भारतसरकार
जल शक्ति मंत्रालय
जल संसाधन, नदी विकास और गंगा संरक्षण विभाग
केंद्रीयभूमिजलबोर्ड

GOVERNMENT OF INDIA
MINISTRY OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES, RIVER DEVELOPMENT & GANGA REJUVENATION

REPORT ON
AQUIFER MAPPING FOR SUSTAINABLE MANAGEMENT OF GROUND WATER RESOURCES IN SRI SATHYA SAI DISTRICT, ANDHRA PRADESH STATE

CENTRAL GROUND WATER BOARD
SOUTHERN REGION
HYDERABAD
FEBRUARY 2025

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REPORT ON
AQUIFER MAPPING FOR SUSTAINABLE MANAGEMENT OF GROUND WATER RESOURCES IN SRI SATHYA SAI DISTRICT, ANDHRA PRADESH STATE
Executive summary

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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
ham	:	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 Sri Sathya Sai district covering about 8925 km^2 lies between 13°40' and 14° 6' Northern Latitude and 76°88' and 78°30' Eastern Longitude. The district is bounded on North by Ananthapuramu District, on the East by YSR Kadapa District & Chittoor District and on West and South West by Karnataka State. Administratively the district is governed by 4 revenue divisions 32 mandals and 461 revenue villages with a population of ~18.40 lakhs (2011 census) (urban:21 %, rural: 79 %). The density of population is 206 persons/Km^2 and there is an increase in 10.60% growth rate over last 10 years. (CPO**, Sri Sathya Sai district, 2020**).

The normal rainfall of the district varies from 354 mm (Chennekothapalle mandal) to 700 mm (Bukkapatnam mandal) with district normal of 591 mm. Southwest monsoon contributes 60 %, Northeast monsoon by 29 % and rest 11% by winter and summer rainfall.

The area is underlain by various geological formation from the oldest Archaean rocks to metasediments of Cuddapah supergroup of Proterozoic age. About 90 % of the area is underlain by crystalline rocks, namely Banded gneissic complex, granites of Archaean to Proterozoic age and remaining 10 % of the area in the northeastern and nortwestern parts of the district is underlain by metasediments of Cuddapah supergroup of Proterozoic age, namely shales and limestone Pediplain is the major landform of the district. The other landforms observed are pediment denudation hills , flood plain, residual hill, channel fill, etc. The district is part of Krishna and Pennar sub basin. During 2019-20 the gross swon area is 71024 hector, in which in Kharif 42382 hectors and in Rabi 28642 hectors. Groundnuts are cultivated in 64% of the total area, followed by horse gram (13.4%), red gram (8.5%), maize (4%), paddy (3%), jowar (2%), green gram (1.5%), and other crops. Forest occupies nearly 13 % of the area. The area is mainly occupied by clayey skeletal soils, fine, mixed loamy soils, loamy soils, montmorillonitic and rock out crops.

Groundwater exploration data revealed that the depth of drilling varies from 27 to 305 m bgl and weathering varies from 5 to 25 m bgl. CGWB drilled 30 bore wells (exploratory, observation and piezometers) in the district. Data analysed from CGWB wells indicates, 06 wells are of shallow depth (30 m), 07 nos are of 30-60 m, 02 nos are of 60-100 m, 10 nos are of 100-150 m, 33nos are of 150-200 m and 05 nos are of 200-305 m depth.

Depth of exploratory wells in granite rocks varies from 27-305 m and deepest fractured encountered is at 157 m (Kanaganapalle). In Gniesses the depth of exploratory wells ranges from 145-200 m and deepest fracture is encountered at 60 m (Gollapalle).

The water levels during pre monsoon season in the range of 2-5 m cover ~ 40% of area, 5-10 m bgl covers 37% of area, 10-20m bgl covers 17% of the area and 20-40m bgl covers 4% of the area. Deep water levels in the range of > 40 m bgl occupy ~1% of area mostly in south eastern part of the district. Shallow water levels (<2 mbgl) occur in northern eastern part of the district covering 1.2% of area. Majority of the water levels during Post monsoon season are in the range of 2-5 m covering ~58 % of area, followed by 5-10 mbgl (23 of area), 10-20 m bgl (2.4%). Shallow water levels (0-2 mbgl) occupy ~16 % of area occur in northern and northesatrn part of the district.

The data analysed from the groundwater quality indicate that during pre-monsoon season, the electrical conductivity varies from 260-4419 (avg: 1534) µ Siemens/cm. High EC (>3000 µ Siemens/cm) is detected in Talupaula, Madakasira, Amadagur, Nallacheruvu,O.D. Cheruvu and Kadiri mandals. The concentration of TDS varies from 165-2658 (avg: 949) and TH varies from 60-1160 (avg: 408) mg/l.The concentration of Ca2+, Mg 2+, Na+, and K+ ranges from 10-257, 9-199, 25-818 and 0.5-464 mg/l respectively. The Nitrate (NO3) concentration ranges from 01 to 674 mg/l. It is noticed that in about 37% of the samples (26 samples) from Rolla, Hindupur, Dharmavaram, Amarapuram, Mudigubba, Gorantala, Madagsira, Amadapur, Agali, Nallamada, Lepakshi, Kadiri,Tanakal, O D Cheruvu, Talupuala and Nallacherevu mandals the quality is not suitable for drinking water purpose (>45 mg/l) (Fig.). The Fluoride concentration varies from 0.26-4.0 mg/l and in 51 samples (73 %) it is within permissible limit of <1.5 mg/l. The high fluoride concentration (>1.5 mg/l) is observed in 19 samples (27%) in Gorantal, Tanakal Talupula, Mudigubba, Chennekothapalle, Madakasira, O D Cheruvu, Somendepalli, Nallamada, Nallacheruvu, Chilmathur, NP Kunta, Amadagur, Bukkapatnam Penukonda and Kadiri mandal.

During post-monsoon season the Electrical conductivity varies from 279-4070 µ Siemens/cm (avg. 1589 µ Siemens/cm). In 89 samples (94%) the EC is within 3000 µ Siemens/cm while in 6 sample (6%) from in Tadimari , Bukkapatnam, Hindupur, Somandepally, Amarapuram, and Dharamvaram the EC is >3000 µ Siemens/cm. The concentration of TDS varies from 179 to 2605mg/l (avg. 995 mg/l). The Nitrate(NO3) concentration ranges from 0.26 to 36.2 mg/l (avg 8.15 mg/l) and it is under permisble limit(<45mg/l). The Fluoride concentration varies from 0.23-1.85 mg/l and found that 68 samples (72%), it is falling under permissible limit of <1.5 mg/l. While in 27 samples (28%)

from Nallamada, Bukkapatnam, Dharmavaram, Amarapuram, Talupula, Amadagur, Ramagiri, Madakasira, Chennakothapalli, Penukonda, Lepakshi, Hindupur, Mudigubba, Nallamada, Agali, and Kanaganipalli mandals are having high fluoride concentration (>1.5 mg/l).

Conceptualization of 3-D hydrogeological model was carried out by integrating and interpreting representative hydrogeological data points for preparation of 3-D map, panel diagram and hydrogeological sections. The lithological information was generated by using the RockWorks-16 software and generated various 3D map as well hydrogeological sections.

As per 2023 GEC report, the net dynamic replenishable groundwater availability is 1121.28 MCM, gross ground water draft for all uses 630.57 MCM, provision for drinking and industrial use for the year 2025 is 111.19 MCM and net annual ground water potential available for future irrigation needs is 561.21 MCM. Out of 32 mandals 04 mandals falls in over-exploited category. 1 in critical category, 3 in semi critical category and rest 24 in safe category. Mandal wise Stage of Ground Water Extraction varies from 19 % (Bukyapatnam) to 161% (Gandlapenta).

In the district 5272 MCM of unstaturated volume (below the depth of 5 m) is avaialable during post-monsoon season of 2022 having 105 MCM of recharge potential (considering 2% specific yield). This can be utilized for implementing management strategy.

De-silting of 4.79 MCM of silt from existing 829 (minor irrigation tanks and Percolation tanks) are taken under state Govt. sponsored NEERU-CHETTU programme has created additional surface storage. This will contribute ~ 1.44 MCM to groundwater (considering 30% of recharge) and with this additional ~240 ha land can be brought under irrigated dry (ID) crops in tank ayacut.

In district there is recharge potential 105 MCM, 144 MCM Utilizable Yield (uncommited Runoff) and 33 MCM of volume is available for considering Recharge. About 5400 artificial recharge structures were constructed (PTs:1502, CDs:3898) in 349 villages. Artificial recharge structures are recommended for 50% of the utilizable yield in the intermittent areas. About 201 artificial recharge structures (159 mini PT’s with 1.5 fillings with a unit cost of Rs 20 lakhs each and 42 CD’s with recharge shafts with 6 fillings with a unit cost of Rs. 15 lakhs each) with a total cost of 38.10 Crores can be taken up. After effective utilization of this yield, there will be 3.43 MCM of groundwater recharge with 100% recharge efficacy.Roof top

rainwater harvesting structures should be made mandatory to all Government buildings (new and existing).

The above interventions costing Rs 61.15 crores (excluding the cost involved in HNSS project), the likely benefit would be the net saving of 6.20 MCM of ground water. This will bring down the stage of ground water Extraction by 0.31 % (from 56.20 % to55.92 %).

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: Sri Sathya Sai district having geographical area of 8925 Sq.Km lies between 13°40' and 14° 6' Northern Latitude and 76°88' and 78°30' Eastern Longitude. The district is bounded on North by Ananthapuramu District, on the East by YSR Kadapa District & Chittoor Distrct and on West and South West by Karnataka State. The District has been divided to 2 Natural Divisions. They are 1) Northern Mandals of Dharmavaram, Bathalapalli, Tadimarri, Mudigubba are mainly made up of arid treeless, expense of poor red soils (2) High Level Land of Penukonda, Roddam,Somandepalli, Hindupur, Lepakshi, Chilamathur, Madakasira, Rolla, Gudibanda and Agali which connects with Mysore plateau at higher elevation of the rest of the district. This part has average sandy red soils of normal productivity. Administratively the district is governed by 4 revenue divisions 32 mandals and 461 revenue villages with a population of ~18.40 lakhs (2011 census) (urban:21 %, rural: 79 %). The density of population is 206 persons/Km^2 and there is an increase in 10.60% growth rate over last 10 years (CPO**, Sri Sathya Sai district, 2020**).

