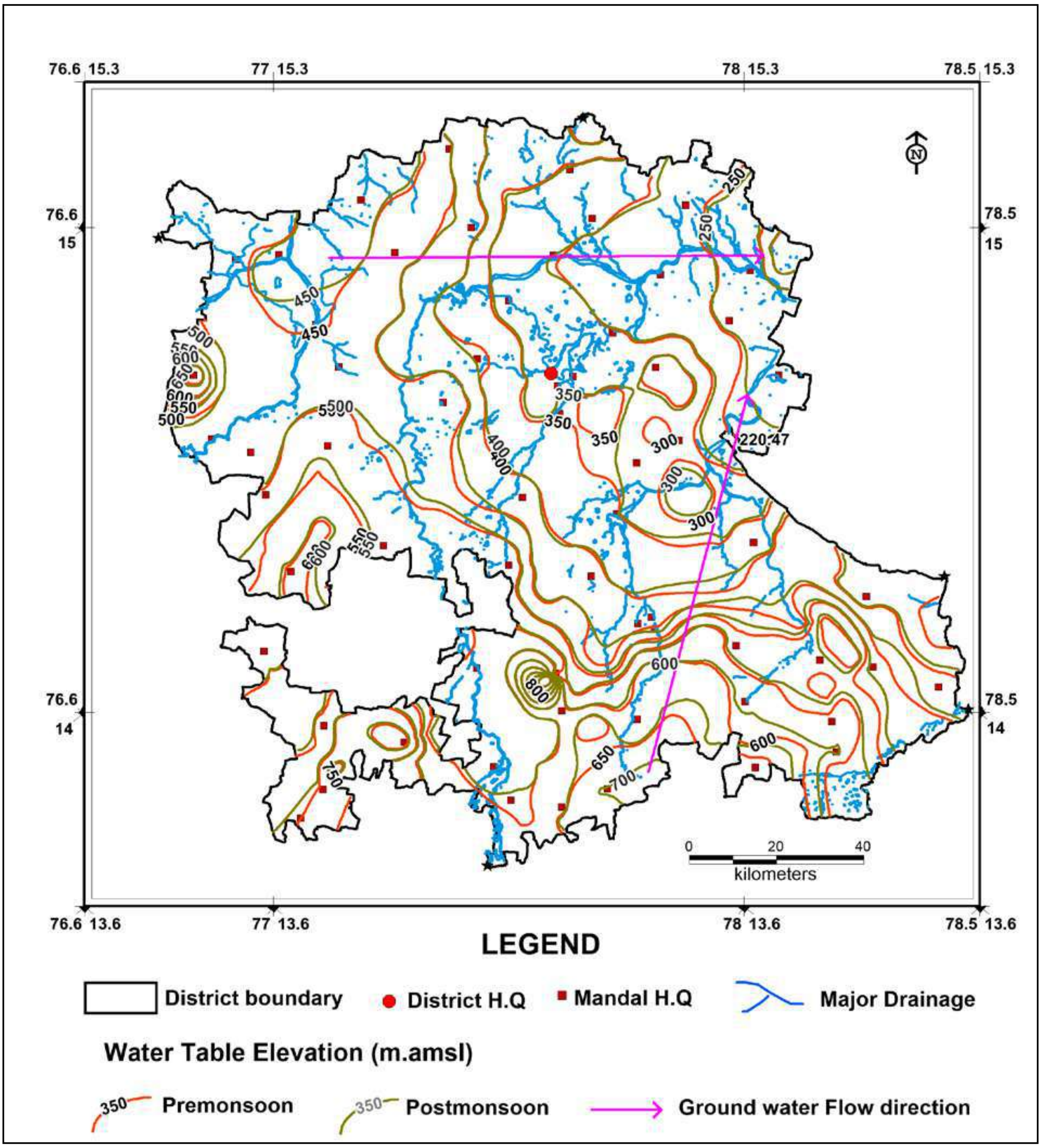


Fig.2.4: Water table elevations (m amsl) during pre and post-monsoon season-2015.

Pre-monsoon season: Majority of the water levels during this season are in the range of 10-20 m cover ~ 40% of area, followed by 20-40 m bgl (35% of area). Deep water levels in the range of > 40 m bgl occupy ~7% of area mostly in southern and south eastern part of the district (**Fig.2.5**). Shallow water levels (2-5 mbgl) occur in northern part of the district covering 4% of area and 5-10 m water levels occupy rest of the area.

Post-monsoon season: Majority of the water levels during this season are in the range of 10-20 m covering ~45 % of area, followed by 5-10 mbgl (26% of area), 20-40 m bgl (18%). Deep water levels in the range of > 40 m bgl occupy 1 % of area (southern and south eastern part) of the district (**Fig.2.6**). Shallow water levels (0-2 and 2-5 mbgl) occupy ~1 and 9 % of area respectively and occur in northern part of the district.

2.2.3 Water Level Fluctuations (May vs. November): The water level fluctuations vary from -10.3.1 to 56.9 m with average rise of 5.8 m (**Fig.2.7**). Out of 203 wells, in 177 wells (87%) rise in water levels (0.2 to 56.85 m) is observed covering most of the area. Falling water levels in the range of -10.3 to -0.04 m is observed in 25 wells and 1 well shows neither rise nor fall in water levels. Fall in water levels is mostly observed in central part of the district.

2.2.4 Long term water level trends: Trend analysis for the last 11 years (2005-2015) is studied from 72 hydrograph stations of CGWB and SGWD. It is observed that during pre-monsoon season 36 wells shows a falling trend (0-1 m: 27, 1-2 m: 7 and >2 m: 2 wells) (max fall: 4.42 m/yr) and 36 wells shows rising trend (0-1 m: 25, 1-2 m: 9 and >2 m: 2 wells) (max rise: 3.8 m/yr). During post-monsoon season 41 shows falling trend (0-1 m: 29, 1-2 m: 9 and >2 m: 3 wells) (maximum fall: 6.21 m/Yr) and 31wells shows rising trends (0-1 m: 20, 1-2 m: 9 and >2 m: 2 wells) (max rise: 3.96 m/yr).

Average water levels for the last 11 years (2005-15) were compared with 2015 data and it is found that during pre-monsoon season 40 wells have shown fall and 12 shown rise and during post monsoon season 36 wells shown fall and 19 shown rise in water levels. The graphical representation of fall and rise is shown in **Fig 2.8**.

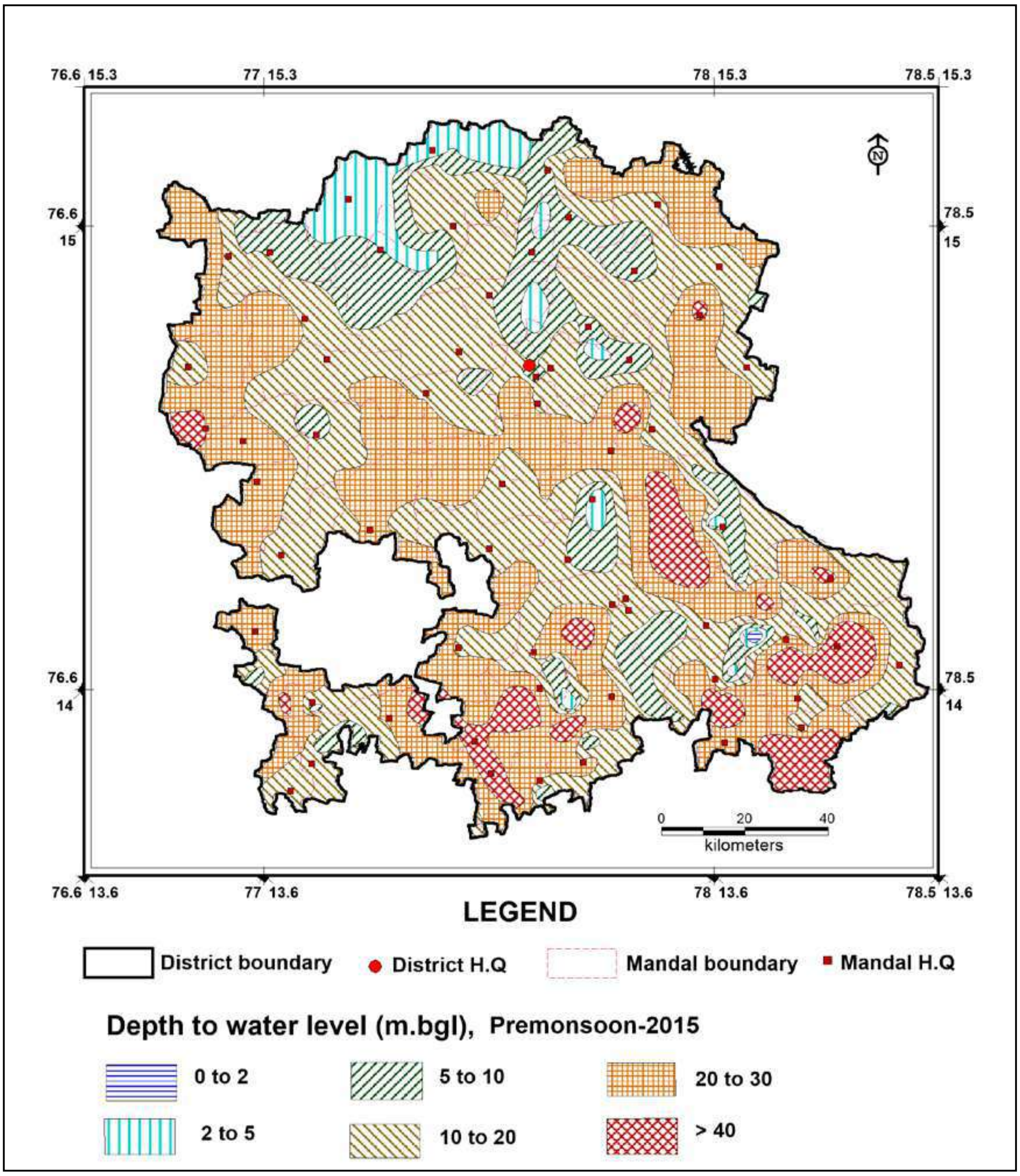


Fig.2.5: Depth to water levels Pre-monsoon (May-2015).

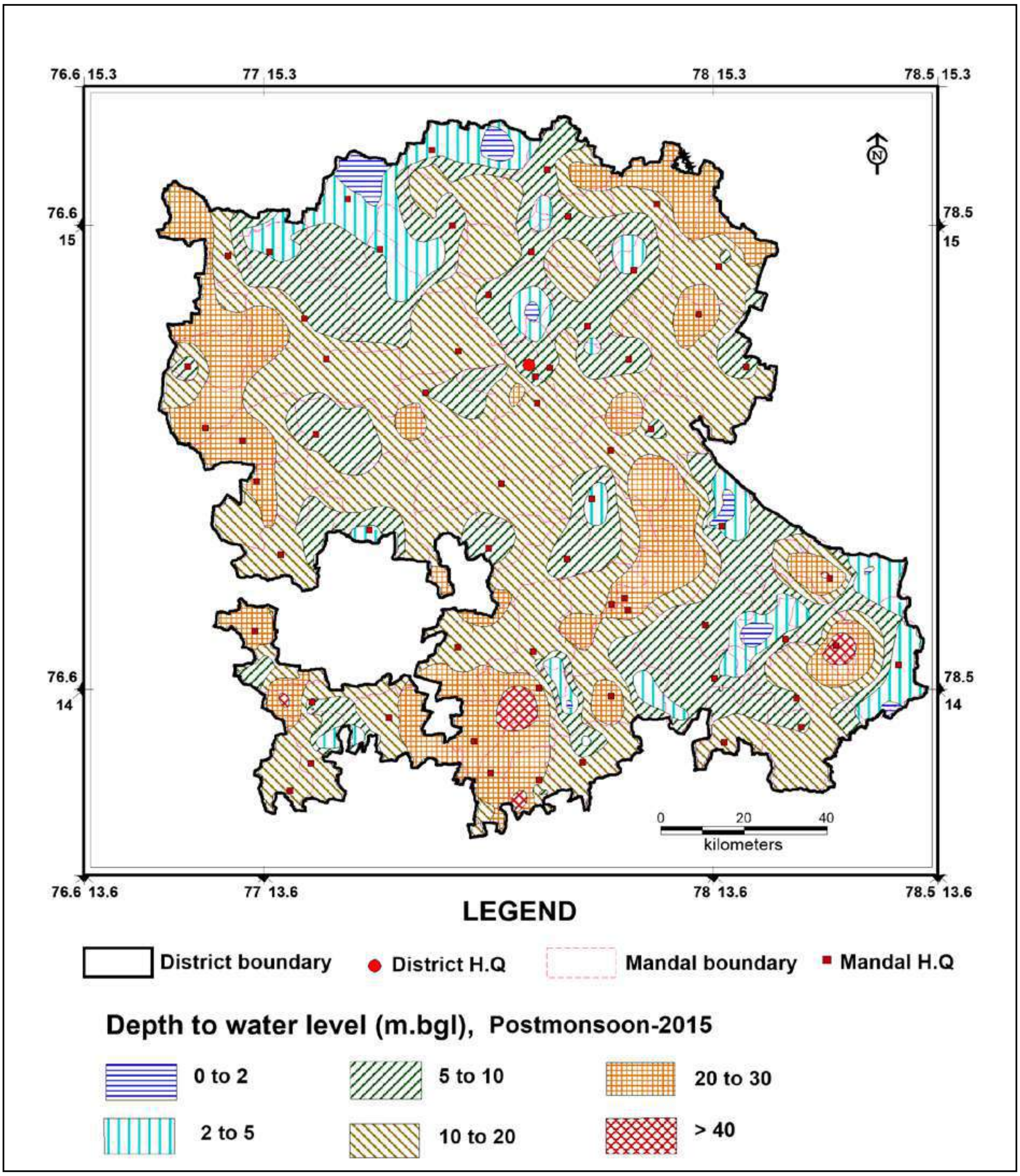


Fig.2.6: Depth to water levels Post-monsoon (Nov-2015).

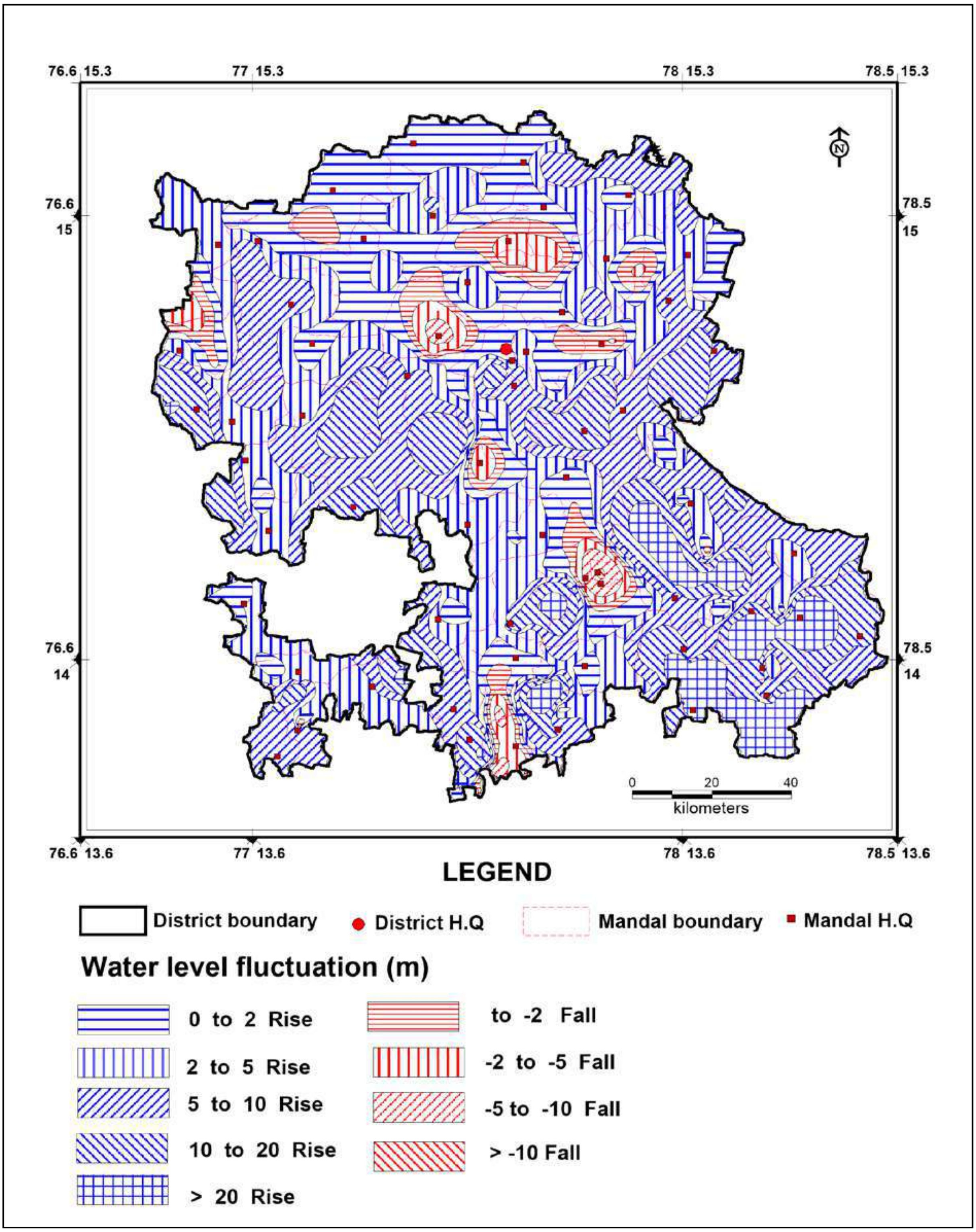


Fig.2.7: Water Level Fluctuations (m) (November-15 with respect to May-2015).

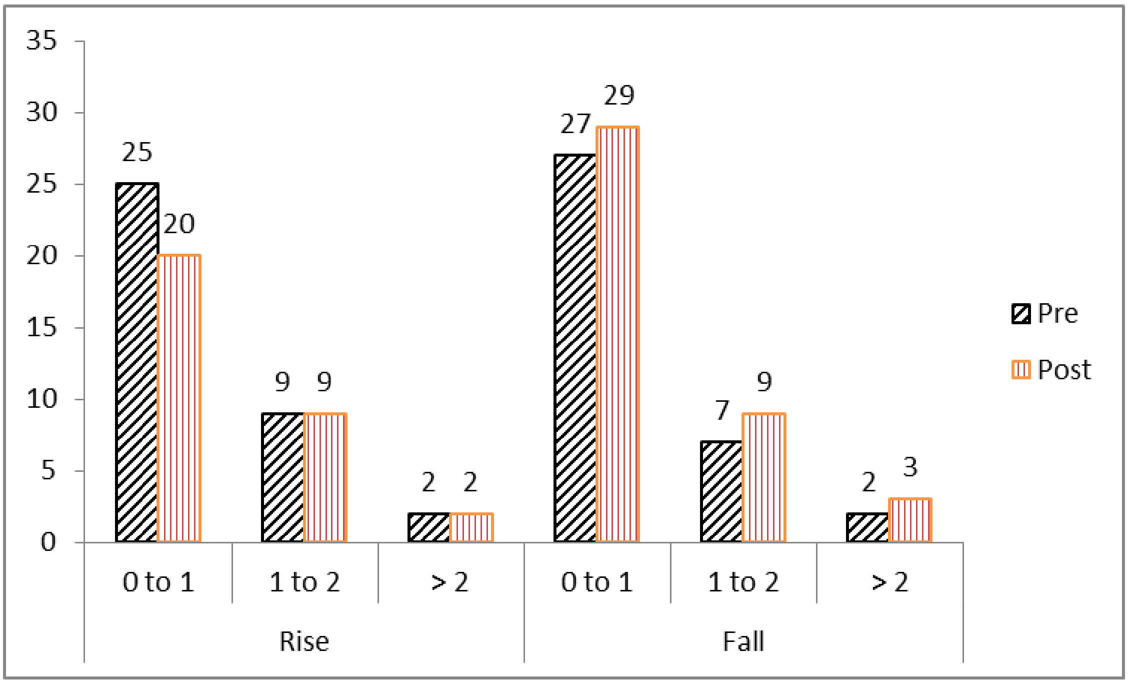


Fig. 2.8: Long-term water level trends (2005-2015).

2.3 Geophysical Studies

A representative 213 geophysical data (VES:188 and bore hole logging:25) is interpreted, which reveals resistivity < 100 ohm (Ω) m for the weathered granite (1-28 m) (Konduru), 50-250 Ω m for underlying fractured granite with maximum thickness of 72 m (Rayapuram) and > 250 Ω m for massive granite.

2.4 Hydro-chemical Studies

To understand chemical nature of groundwater, total 369 data is utilized from ground water monitoring wells (Pre:298 and Post:71). During pre-monsoon season of 2015 (CGWB: 27 and SGWD: 271 wells (mostly tapping combined aquifers Aq-1 and aq-2) were analysed. 71 samples (all SGWD) during post-monsoon season of 2014 are analysed. Parameters namely pH, EC (in µS/cm at 25 ° C), TH, Ca, Mg, Na, K, CO_3, HCO_3, Cl, SO_4 and NO_3 (27 samples) were analyzed. To study the distribution of fluoride in ground waters from the district 246 data points (for the year 2015 and historical data) is used.

Pre-monsoon (May-2015)

Groundwater from the area is mildly alkaline to alkaline in nature with pH in the range of 6.87-8.3 (Avg: 8.0). Electrical conductivity varies from 180-6622 (avg: 1557) µ Siemens/cm. In majority of area covering northern, central and south-eastern part (62 %) EC is in the range of 1500-3000 µ Siemens/cm, in 35 % of the area EC is < 1500 µ Siemens/cm, in rest of the area (3%) high EC (>3000 µ Siemens/cm) is detected in 3 patches covering Vidapnakal, Vajrakarur, Urvakonda, O.D. Cheruvu and Madakasira mandals (**Fig.2.9**). The concentration of TDS varies from 115-4238 (avg: 993) and TH varies from 63-2405 (avg: 511) mg/l. In 67 samples TH is beyond maximum permissible limit of BIS (600 mg/l).