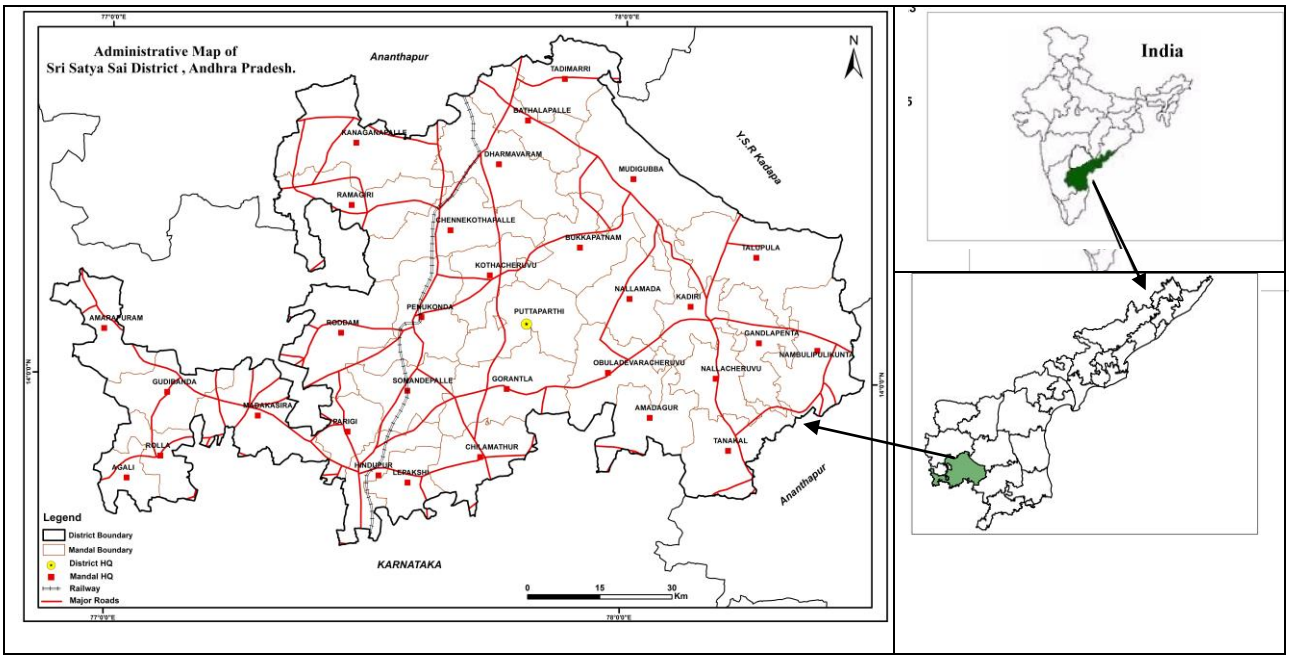

Fig.1.1: Location of Sathya sai district, Andhra Pradesh

1.4 Climate and Rainfall: The district receives fairly good amount of normal rainfall. The normal rainfall of the district is 590.9 mm. The normal rainfall for the South West Monsoon period is 356.5 mm which forms about 60.3 % of the total rainfall for the year. The normal rainfall for North East monsoon period is 170.8mm only, which forms 28.9% of the total rainfall for the year (October to December). The other months are almost dry. March, April and May are warm months where the normal Maximum temperature ranges between 37.60°C to 39.20°C, where as the actual Maximum temperature recorded during March, April and May are 38.20°C, 40.40°C and 40.40°C respectively. The normal minimum temperature ranges between 17.50°C to 17.70°C in January and December, whereas the actual Minimum temperature recorded during January and December are 18.50°C and 17.40°C respectively.

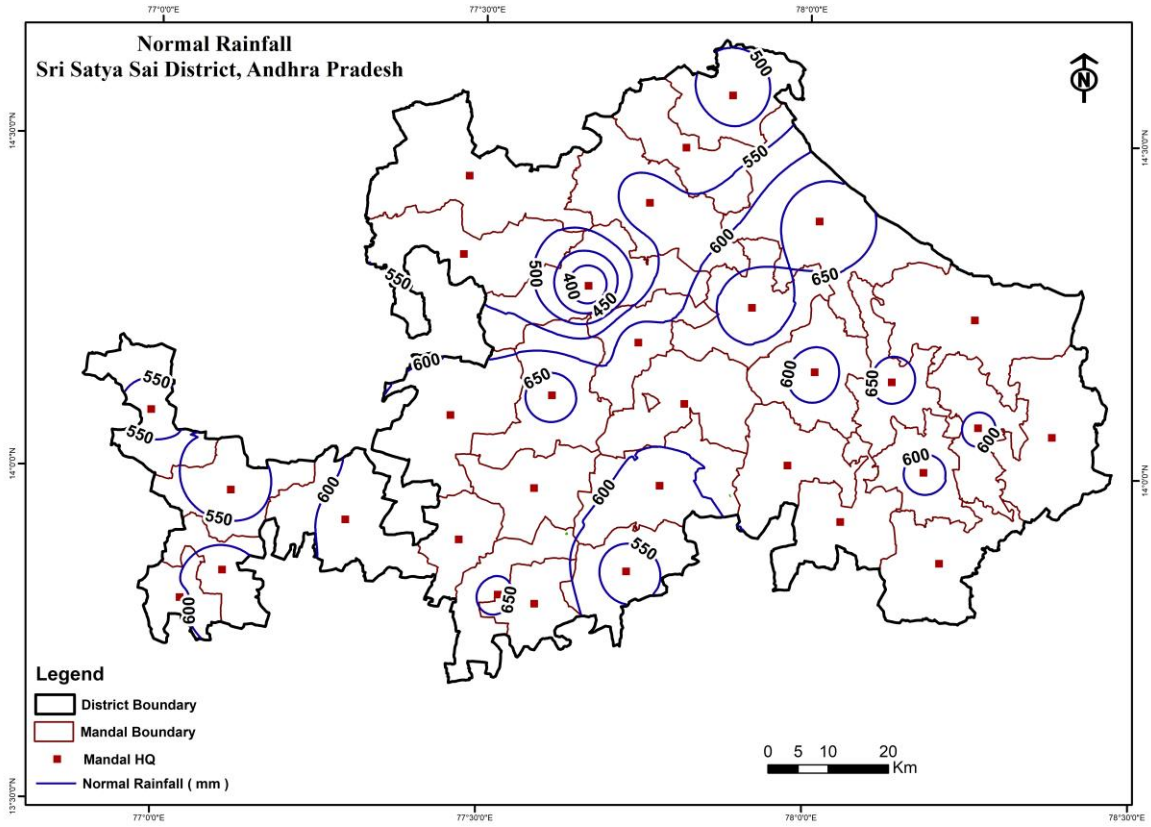

Fig.1.2: Normal Rainfall map of Sri Sathya Sai district.

1.5 Geomorphological Set up: Pediplain is the major landform of the district. The other landforms observed are pediment denudation hills , flood plain, residual hill, channel fill, etc.

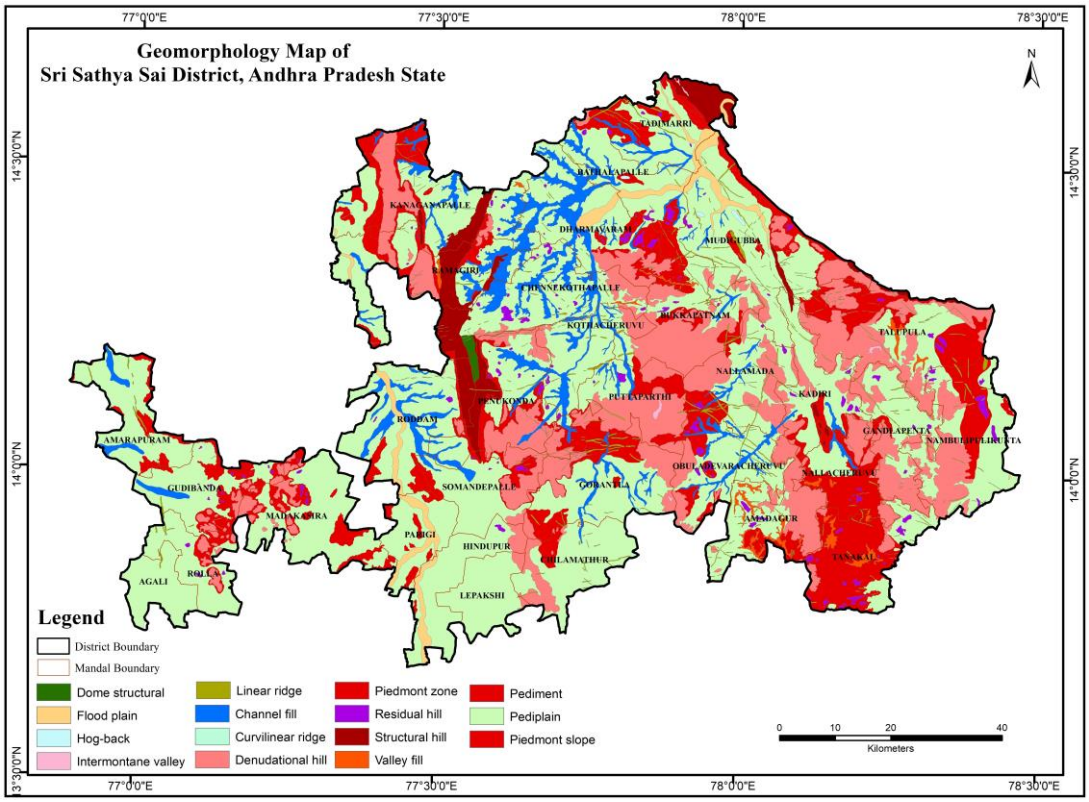

Fig.1.3: Geomorphology of Sri Sathya Sai district.

1.6 Drainage and Structures: The district is mainly drained by the rivers Pennar and its tributararies Jayamangala, Chitravathi, Vedavathi Maddileru, Papagni, Vandamanneru, Tadakaleru and Pandameru. Map depicting drainage, hills and water bodies is presented in **Fig.1.4**.