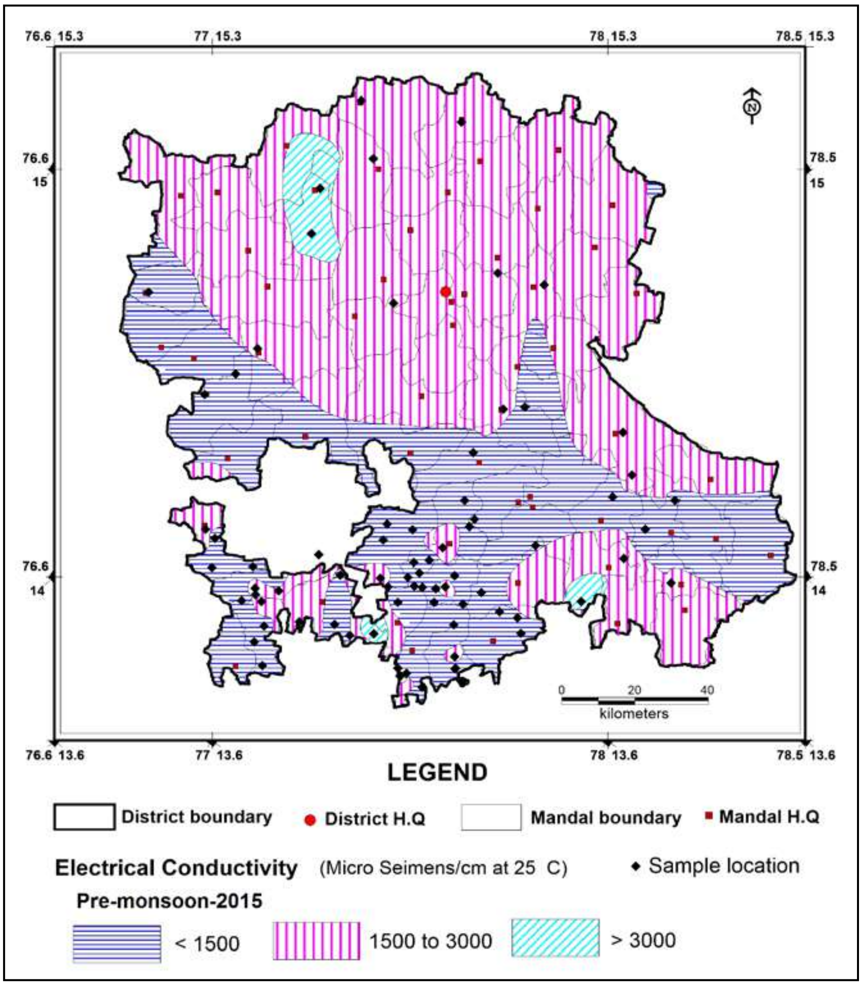


Fig.2.9: Distribution of Electrical conductivity (Pre-monsoon-2015).

The concentration of Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} ranges from 16-320, 5-390, 2-640 and 1-600 mg/l respectively. The concentration of bicarbonate (HCO_3) varies from 79-854 (avg: 238 mg/l) and 16 sample it is beond drinking water standards of BIS (600 mg/l). Chloride (Cl) concentration varies from 14-1500 mg/l (avg: 265) and found that 9 samples it is beyond permissible limts of BIS (1000 mg/l). Sulphate (SO_4) concentration varies from 1-558 mg/l (avg: 103) and found that 9 sample it is beyond permissible limit of BIS (400 mg/l). Concentration of NO_3 (CGWB monitoring wells only) ranges from 2-449 mg/l. Nitrate concentration in 20 samples (26 %) is beyond maximum permissible limit of BIS (45 mg/L) (**Fig.2.10**).

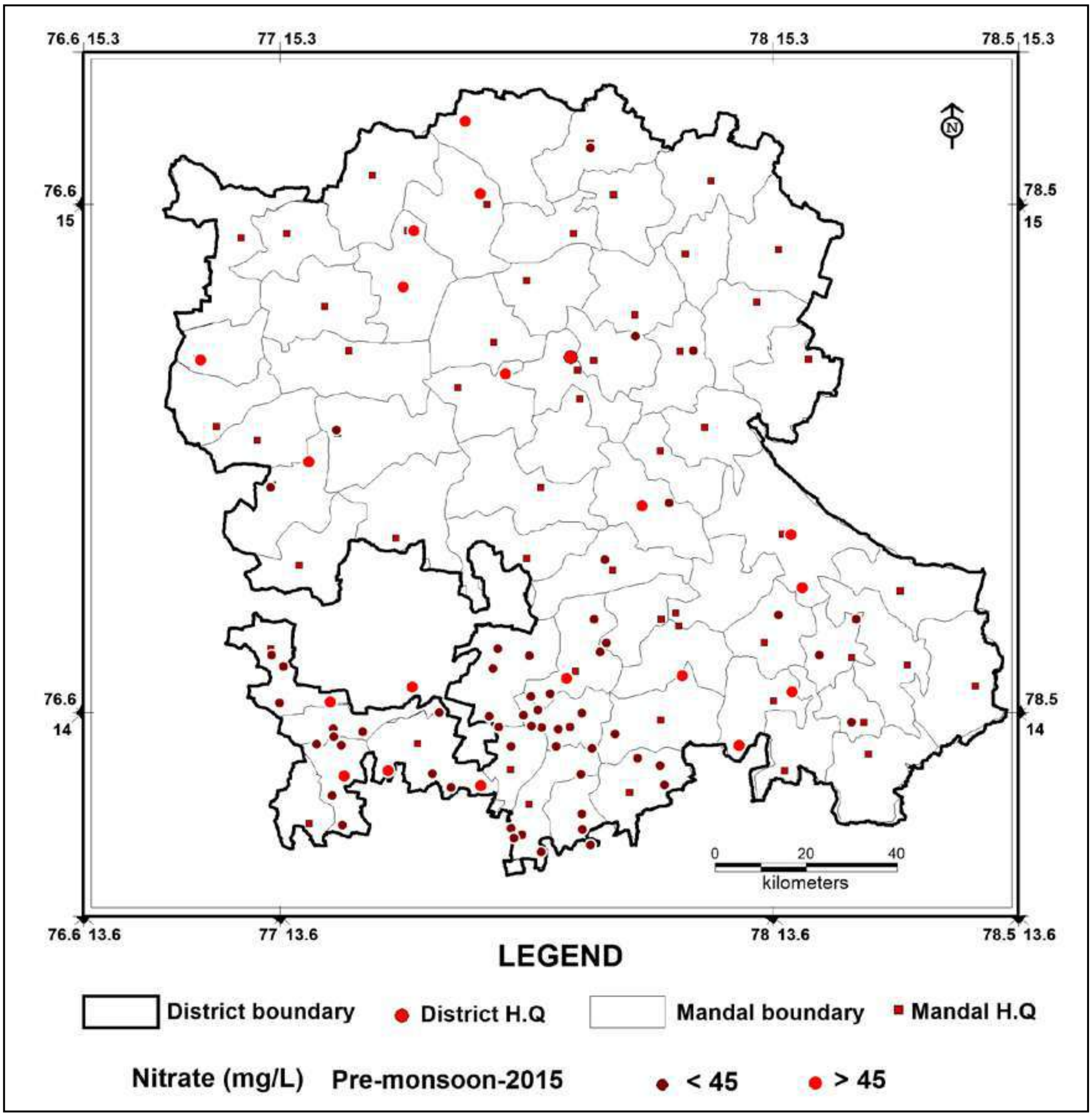


Fig.2.10: Distribution of Nitrate (Pre-monsoon-2015).

Post-monsoon (Nov-2014)

Groundwater from the area is mildly alkaline to alkaline in nature with pH in the range of 7.6-8.9 (Avg: 8.32). Electrical conductivity varies from 209-4380 (avg: 1158) µ Siemens/cm. Concentration of TDS varies from 134-2803 mg/l (avg: 741) and TH varies from 80-879 (avg: 300) mg/L. In 6 samples TH is beyond maximum permissible limit of BIS-2012 (600 mg/l).

The concentration of Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} ranges from 8-96, 5-175, 10-460 and 3-32 mg/l respectively. The concentration of total carbonate (CO_3 + HCO_3) varies from 90-620 mg/l (avg: 333 mg/l) and 1 sample it is beond drinking water standard of BIS (600 mg/l).

Chloride (Cl) concentration varies from 10-960 mg/l (avg: 149) and all samples fall within permissbible limts of BIS (1000 mg/l). Sulphate (SO_4) concentration varies from BDL-86 mg/l (avg: 23). Concentration of NO_3 ranges from 2-88 mg/l and in 5 samples it is beyond maximum permissible limits of BIS (45 mg/l).

Distribution of Fluoride (F) : All historical data of CGWB and SGWD from 246 locations is utilized to study the F concentration in ground water from the district. Fluoride concentration varies from 0.1-7.2 mg/l (**Fig 2.11**) and in~58 % of samples (142 nos) and ~58 % area, F concentration is beyond maximum permissible limits of BIS (1.5 mg/l). Maximum 6.4 mg/l is detected in Atmakur mandal.

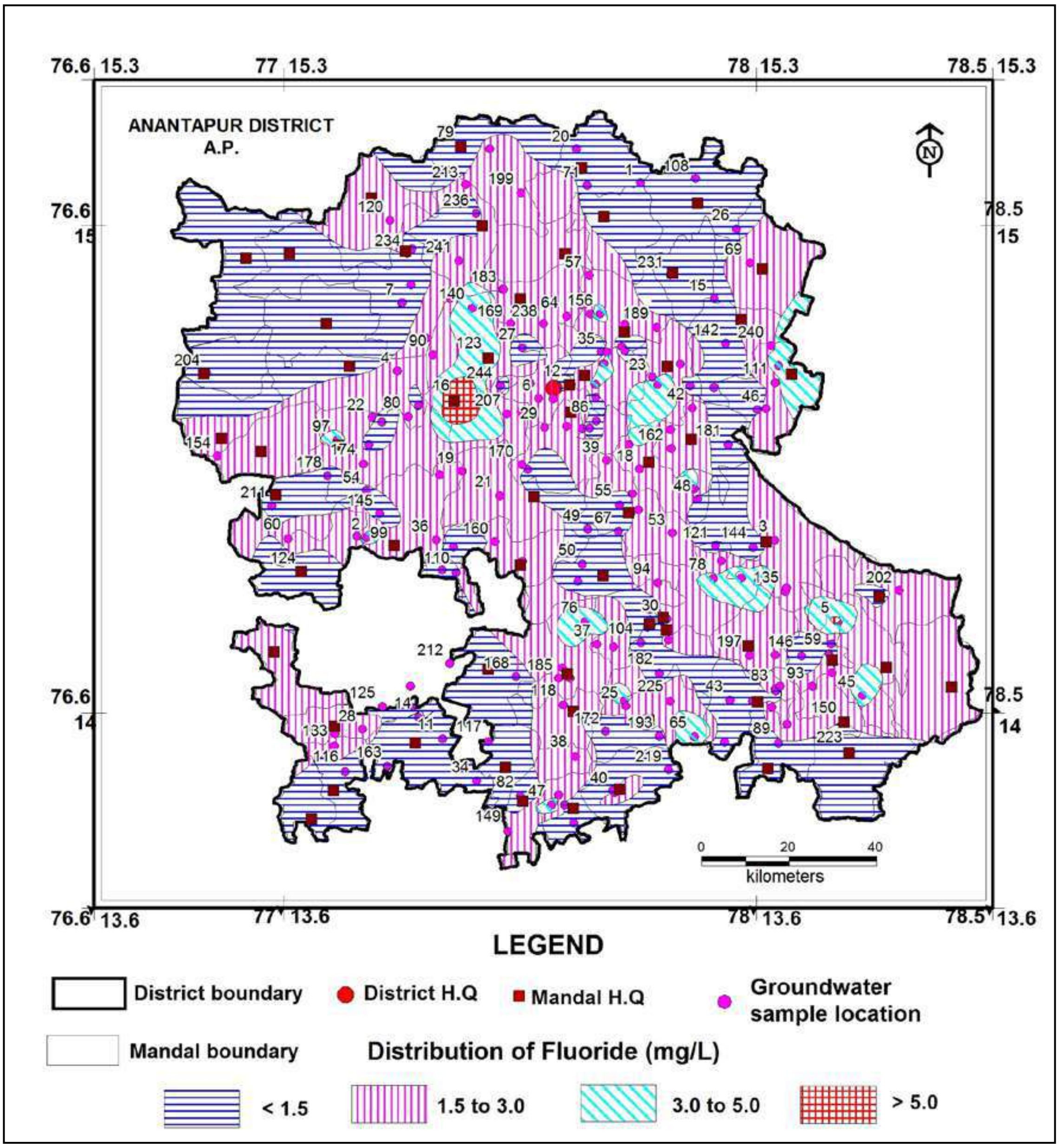


Fig.2.11: Distribution of Fluoride.

2.4.1 Suitability of Groundwater for drinking purpose

Suitability of ground water for different purposes is assessed based on the BIS (2012) standards. It is found that during pre-monsoon season of 2015, 27 % samples (82 out of 298 analyzed) are not suitable for drinking purpose where either TH, Ca, Mg, SO_4, HCO_3 NO_3 and F are beyond the maximum permissible limit of BIS. During post-monsoon season of 2014 it is found that 13% of samples (9 out of 71) are not suitable for drinking purposes where either TH or NO_3 are beyond the maximum permissible limits of BIS. Historical data on fluoride suggest that 58% of samples (142 out of 246) are unfit for human consumption where F concentration is beyond the maximum permissible limits of BIS (2012).

2.4.2 Suitability for Irrigation Purpose: Productivity and quality of agricultural crops largely depends on quality of groundwater supplied for irrigation (**US Salinity Laboratory Staff 1973**) and in the ditrict ~83 % of irrigation water requirement is met through groundwater. In order to find out suitability of groundwater for irrigation, EC along with Na^+ plays an important role. The Wilcox plot (**USSL diagram, 1954;Wilcox, 1955**) is a simple scatter plot of Sodium Hazard (SAR) on the Y-axis vs. Salinity Hazard (Conductivity) on the X-axis (**Fig.2.12**). The US salinity diagram describes that majority of sample falls in C_3S_1 (high salinity hazard and low alkali hazard) type of water followed by C_4S_1 (very high salinity hazard and low alkali hazard) and C_2S_1types (medim salinity hazard and low alkali hazard). Salinity hazard ‘Medium’ to ‘High’ requires treatment before irrigation applications, lest it reduces the soil nutrition capacity for plant growth. The low sodium (alkali) hazard and high salinity (conductivity) hazard represents the suitability for salt tolerant plants but restricts its suitability for irrigation, particularly in soils with restricted drainage (**Karanth,1987**).

2.4.3 Groundwater facies

For identification of different water facies of groundwater, Piper diagram is widely used as it gives best graphical representation (**Hill, 1940; Piper 1944**). Groundwater from the area can be grouped broadly into 9 types (**Fig.2.13**). Ground water from the area is mainly of 3 types namely Ca-Cl, Ca-Na-Cl and Ca-HCO_3-Cl.

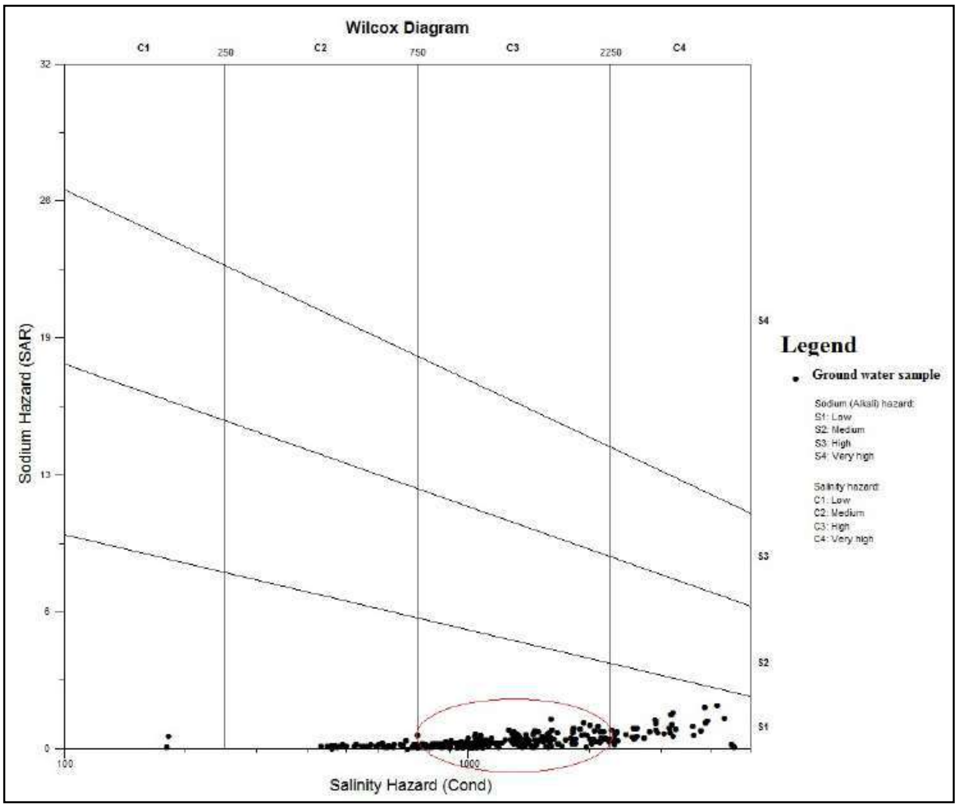


Fig.2.12: USSL Plot, Pre-monsoon-2015, Ananthapur District.

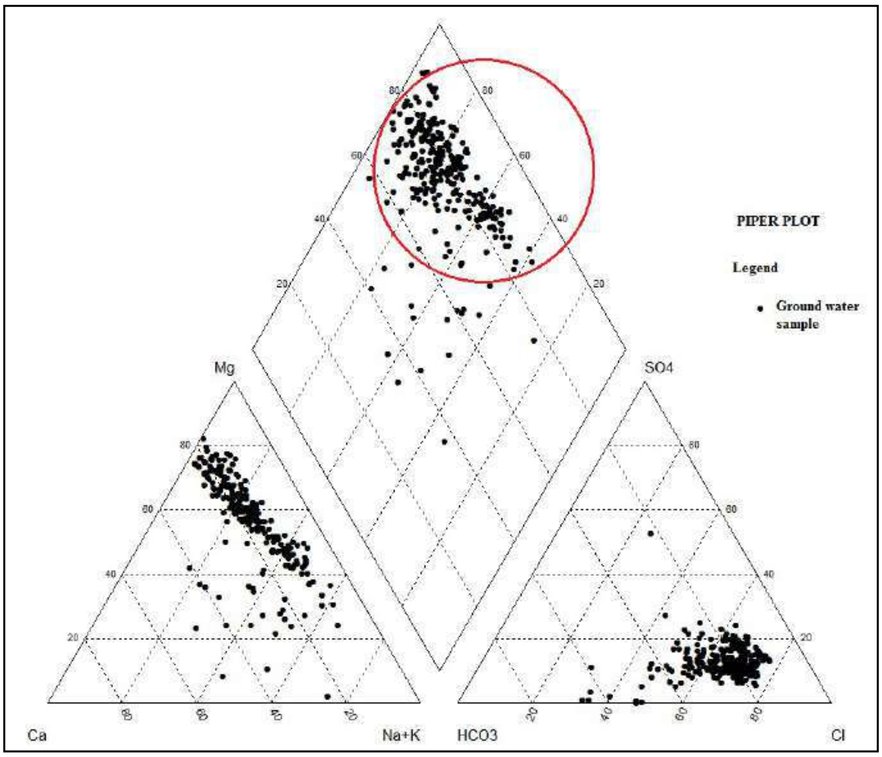


Fig.2.13: Piper Plot, Pre-monsoon-2015, Ananthapur District.

3. DATA INTERPRETATION, INTEGRATION and AQUIFER MAPPING

Conceptualization of 3-D hydrogeological model was carried out by interpreting and integrating representative 651 data points (Exploratory wells: 108, Geophysical: 213 and 330 well inventory data) down to 200 m is used for preparation of 3-D 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 Ananthapuramu district (**Fig.3.1)** along with panel diagram (**Fig. 3.2**) and hydrogeological sections (**Fig-3.3 and 3.4a-f**).

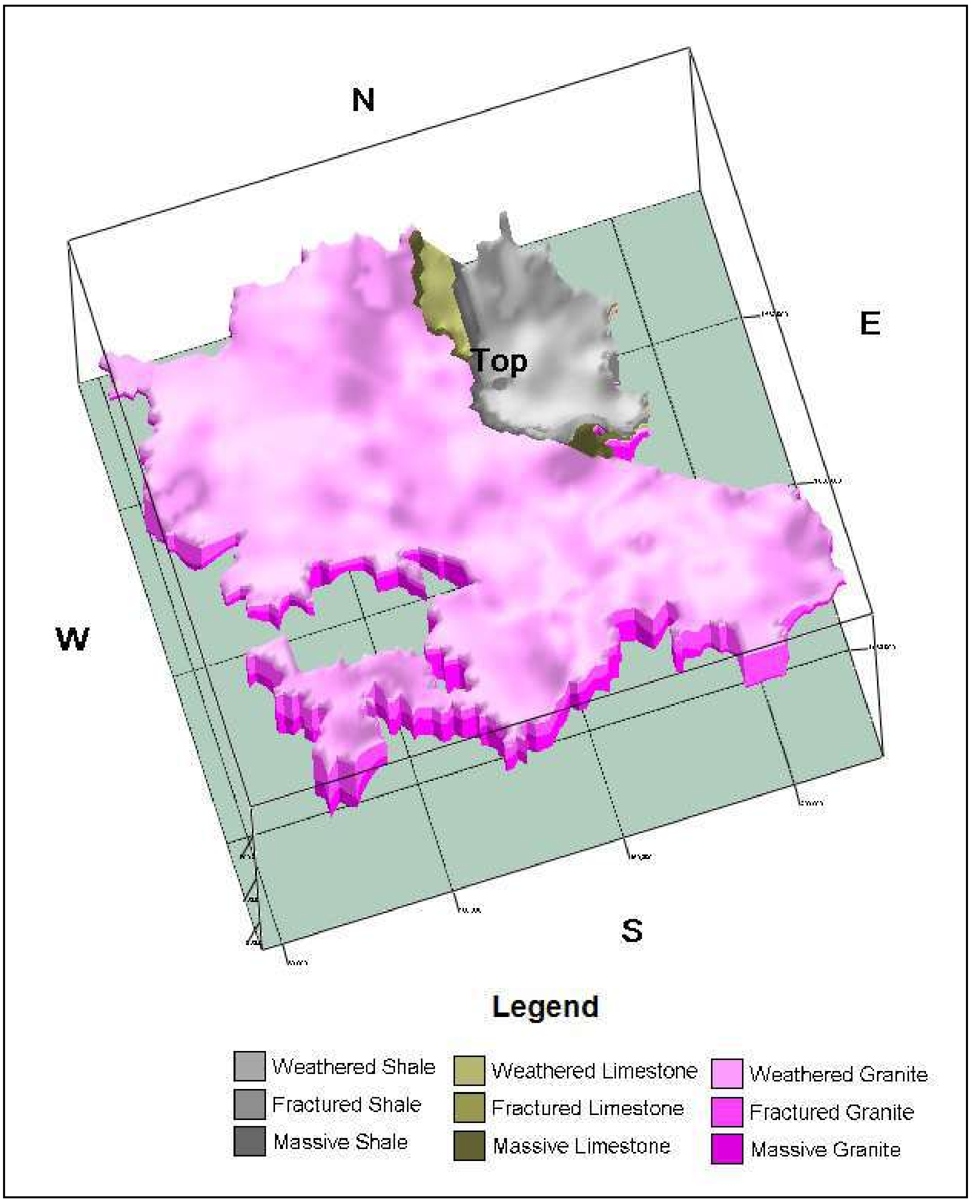


Fig.-3.1:3-D Model for Ananthapuramu district.