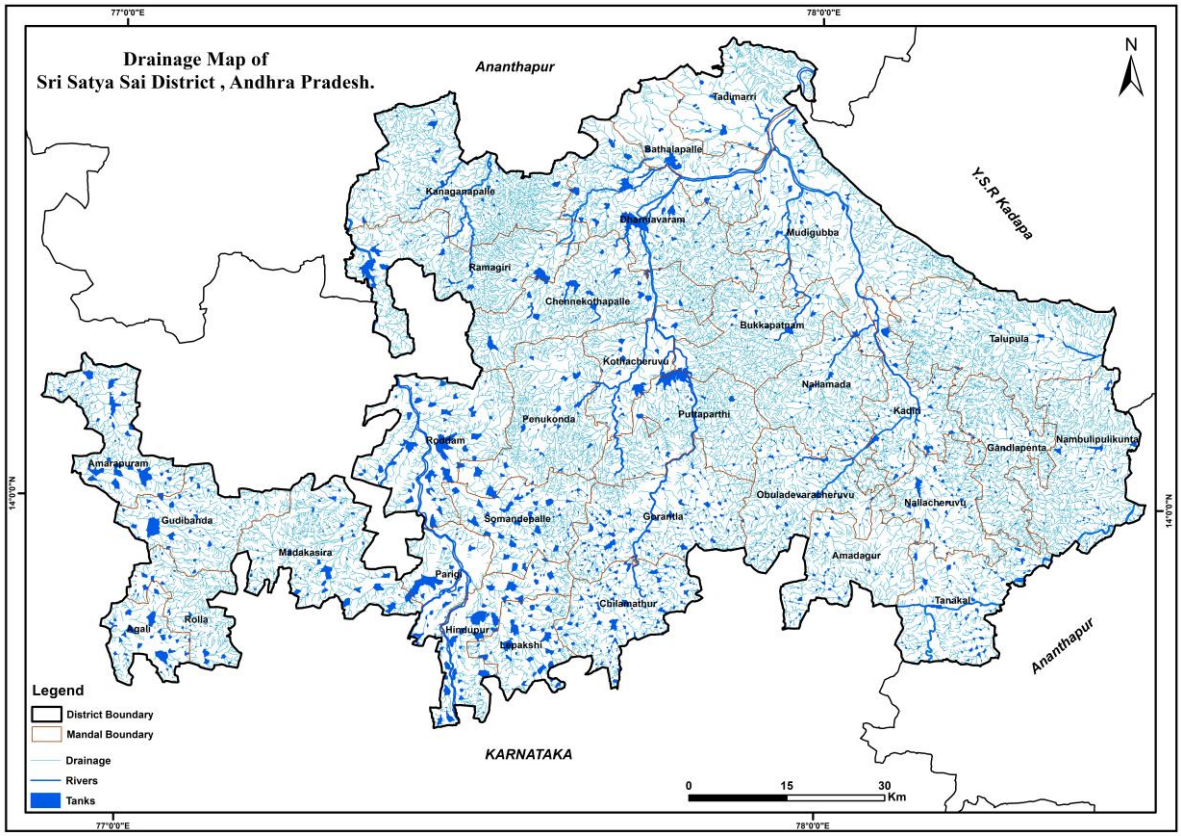

Fig.1.4: Drainage map of Sri Sathya Sai district of A.P.

1.7 Land utilization: The total geographical area of the district is 8.925 lakh Hects. During the 2019-20 period, the total gross sown area was 71,024 hectares, with 42,382 hectares sown during the Kharif season and 28,642 hectares during the Rabi season. Groundnuts are cultivated in 64% of the total area, followed by horse gram (13.4%), red gram (8.5%), maize (4%), paddy (3%), jowar (2%), green gram (1.5%), and other crops.

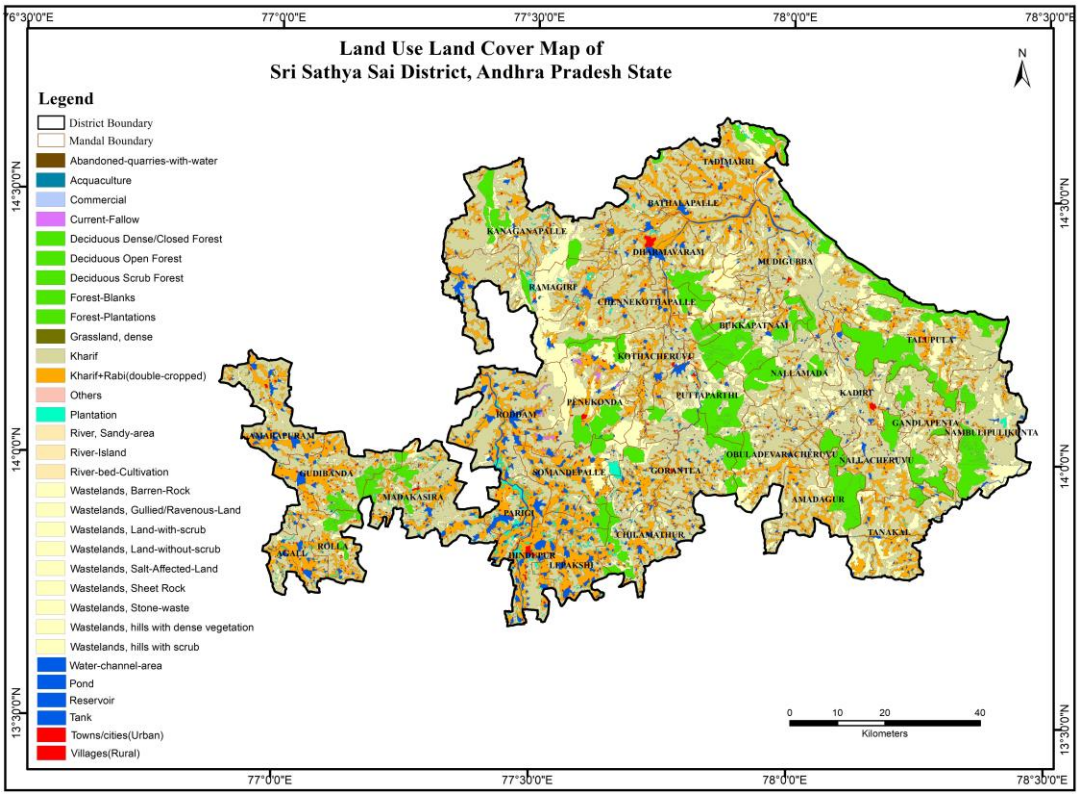

Fig.1.5: Land use and land cover of Sri Sathya Sai district.

In the district, there are 158920 marginal farmers (<2.47 acres of land), 120126 small farmers (2.47-4.93 acres), 74301 semi-medium (4.94-9.87 acres), 11814 medium (9.88-24.7 acres) and 952 large farmers (>24.71 acres).

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

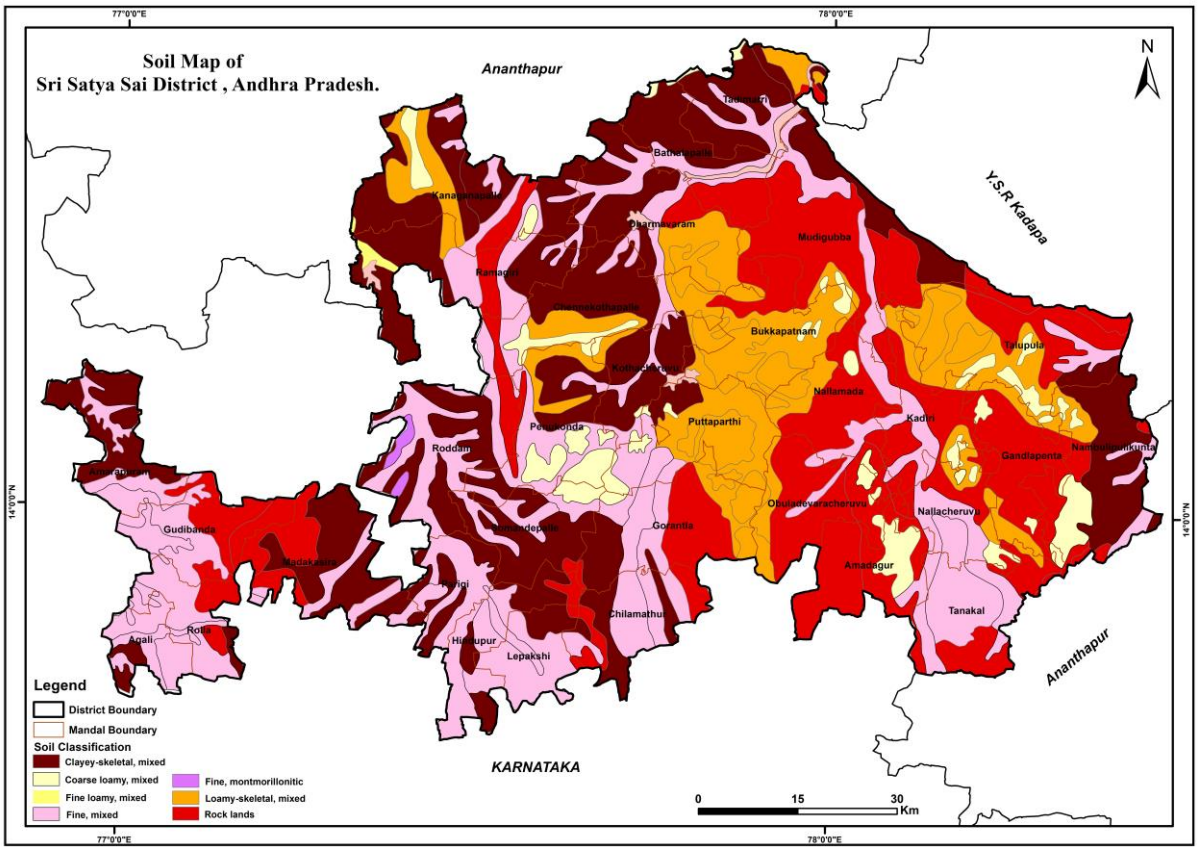

Fig.1.6: Soil map of Sri Sathya Sai district.