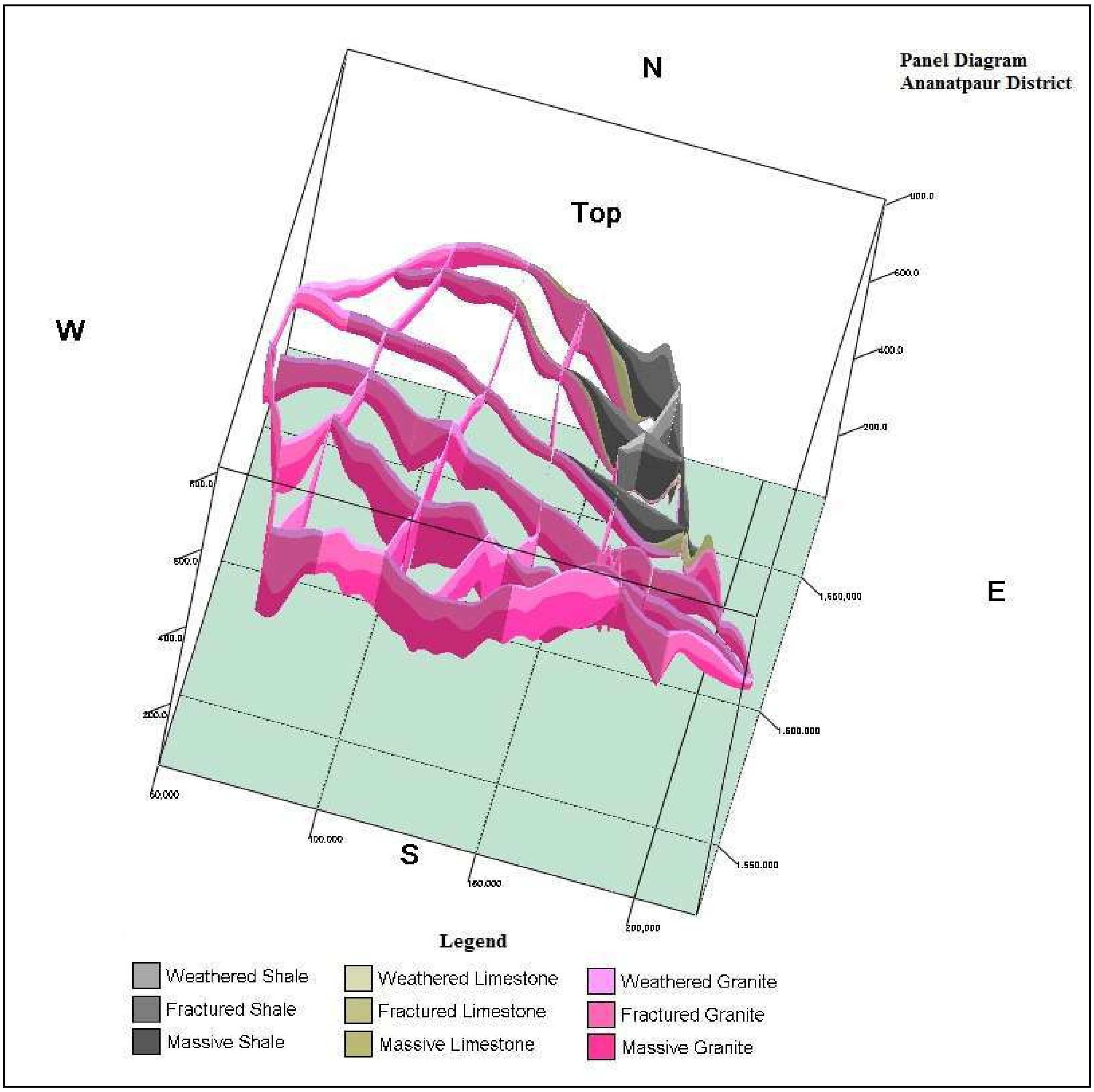


Fig.-3.2: Panel diagram-Ananthapuramu district.

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 (~20-199 m).

3.2 Hydrogeological Sections

Hydrogeological sections (6 nos) are prepared in N-S, NW-SE, W-E (North), W-E (middle) W-E (South) and SW-NE directions (**Fig. 3.3**).

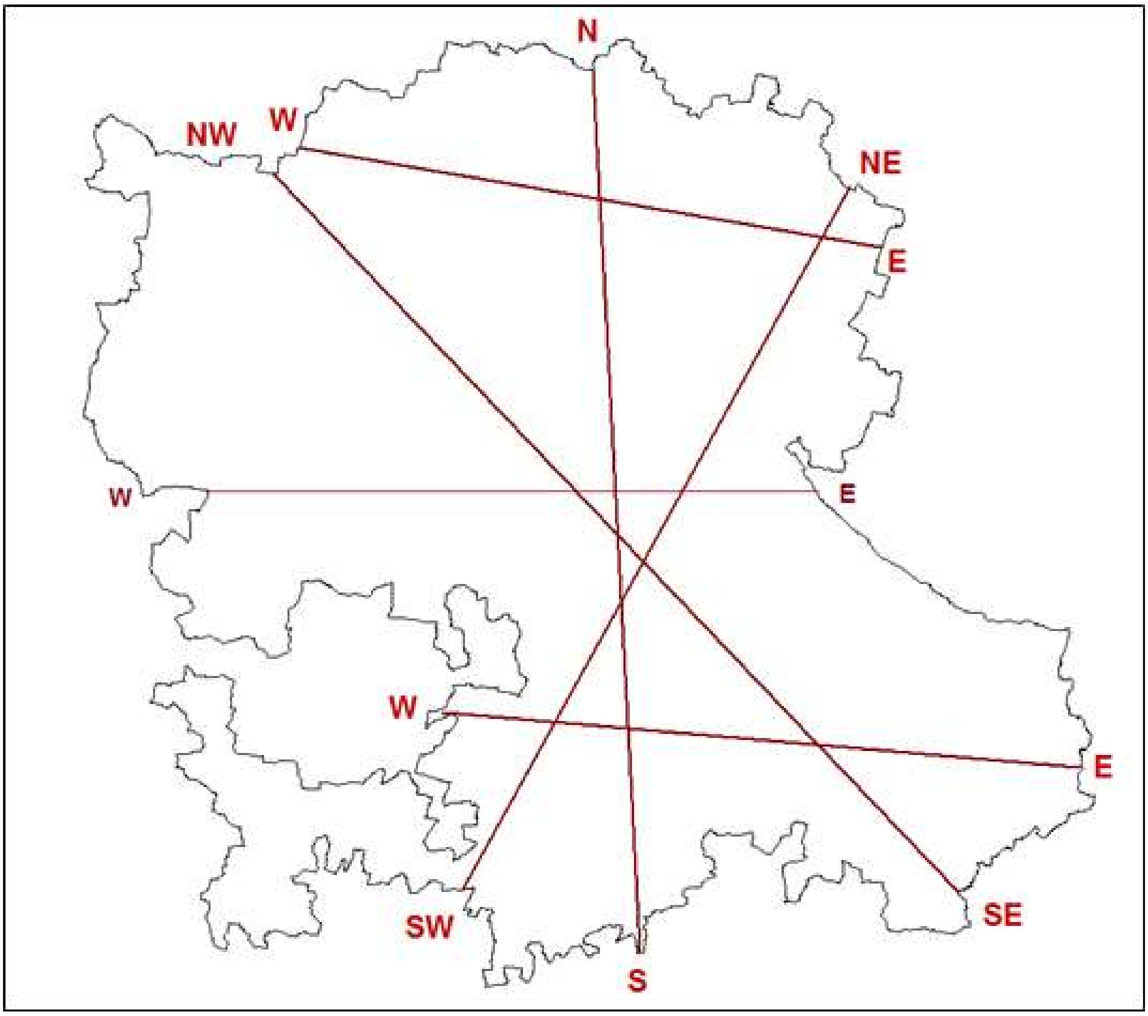


Fig.-3.3: Map showing orientation of various sections.

3.2.1 North-South Section: The section drawn vertically along the N-S direction covering distance of ~160 kms (**Fig.3.4a**). It depicts thick fractured zone in northern parts compared to massive nature of granite in southern parts. The central parts of the section show less weathering and fractures.

3.2.2 North-West and South-East Section: The section drawn along the NW-SE direction covering distance of ~180 kms (**Fig.3.4b**). It depicts thick fractured zone in central parts and south eastern parts. Shallow depth of weathering and fracturing is observed in north-western part.

3.3.3 South-West and North-East Section: The section drawn along the SW-NE parts covering distance of ~160 kms (**Fig.3.4c**). It depicts uniform occurrence of fracture zone in south west and central parts of the section, where as the shales are abutting against granite in north eastern parts.

3.2.4 West-East Section (Northern parts of Ananthpuramu district): The section drawn horizontally along the West-East direction in Northern parts of the district covering distance of ~100 kms (**Fig.3.4d**). It depicts the occurrence of fracture zone on central parts of the section and occurrence of weathering zones in western parts. The shales are abutting against granite in eastern parts.

3.2.5 West-East Section (Middle parts of Ananthpuramu district): The section drawn horizontally along the West-East direction in middle parts of the district covering distance of ~130 kms (**Fig.3.4e**). It depicts the uniform occurrence of weathered and fractured zones in the west and central parts of the district. In the eastern parts of the district, the shales are abutting against granites.

3.2.6 West-East Section (Southern parts of Ananthpuramu district): The section drawn horizontally along the west-east direction in southern parts of the district covering distance of ~75 kms (**Fig.3.4e**). It depicts the occurrence of weathered and fractured zones in the central and eastern parts of the section than the western parts.

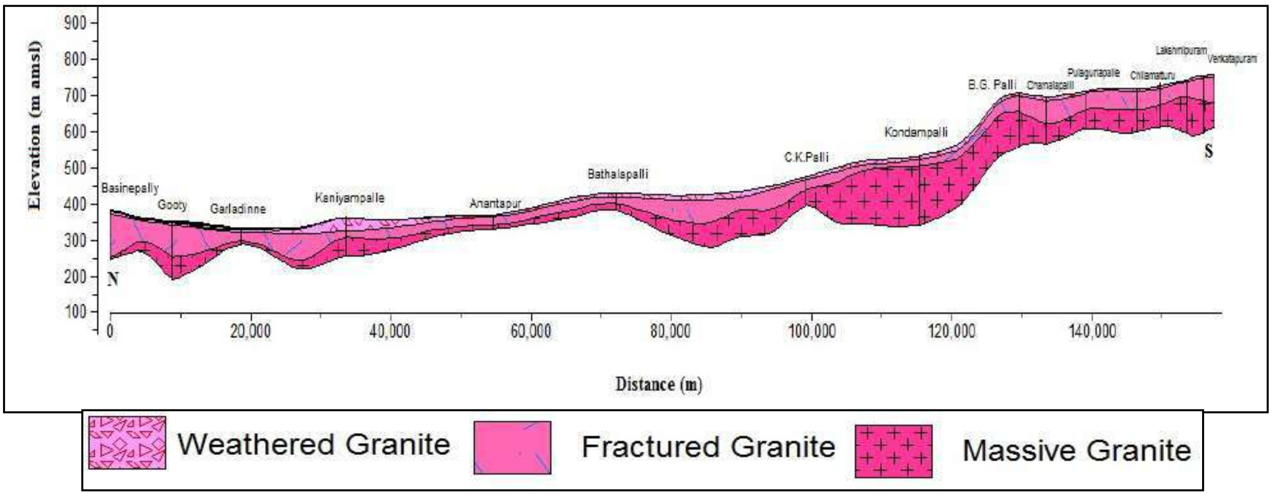


Fig-3.4 a: North-South (N-S) Section

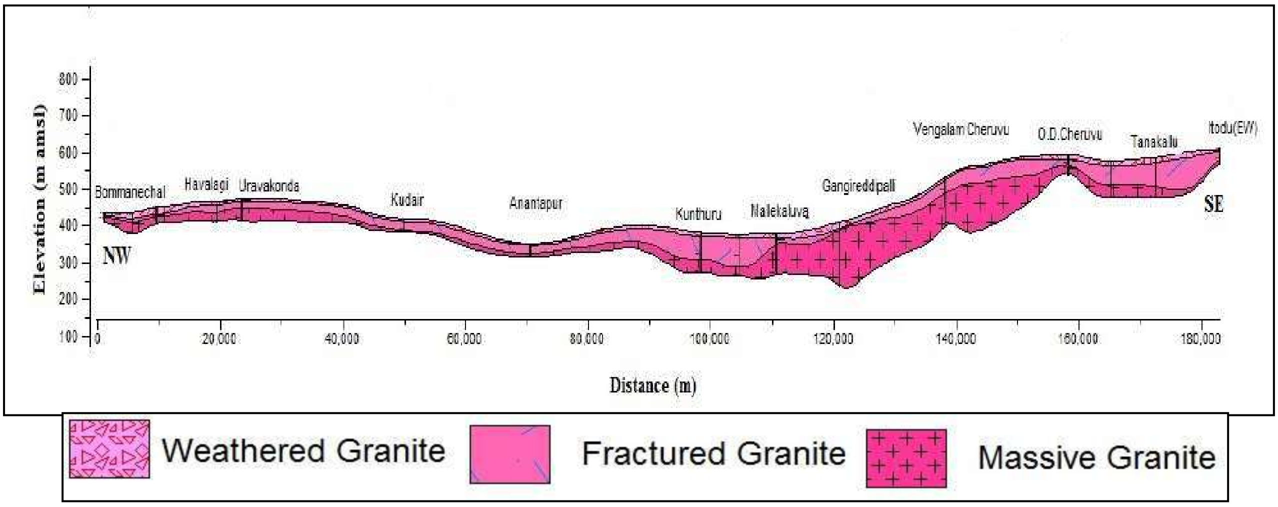


Fig-3.4 b: North West – South East (NW-SE) Section

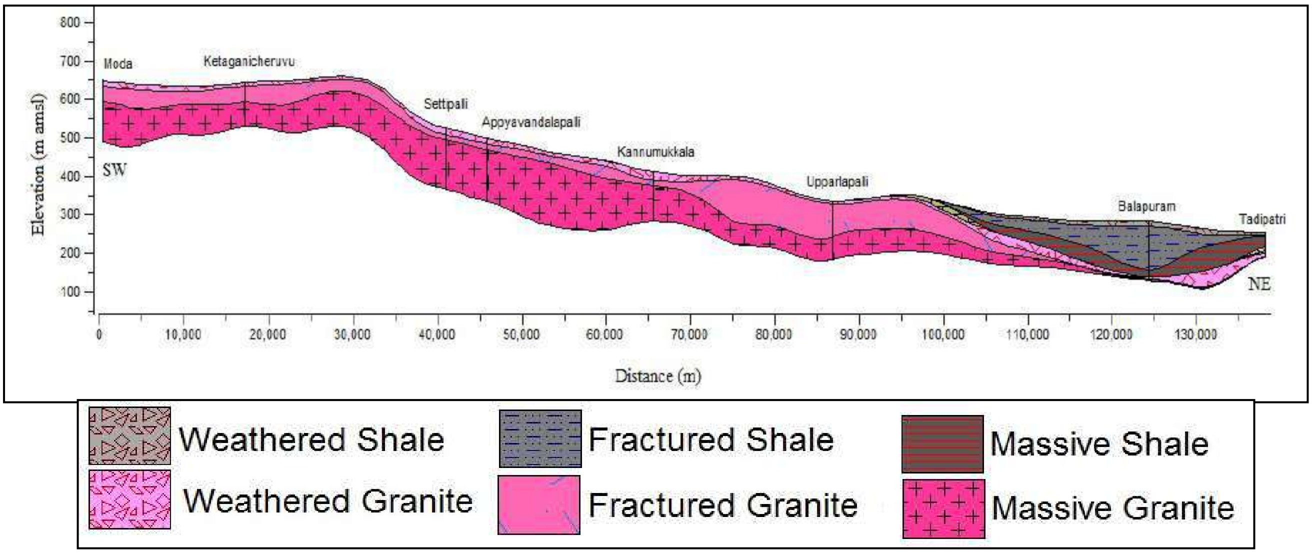


Fig-3.4 c: South West – North East (SW-NE) Section

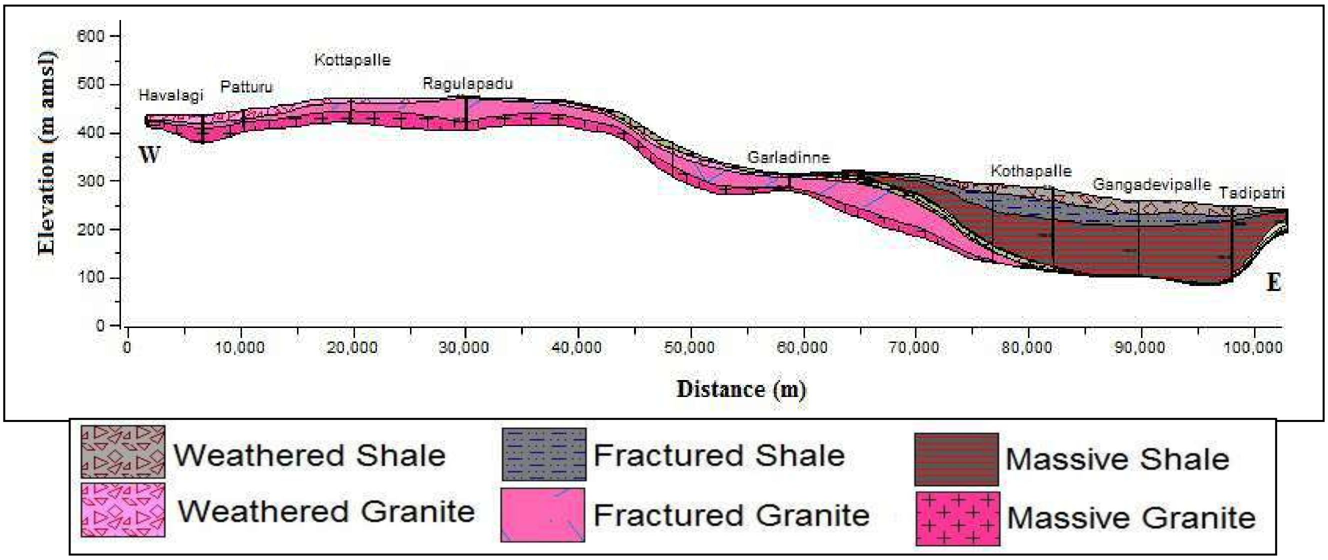


Fig-3.4 d: West –East (W-E) Section (North of Ananthapuramu District)

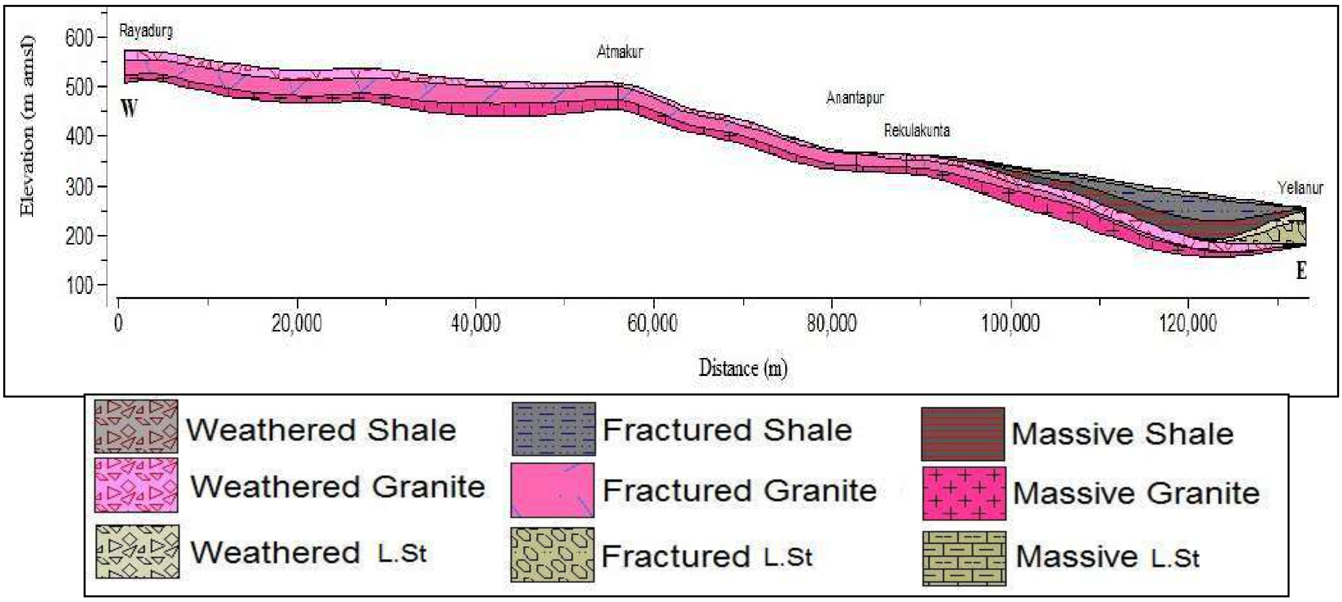


Fig-3.4 e: West –East (W-E) Section (Middle of Ananthapuramu District)