1.9 Irrigation:

There are 3 Medium Irrigation Projects, i.e.,1. Pennar Kumdvathi Project, 2. Yogi Vemana Reservoir, 3.Upper Pennar Project (Partly). The Ayacut particulars of these projects are given below:

PROJECT NAME	**MANDAL**	**VILLAGES COVERED**	**AYACUT (in Hec.)**
Pennar Kumdvathi	1.HINDUPUR	8	480
	2.PARIGI	11	2000
	TOTAL	**19**	**2480**
Yogi Vemana	1.MUDIGUBBA	13	5212
	GRAND TOTAL	**32**	**7692**
Upper Pennar Project	1.RAMAGIRI	**3**	317
	2.KANAGANAPALLI	**3**	2138
	Total	**6**	**2373**

1.10 Prevailing water conservation/Recharge practices: In the district there are **~1502** percolation tanks, ~3898 Check dams with combine capacity of ~30 MCM.

1.11 Geology: About 90 % of the area is underlain by crystalline rocks, namely Banded gneissic complex, granites of Archaean to Proterozoic age and remaining 10 % of the area in the northeastern and nortwestern parts of the district is underlain by metasediments of Cuddapah supergroup of Proterozoic age, namely shales and limestone (**Fig1.7**).

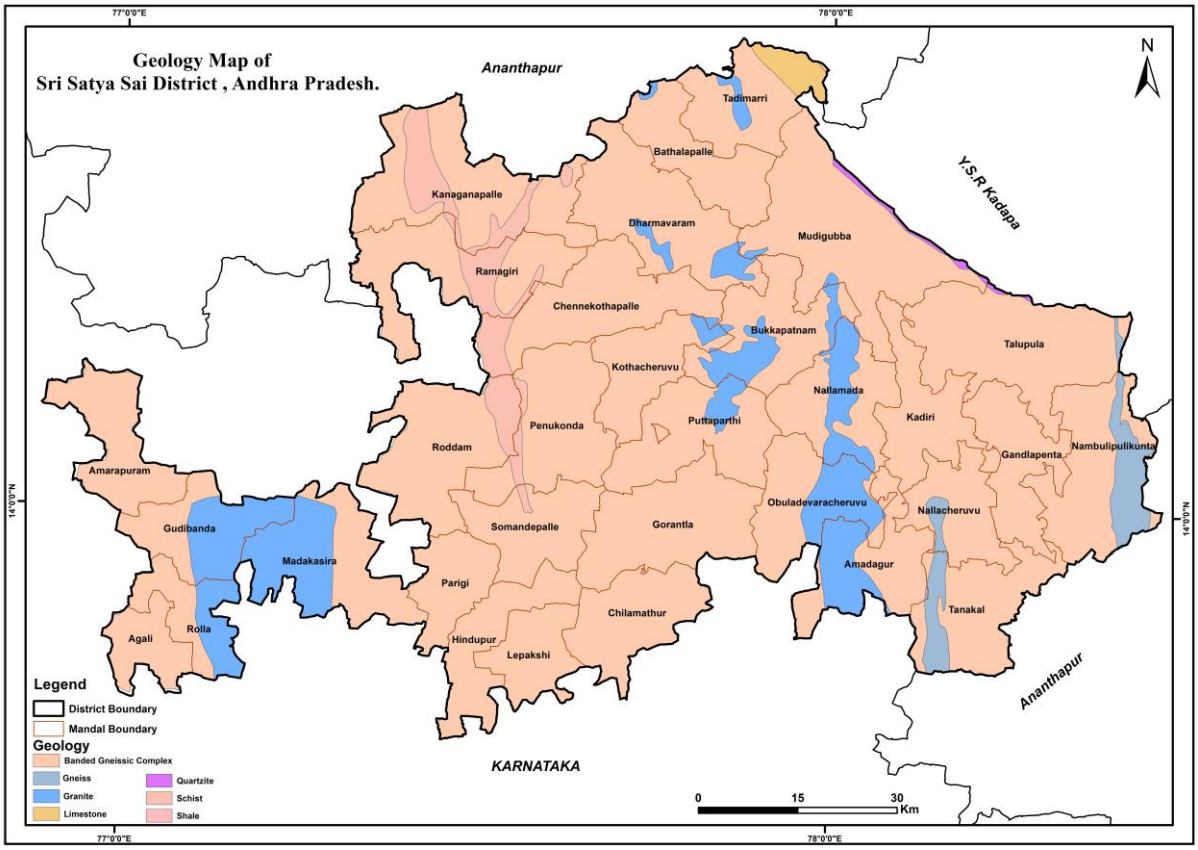

Fig.1.7: Geology of Sri Sathya Sai district.

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

		electrical and gravity data generation	
		Hydrological Parameters on groundwater recharge	Soil infiltration studies, rainfall data analysis, canal flow and recharge structures.
		Preparation of Hydrogeological map (1:50, 000 scale)	Water level monitoring, exploratory drilling, pumping tests, preparation of sub-surface hydrogeological sections.
		Generation of additional water quality parameters	Analysis of groundwater for general parameters including fluoride.
3.	Aquifer Map Preparation (1:50,000 scale)	Analysis of data and preparation of GIS layers and preparation of aquifer maps	Integration of Hydrogeological, Geophysical, Geological and Hydo-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 prutting 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 481 hydrogeological data points (Exploration: 30, Geophysical: 147 and well inventory: 304) (**Fig.2.1)** hydrogeological map is prepared.

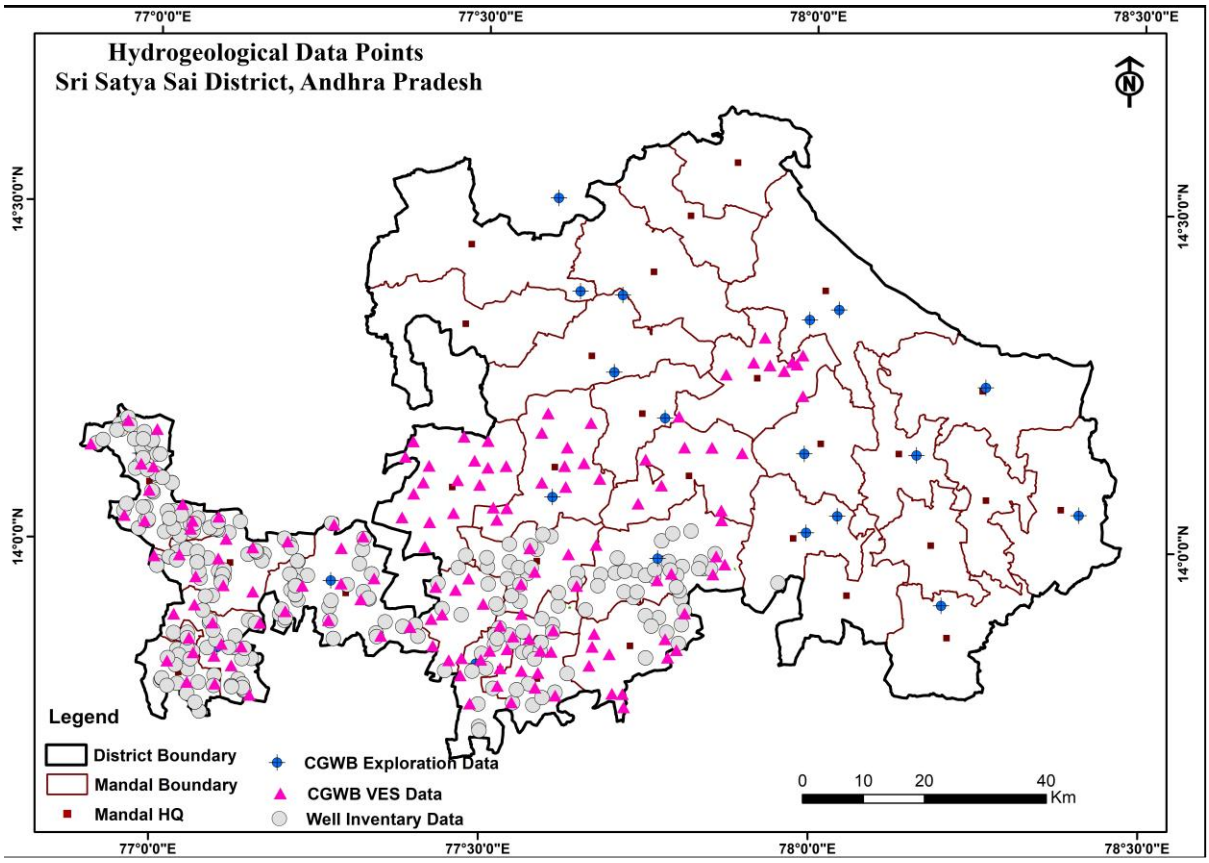

Fig. 2.1: Hydrogeological data availability.

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 over exploitation, 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 12 litres/second (lps). Majority of fractures occur within 100 m depth and deepest fracture is encountered at the depth of 158 m depth (Dharmavaram Mandal). The hydrogeological map of the area is presented in **Fig. 2.2**.

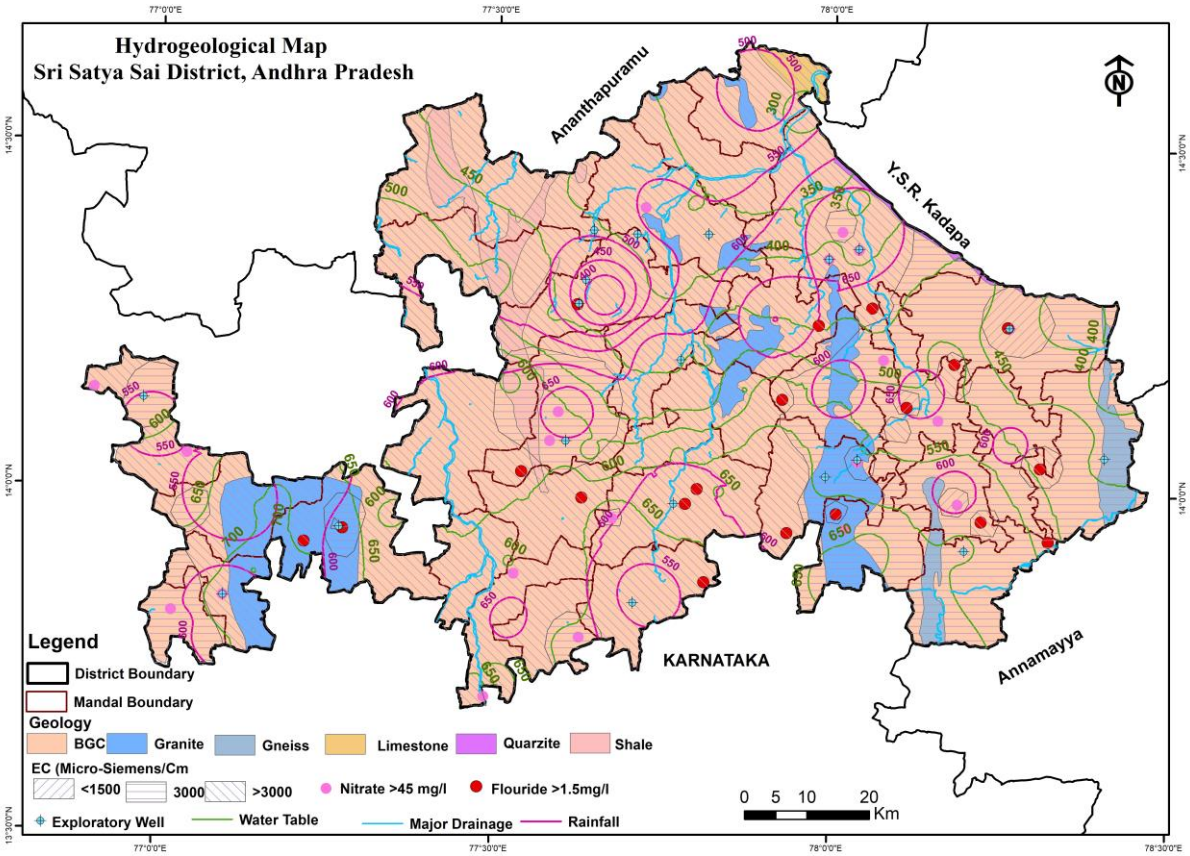

Fig.2.2: Hydrogeological map of Sri Sathya Sai district.

2.1.2 Exploratory Drilling: CGWB drilled 30 bore wells (exploratory, observation and piezometers) in the district. Data analysed from CGWB wells indicates, 06 wells are of shallow depth (30 m), 07 nos are of 30-60 m, 02 nos are of 60-100 m, 10 nos are of 100-150 m, 33nos are of 150-200 m and 05 nos are of 200-305 m depth**.**

Depth of exploratory wells in granite rocks varies from 27-305 m and deepest fractured encountered is at 157 m (Kanaganapalle). In Gniesses the depth of exploratory wells ranges from 145-200 m and deepest fracture is encountered at 60 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**.

2.2 Water Levels (2022): Ground water levels from 40 wells (CGWB) 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 2022, the water-table elevation ranges from 280-753 and 282-754 meter above mean sea

level (m amsl) respectively and general ground flow is towards North and NE direction. (**Fig.2.4**).

2.2.2 Depth to Water Levels (DTW): The DTW varies from 0.14 to 41 meter below ground level (m bgl) (average: 8.26 m bgl) and 0.0-15.95 m bgl (average: 4.19) during pre and post-monsoon season of 2022 respectively.

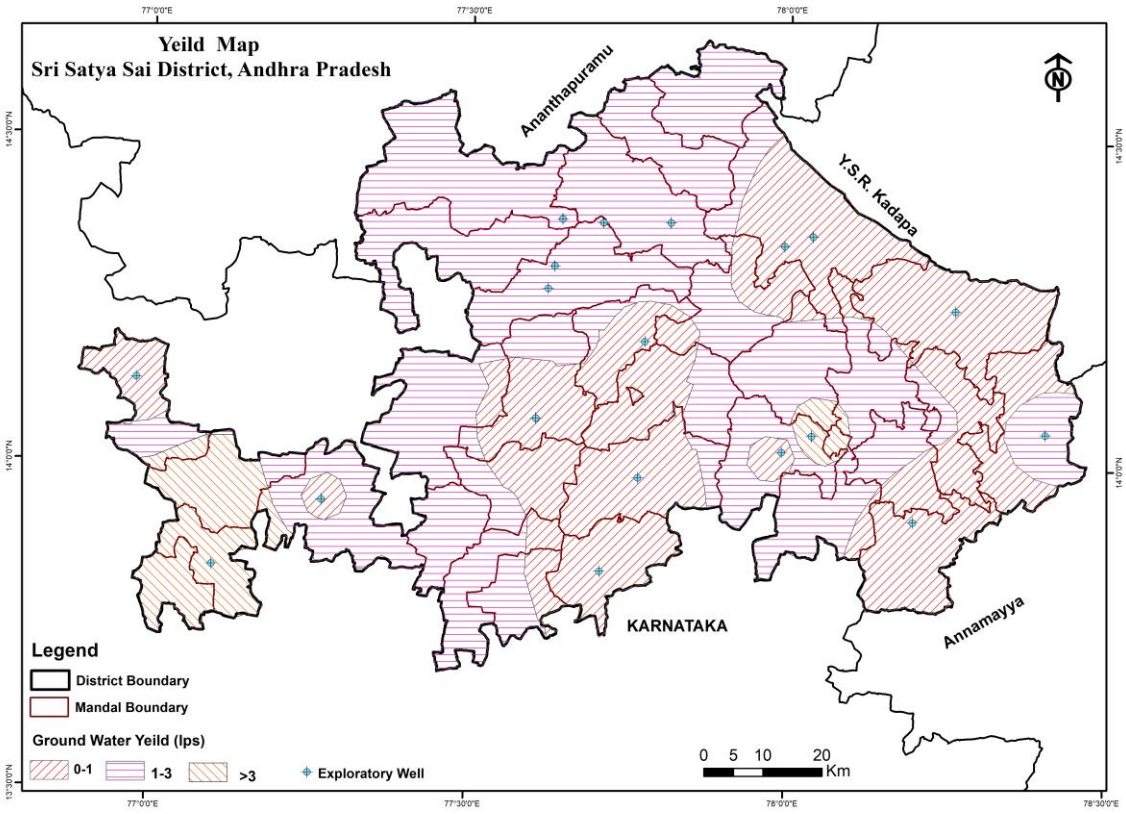

Fig.2.3: Ground water yield, Sri Sathya Sai District, A.P.

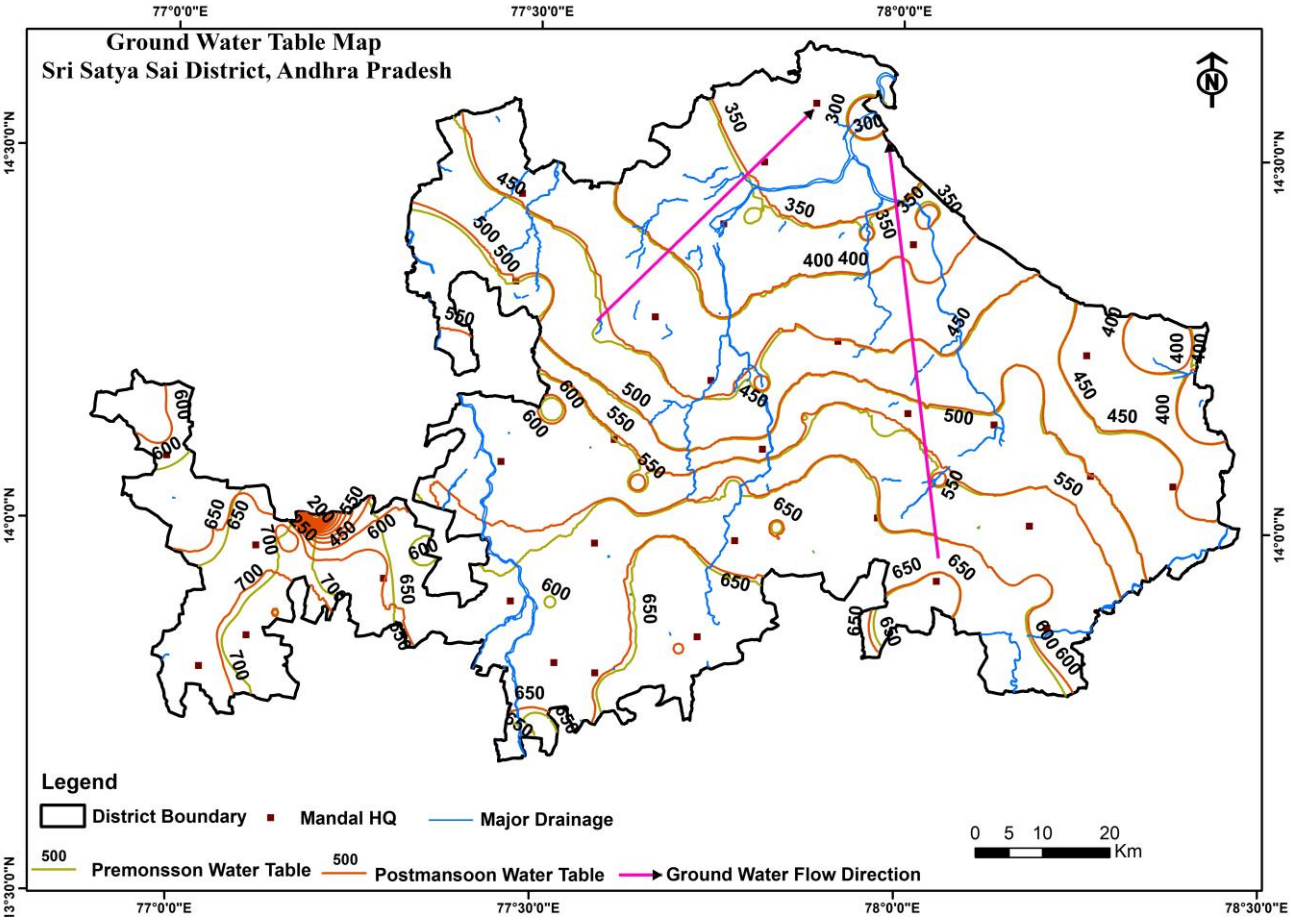

Fig.2.4: Water table elevations (m amsl) during pre and post-monsoon season-2022.