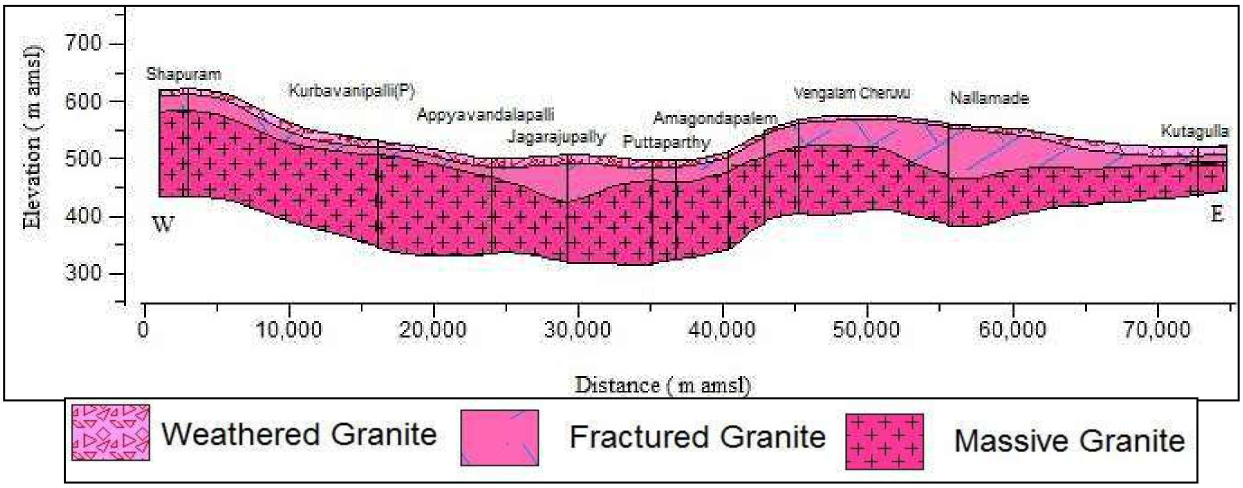


Fig-3.4 f: West –East (W-E) Section (South of Ananthapuramu District)

3.3 Aquifer Characterization

3.3.1 Weathered zone:

In Cuddapah Group of rocks (Shales and Limestones) average depth of weathering varies from 13-31 m (avg: 20 m). In granite it varies from 5-26 m (avg: 11 m) and in gneisses it ranges from 5-30 m (avg: 13 m). The weathered zone in most of aquifers has gone dry in considerable part due to over-exploitation (excluding command area) and scanty rainfall.

Thickness of weathered zone is < 10 m in most part of area followed by 10-20 m. Deep weathering (> 20 m) occurs in north-eastern and south-western part of the district (**Fig.3.5**). Ground water yield from weathered limestone/shale formation varies from 0.2 to 3.5 lps in granite/gneiss aquifer it ranges from <0.1 to 4.5 lps (avg: 1.5 lps).

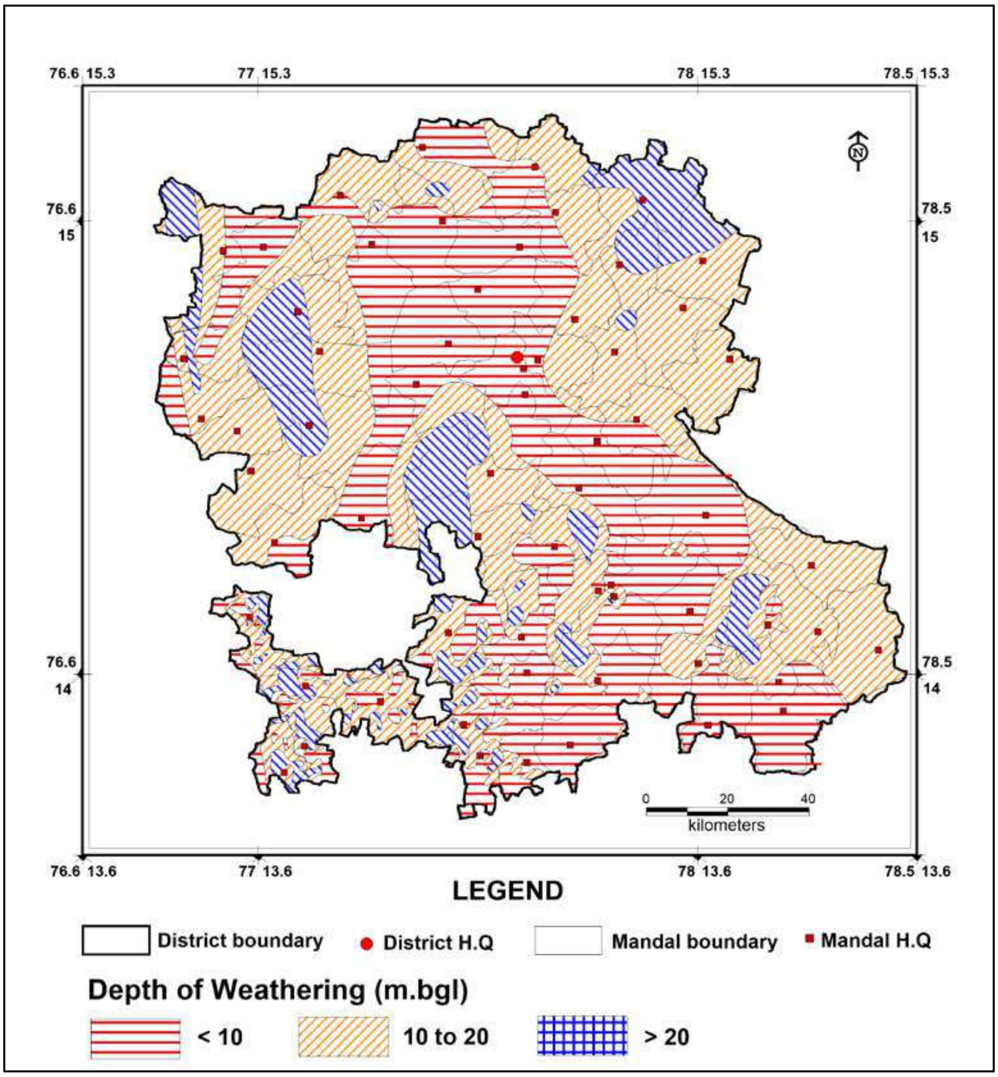


Fig.3.5: Thickness of weathered zone-Ananthapuramu district.

3.3.2 Fractured zone:

In Cuddapah Group of rocks (Limestones and shales) depth of fracturing varies from 20-188.3 m and deepest fracture is encountered at 188.3 m (Konnauppalepadu). In granite it varies from 11 to 199 m and in gneisses it ranges from 13-169 m. The depth of fracture map is presented in **Fig. 3.6.** ~ 83% of fractures occur within 100 m depth and rest occur below this depth (**Fig.3.7**). Ground water yield from fractured limestone/shale formation varies from 0.2 to 5.5 lps in granite it ranges from <0.1 to 12 lps and gniesses it ranges from 0.1 to 10 lps.

The combine transmissivity (T) in weathered and fracture zone in limestone/shale aquifer varies from 2 to 210 m^2/day, in granite aquifer it ranges from 1 to 316 m^2/day and in gneisses it varies from 4 to 175 m^2/day. The combine storativity (S) in weathered and fracture zone in limestone/shale aquifer varies from 0.00011 to 0.001, in granite aquifer it ranges from 0.0002 to 0.001and in gneisses it varies from 0.00037 to 0.025.

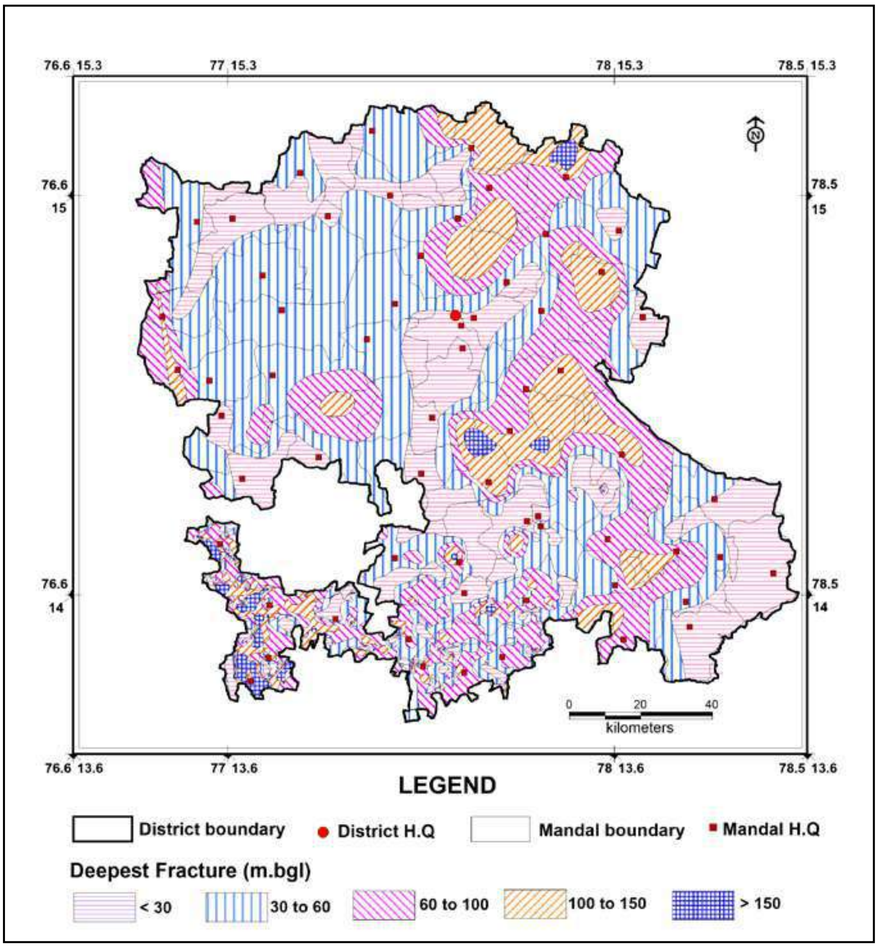
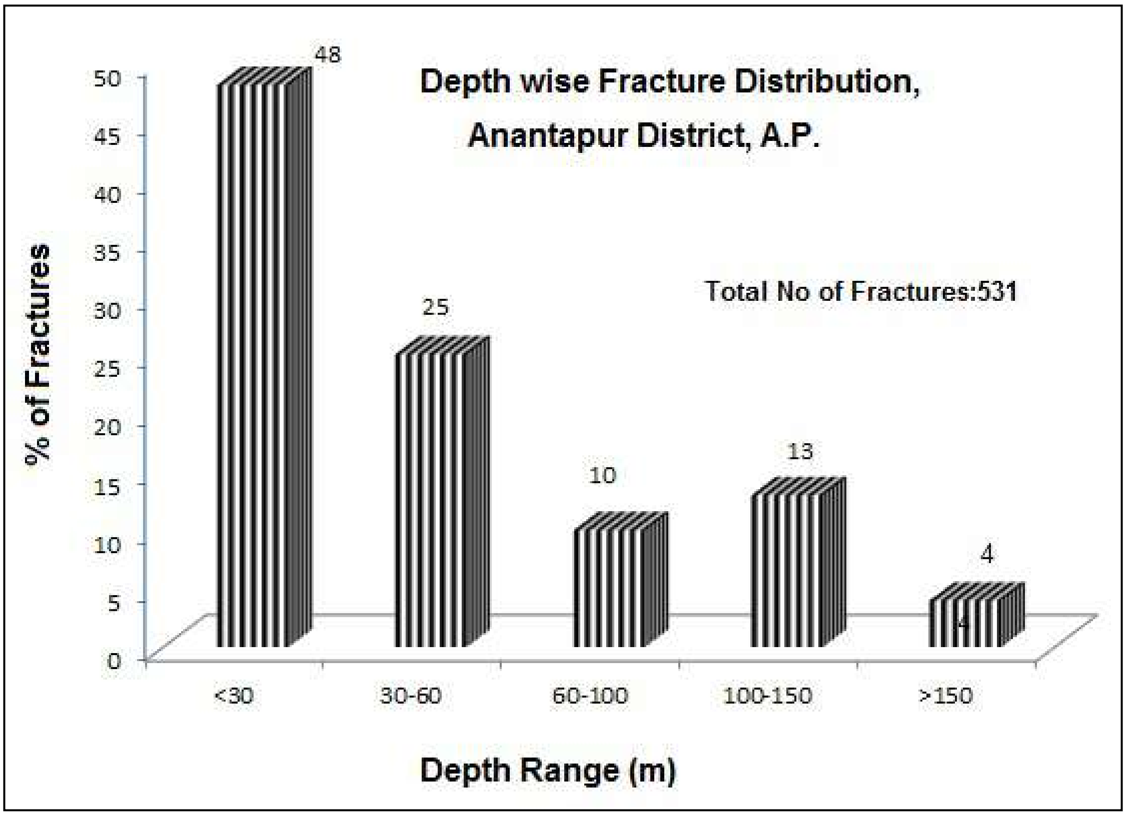