Pre-monsoon season: The water levels during this season are in the range of 2-5 m cover ~ 40% of area, 5-10 m bgl covers 37% of area, 10-20m bgl covers 17% of the area and 20-40m bgl covers 4% of the area. Deep water levels in the range of > 40 m bgl occupy ~1% of area mostly in south eastern part of the district (**Fig.2.5**). Shallow water levels (<2 mbgl) occur in northern eastern part of the district covering 1.2% of area.

Post-monsoon season: Majority of the water levels during this season are in the range of 2-5 m covering ~58 % of area, followed by 5-10 mbgl (23 of area), 10-20 m bgl (2.4%). Shallow water levels (0-2 mbgl) occupy ~16 % of area occur in northern and northesatrn part of the district.

2.2.3 Water Level Fluctuations (May Vs. November): The water level fluctuations vary from -9.4 to 34.71 m with average rise of 4.70 m. Out of 145 wells, in 130 wells (%) rise in water levels (0.08 to 34.71 m) is observed covering most of the area. Falling water levels in the range of -9.4 to -0.08 m is observed in 15 wells.

2.2.4 Long term water level trends: Trend analysis for the last 10 years (2013-2022) is studied from 29 hydrograph stations of CGWB. It is observed that during pre-monsoon season 13 wells shows a falling trend (max fall: 1.52 m/yr) and 16 wells shows rising trend (max rise: 0.9 m/yr). During post-monsoon season 03 shows falling trend (maximum fall: 0.15 m/Yr) and 26 wells shows rising trends (max rise: 9 m/yr).

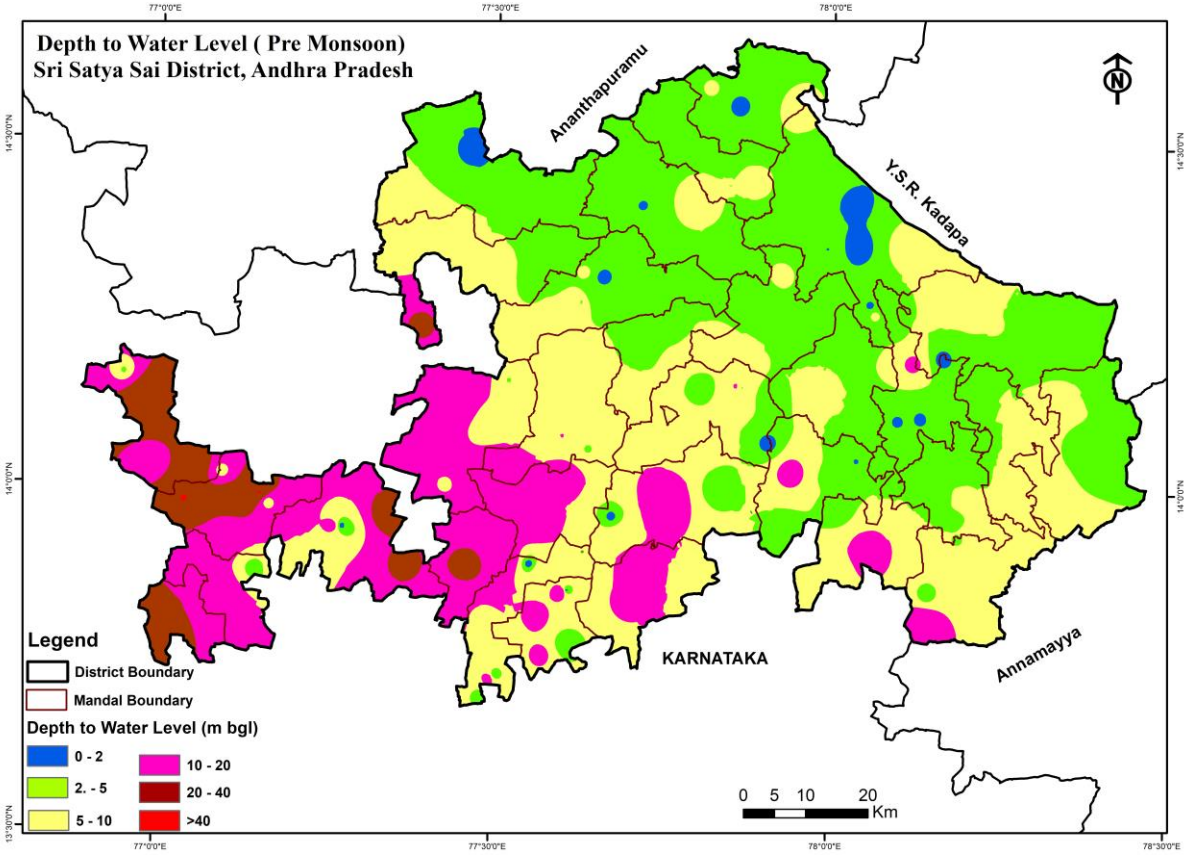

Fig.2.5: Depth to water levels Pre-monsoon (May-2022).

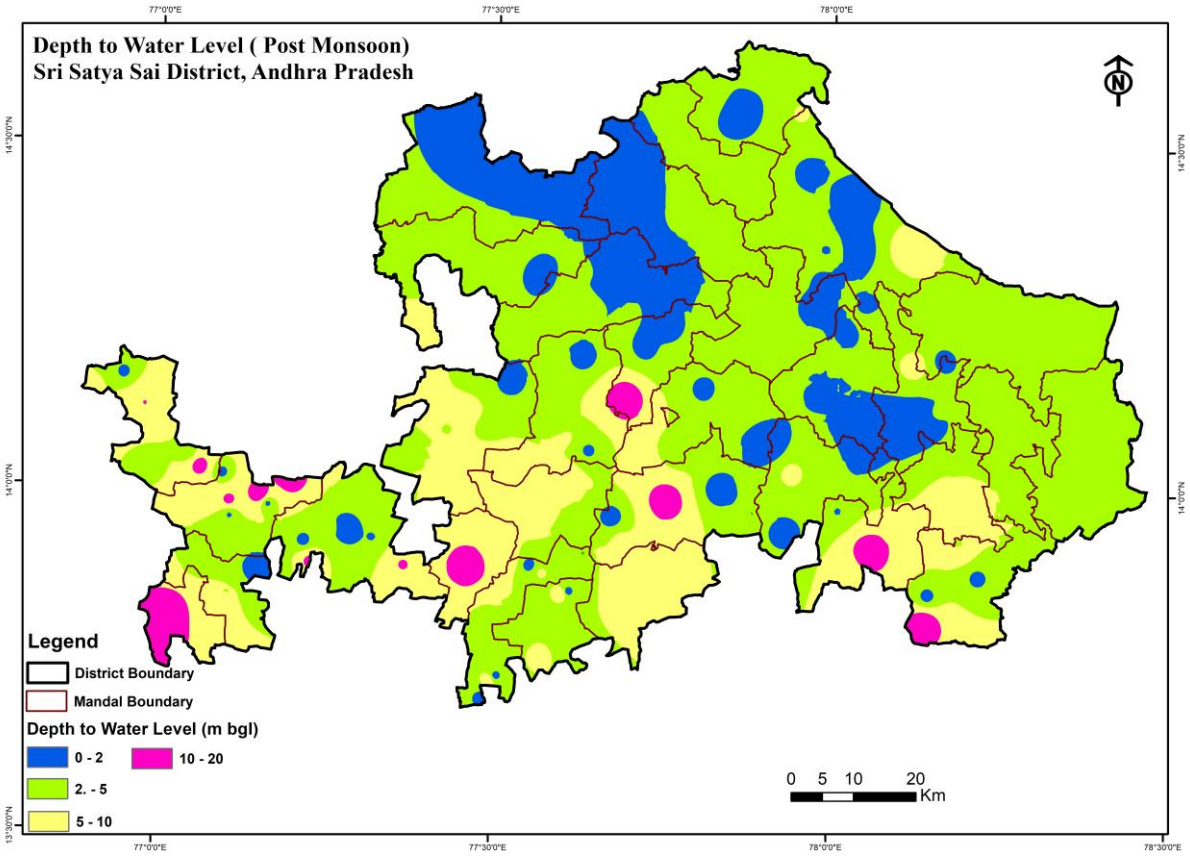

Fig.2.6: Depth to water levels Post-monsoon (Nov-2022).

2.3 Geophysical Studies

A representative 147 geophysical data (VES:147) is interpreted, which reveals resistivity < 100 ohm (Ω) m for the weathered granite (1-28 m), 50-250 Ω m for underlying fractured granite with maximum thickness of 72 m and > 250 Ω m for massive granite.

2.4 Hydro-chemical Studies

To understand chemical quality of groundwater, total 165 data is utilized from ground water monitoring wells (Pre:70 and Post:95). During pre-monsoon season of 2022 (CGWB: 70 wells (mostly tapping combined aquifers Aq-1 and aq-2) were analysed. 126 samples (all SGWD) during post-monsoon season of 2022 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 were analyzed. Out of which, five parameters namely pH, EC, TDS, NO_3 and F were interpreted for suitability for drinking purposes and is assessed as per BIS standards (2012).

Pre-monsoon (May-2022)

Groundwater from the area is alkaline in nature with pH in the range of 7.0-8.1 (Avg: 7.51). Electrical conductivity varies from 260-4419 (avg: 1534) µ Siemens/cm. High EC (>3000 µ Siemens/cm) is detected in Talupaula, Madakasira, Amadagur, Nallacheruvu,O.D. Cheruvu and Kadiri mandals (Fig.2.7). The concentration of TDS varies from 165-2658 (avg: 949) and TH varies from 60-1160 (avg: 408) mg/l.

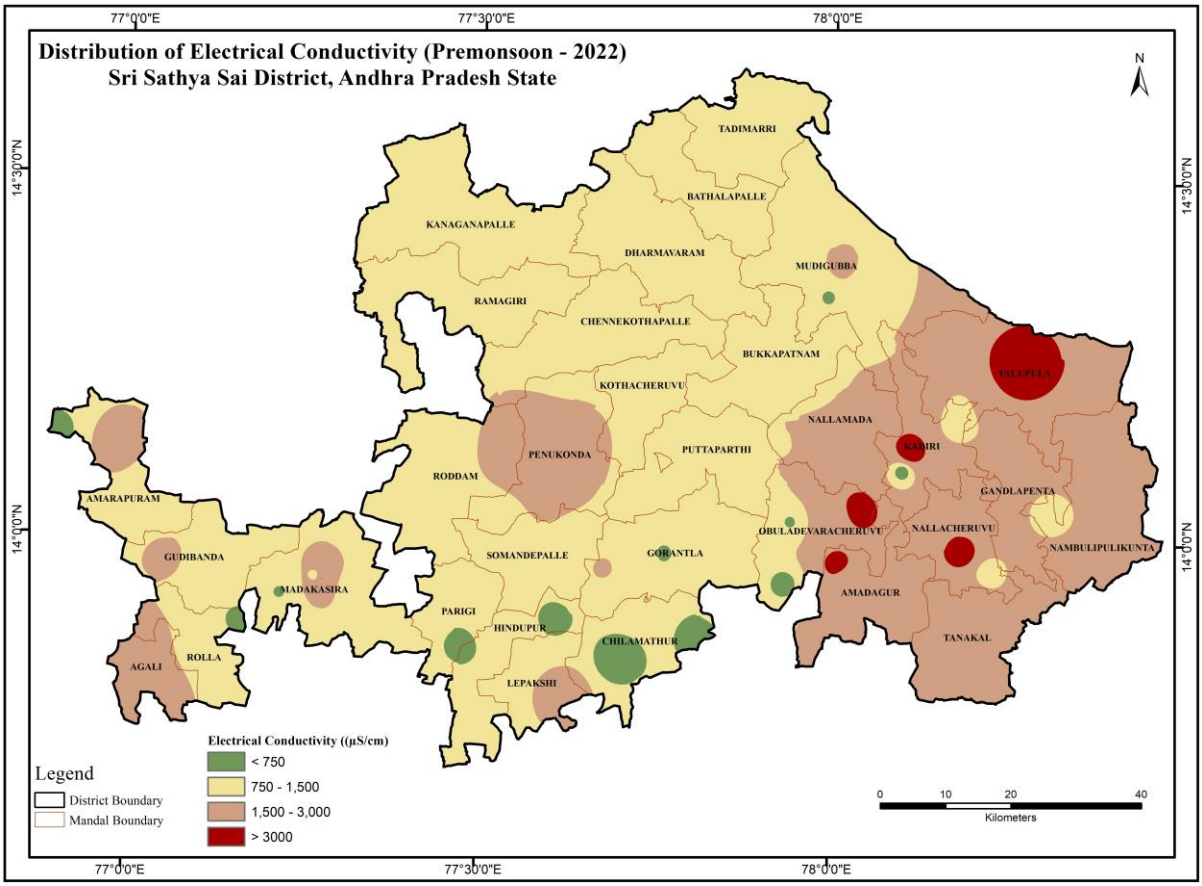

Fig.2.7: Concentration of Electrical conductivity (Pre-monsoon-2022).

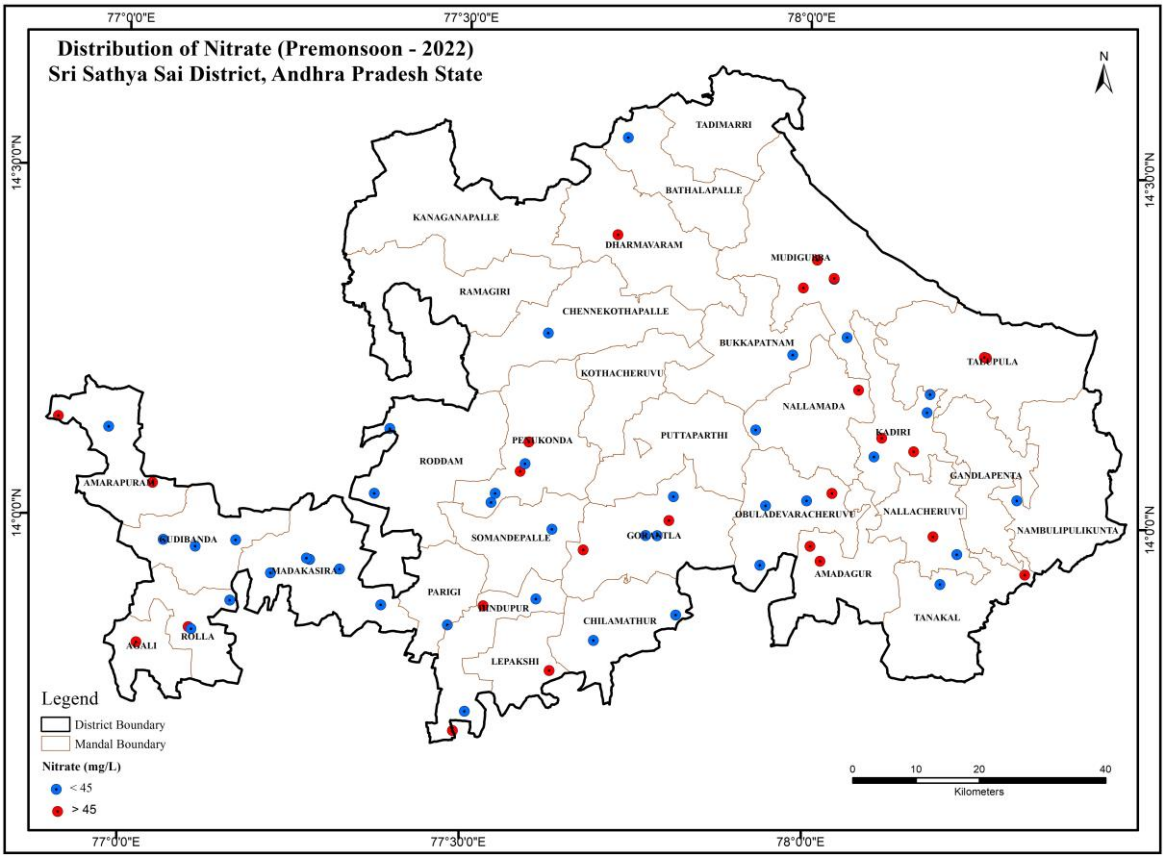

Fig.2.8: Distribution of Nitrate (Pre-monsoon-2022).

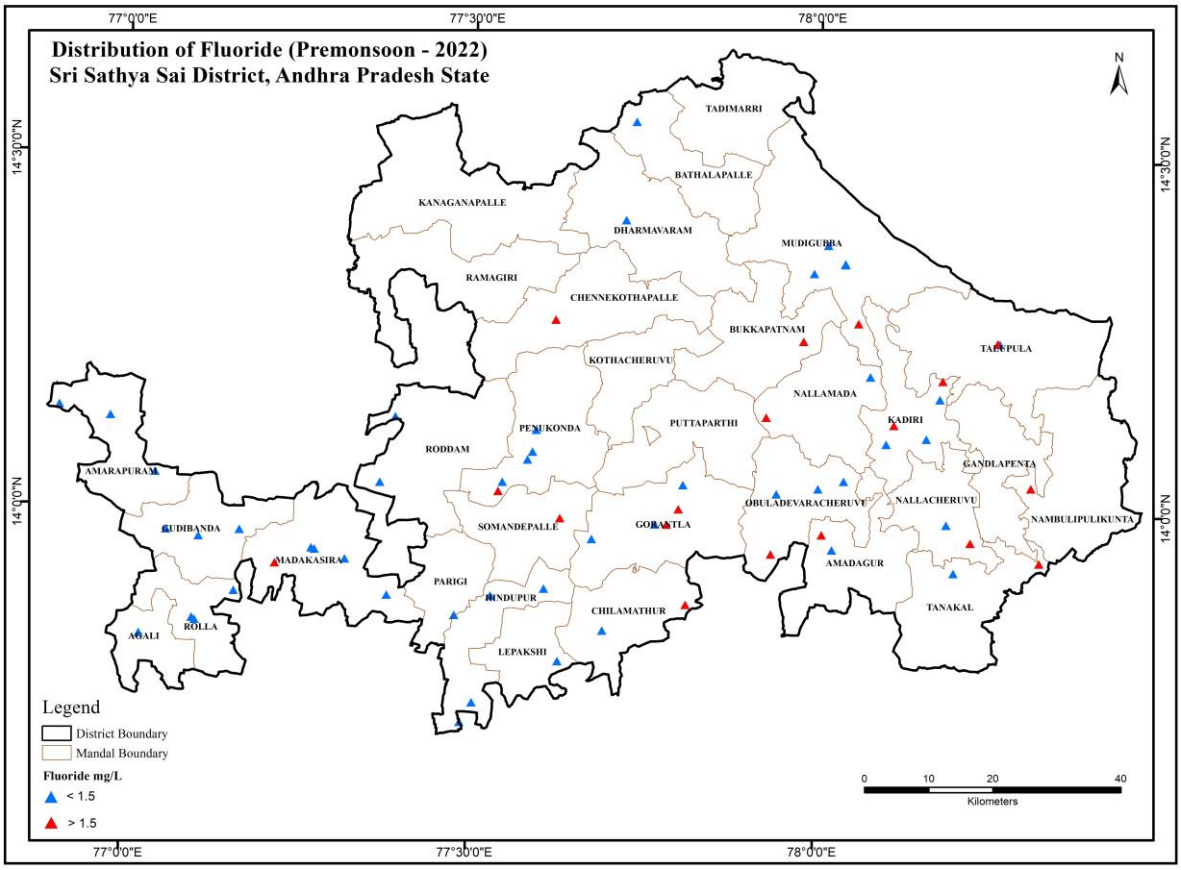

Fig.2.9: Distribution of Fluoride (Pre-monsoon-2022).

The concentration of Ca2+, Mg 2+, Na+, and K+ ranges from 10-257, 9-199, 25-818 and 0.5-464 mg/l respectively. The NO3 concentration ranges from 01 to 674 mg/l. It is noticed that in about 37% of the samples (26 samples) from Rolla, Hindupur, Dharmavaram, Amarapuram, Mudigubba, Gorantala, Madagsira, Amadapur, Agali, Nallamada, Lepakshi, Kadiri,Tanakal, O D Cheruvu, Talupuala and Nallacherevu mandals the quality is not suitable for drinking water purpose (>45 mg/l) (Fig.2.8). The Fluoride concentration varies from 0.26-4.0 mg/l and in 51 samples (73 %) it is within permissible limit of <1.5 mg/l. The high fluoride concentration (>1.5 mg/l) is observed in 19 samples (27%) in Gorantal, Tanakal Talupula, Mudigubba, Chennekothapalle, Madakasira, O D Cheruvu, Somendepalli, Nallamada, Nallacheruvu, Chilmathur, NP Kunta, Amadagur, Bukkapatnam Penukonda and Kadirir mandal (Fig. 2.9).