Fig.-3.6: Depth of fractured zone (Maximum depth) (m bgl).



4.

Fig.-3.7: Depth wise distribution of fractures in Anatapuramu district.

4.0 GROUND WATER RESOURCES (2013)

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 command/ non-command area and mandal wise resources are given in **Table-4.1 and Annexure-1** respectively.

As per 2013 GEC report, the net dynamic replenishable groundwater availability is 1495..3 MCM, gross ground water draft for all uses 1403.7 MCM, provision for drinking and industrial use for the year 2025 is 186.8 MCM and net annual ground water potential available for future irrigation needs is 347.6 MCM. Stage of ground water development varies from 27 % in Nallamada mandal to 267 % in Putlur mandal (avg: 94 %). Out of 63 mandals 31 mandals falls in over-exploited category (44% of area), 7 in critical category, 10 in semi critical category and rest 15 in safe category. The in-storage ground water resources down to the maximum fractured depth (199 m) are 501.8 MCM.

Table-4.1: Computed Dynamic, In-storage ground water resources, Ananthapuramu district.

Parameters	Command	Non-command	**Total**
As per GEC 2013	MCM	MCM	MCM
Dynamic (Net GWR Availability)	**265.03**	**1230.24**	**1495.27**
• Monsoon recharge from rainfall	77.31	630.71	708.02
• Monsoon recharge from other sources	77.47	117.73	195.20
• Non-Monsoon recharge from rainfall	47.98	382.49	430.47
• Non-monsoon recharge from other sources	89.72	224.21	313.93
• Provisional for natural discharge	27.34	124.91	152.25
Gross GW Draft	**156.86**	**1246.86**	**1403.72**
• Irrigation	141.45	1154.97	1296.42
• Domestic and Industrial use	15.41	91.89	107.30
Provision for Drinking and Industrial use for the year 2025	19.24	167.6	186.84
Net GW availability for future irrigation	108.86	238.78	347.64
Stage of GW development (%)	59	101	94
	Mandal wise it varies from 27 % (Nallamada) to 267% (Putlur)		
In-storage GW Resources (down to the maximum depth of fractures)	**501.8**		

5. GROUND WATER RELATED ISSUES and REASONS FOR ISSUES

5.1 Issues

Pollution (Geogenic and Anthropogenic)

1. Few mandals are fluorosis endemic where fluoride (geogenic) as high as 7.2 mg/L is found in groundwater. The high fluoride concentration (>1.5 mg/L) occur in 58 % of area.

2. High nitrate (> 45 mg/L) due to anthropogenic activities is observed in 26 % samples (20 nos).

3. The high concentration of EC (> 3000 micro-seimens/cm) in 3 % of the area is observed during pre-monsoon season of 2015 falling in Vidapnakal, Vajrakarur, Urvakonda, O.D. Cheruvu and Madakasira mandals.

Over-exploitation

4. ~ 8423 Km^2 area (44%) covering 31 mandals is categorized as over-exploited where ground water balance for future irrigation is zero or negative.

Deep water levels

5. Deep water levels (> 20 m bgl) are observed during pre as well as post-monsoon season in 42 % and 19 % of the area respectively.

6. Out of 72 wells analyzed, 36 wells and 41 wells shows falling trends in pre and post-monsoon season in the last 11 years (@-0.02 to -4.4 and -0.04 to -6.2 m/yr) respectively.

Sustainability

7. Low yield (< 1 lps) occurs in the area covered by BGC formation.

Unscientific construction of ARS

8. In 590 villages' excess 6235 ARS (CD: 4733 and PT: 1502) are constructed unscientifically where there was no surplus runoff water available. Inorder to fill these structures additional 146 MCM of surface water has to be brought from external sources.

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

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

6. MANAGEMENT STRATEGIES

Low rainfall and high dependence on groundwater led to a steady fall in water levels and desaturation of weathered zone in some parts, raising questions on sustainability of existing groundwater structures, food and drinking water security. The occurrence of fractures in fractured zone 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 m depth (83 %) (**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 2.21 lakh MCM of unstaturated volume (below the depth of 3 m) is avaialable during post-monsoon season of 2015 having 3272 MCM of recharge potential (Weathered zone:3236 and Fractured zone:35) (considering 2% specific yield) . This can be utilized for implementing management strategy.
- In 590 villages' excess 6235 ARS (CD: 4733 and PT: 1502) are constructed unscientifically where there was no surplus runoff water avaialable. Inorder to fill these structures additional 146 MCM of surface water has to be brought from external sources (from outside the district) (**source: www.emuster.in/nregs_ap/reports/index.aspx**).
- For recharging the entire unsaturated zone in weathered aquifer, 2712 MCM of surface water is required to recharge up to 3 m bgl. In 97 villages total runoff is more than unsaturated volume of the aquifer.

The study suggests notable measures for sustainable groundwater management, which involves a combination of supply side and demand side measures

6.1.1 Supply side measures:

Ongoing Projects

Repair Renovation and Restoration of existing tanks:

- De-silting of 8.35 MCM of silt from existing 1438 (minor irrigation tanks and Percolation tanks) are taken under state Govt. sponsored NEERU-CHETTU programme has created additional surface storage. This will contribute ~ 2.5 MCM to groundwater (considering 30% of recharge) and with this additional ~416 ha land can be brought under irrigated dry (ID) crops in tank ayacut.

To be taken up

Artificial Recharge structures:

Constructions of 1688 artificial recharge structures (ARS) with 30.4 MCM of available surface water, costing ~118.8 crore rupees are proposed in 370 villages.

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 3 m). Initially village wise dynamic groundwater resources of 2013 are considered. Potential surface run off is estimated by following standard procedures. On conservative side 25 % run off yield is considered as non-committed yield for recommending artificial recharge structures.

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 the hydrogeological characteristics, the area is further sub-divided into following six categories (**Table-6.1**).

- 1688 artificial recharge structures (1000 CD's with 4 filling and 688 mini PT's with 1.5 fillings) costing **118.8** crores can be taken up (**Annexure-2**).
- After effective utilization of this yield, there will be 15.2 MCM of ground water recharge (50 % of total utilizable yield).
- Roof top rainwater harvesting structures should be made mandatory to all Government buildings (new and existing).

Table-6.1: Hydrogeological characteristics of area.

Category	Hydrogeologic characterizations
1	Ground water quality safe area (EC < 3000 and F <1.5 mg/L) with no further scope for artificial recharge
2	Ground water quality safe area (EC < 3000 and F <1.5 mg/L) with further scope for artificial recharge
3	Ground water quality safe area(EC < 3000 and F <1.5 mg/L) further scope for artificial recharge from external source of water (outside the district)
4	Ground water quality problematic area (EC > 3000 and F >1.5 mg/L) with no further scope for artificial recharge
5	Ground water quality problematic area (EC > 3000 and F >1.5 mg/L) with further scope for artificial recharge
6	Ground water quality problamatic area (EC > 3000 and F >1.5 mg/L) with further scope for artificial recharge from external source of water (outside the district)

Contemplated Projects:

Under Handri Niva Sujala Sravanthi (HNSS) drinking water supply scheme there is provision to supply drinking water needs of 33 lakh population and to create additional ~157000 hectare of irrigation potentential in Anantapuramu district at the cost of 492 crores. The scheme is to lift 40 TMC of surplus water from river Krishna at Malayala village in Kurnool district.

As the scheme is to provide drinking water needs to most of population, there will be net saving of ground water from the district.

Considering the 12560 MCM of water requirement for 157000 hactares (@0.08MCM/ha). If micro irrigation prctices are implemented, than it will irrigate about 2.10 lakh hacteres (additional 52300 hactares).

Other supply side measures:

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. Total 19280 farm ponds are recommended (20 in each village in 964 villages) with total cost of **48.2** crores.

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

Ongoing Work

- In the district till date a total number of 203145 no's drip and sprinklers are sanctioned which has irrigated ~203145 ha of land saving ~4063 MCM of groundwater from the district considering 25% of net savings as compared to traditional practice of flood irrigation.

Proposed Work

- ~48200 ha of present irrigated land can be brought under micro-irrigation (@50 ha/village) costing about **289.2 crores** (considering 1 unit/ha @0.6 lakh/ha). With this **96.4 MCM** of ground water can be conserved over the traditional irrigation practices (considering 0.006 MCM/ha for ID crops against 0.008 MCM/ha).
- Change in cropping pattern from water intensive paddy druing rabi season to other 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.
- As a mandatory measure, every groundwater user should recharge rainwater through artificial recharge structures in proportionate to the extraction.
- 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.
- 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.

- The other measure includes providing supplementary calcium, phosphorous rich food along with multivitamin tablets to the children below the ages of 14 years in fluoride endemic villages along with mid day meal scheme. Creating awareness about safe drinking water habits, effects of high fluoride and nitrate rich groundwater, improving oral hygiene conditions are recommended.

6.2 Expected results and out come

With the above interventions costing Rs **456.2** crores (excluding the cost involved in HNSS project), the likely benefit would be the net saving of 116.6 MCM of ground water. This will bring down the stage of ground water development by 7 % (from 94 % to 87 %).

Acknowledgment

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