Post-monsoon (Nov-2022)

Groundwater from the area is mildly alkaline in nature with pH in the range of 7.3-8.70 (avg. 8.11). The Electrical conductivity varies from 279-4070 µ Siemens/cm (avg. 1589 µ Siemens/cm). In 89 samples (94%) the EC is within 3000 µ Siemens/cm while in 6 sample (6%) from in Tadimari , Bukkapatnam, Hindupur, Somandepally, Amarapuram, and Dharamvaram the EC is >3000 µ Siemens/cm. (Fig. 2.10). The concentration of TDS varies from 179 to 2605mg/l (avg. 995 mg/l).

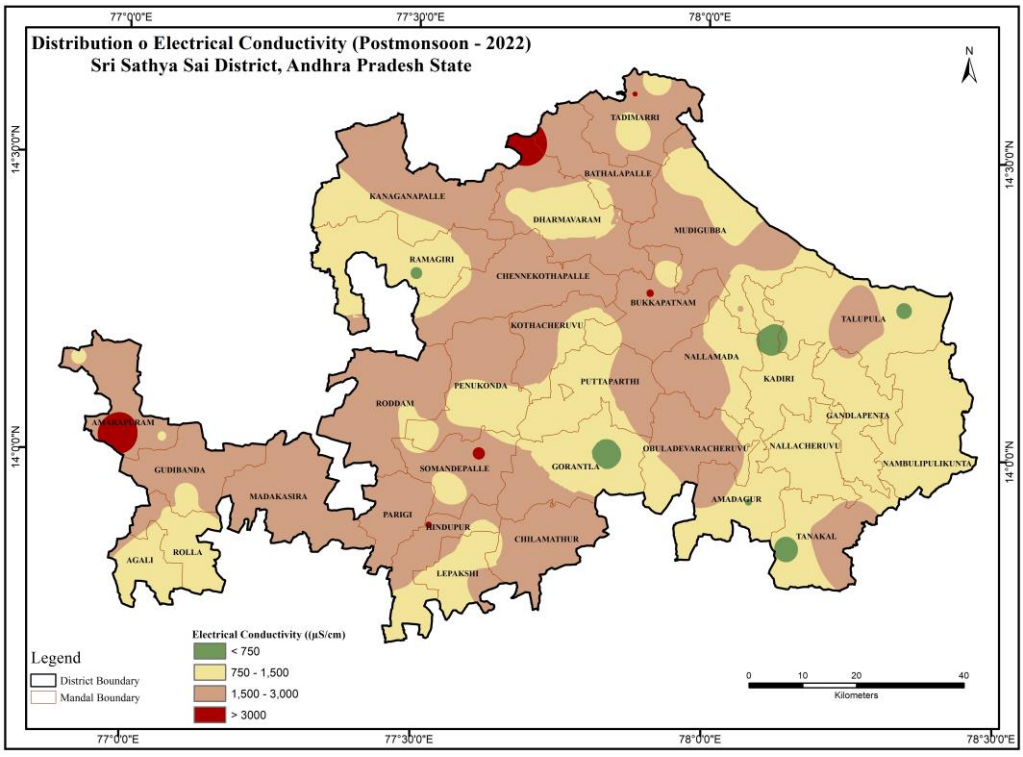

Fig.2.10: Concentration of Electrical conductivity (Post -monsoon-2022)

The Nitrate(NO_3) concentration ranges from 0.26 to 36.2 mg/l (avg 8.15 mg/l) and it is under permisble limit(<45mg/l). (Fig. 2.11). The Fluoride concentration varies from 0.23-1.85 mg/l and found that 68 samples (72%), it is falling under permissible limit of <1.5 mg/l. While in 27 samples (28%) from Nallamada, Bukkapatnam, Dharmavaram, Amarapuram, Talupula, Amadagur, Ramagiri, Madakasira, Chennakothapalli, Penukonda, Lepakshi, Hindupur, Mudigubba, Nallamada, Agali, and Kanaganipalli mandals are having high fluoride concentration (>1.5 mg/l).

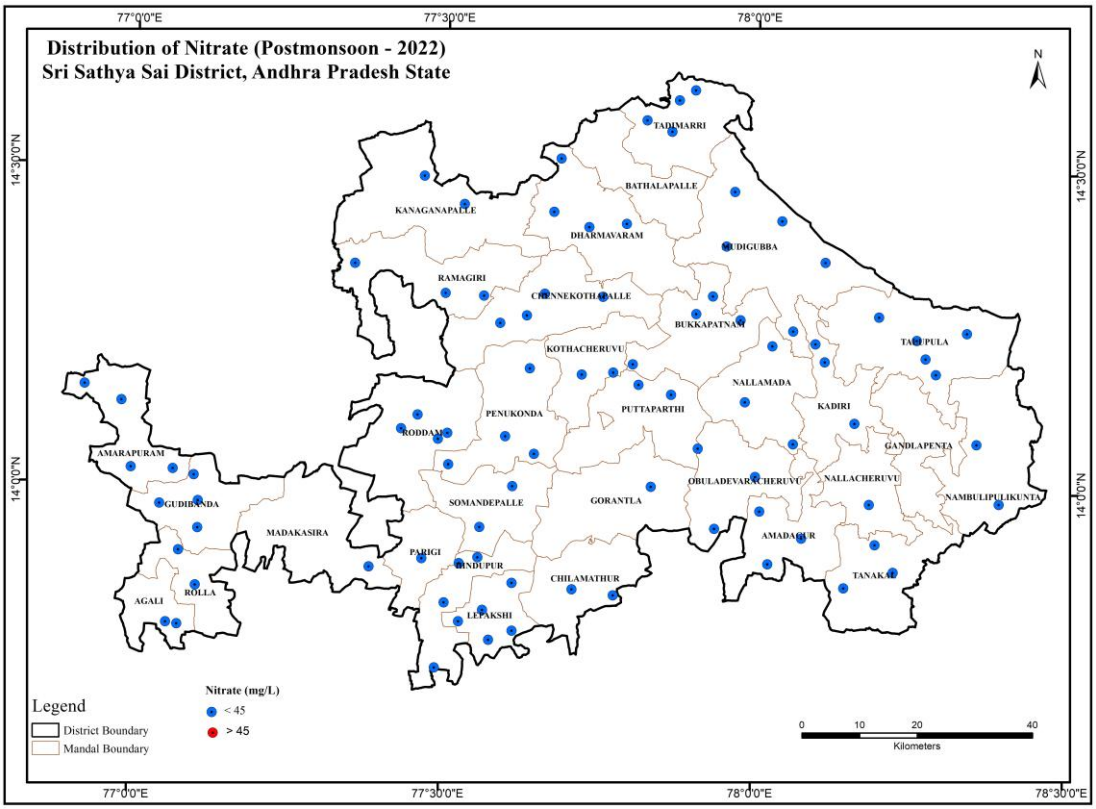

Fig.2.11: Distribution of Nitrate Concentration (Post-monsoon-2022)

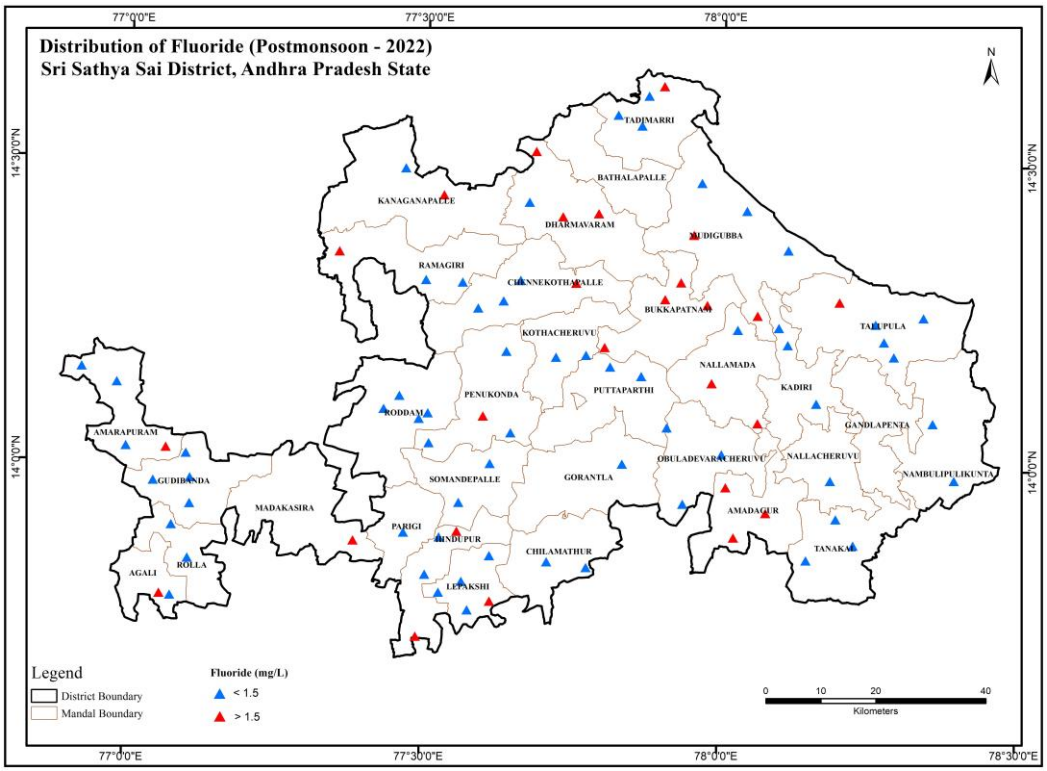

Fig.2.12: Distribution of Fluoride Concentration during (Post-monsoon-2022).

3. DATA INTERPRETATION, INTEGRATION AND AQUIFER MAPPING

Conceptualization of 3-D hydrogeological model was carried out by interpreting and integrating representative 481data points (Exploratory wells: 30, Geophysical: 147 and 304 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-b).

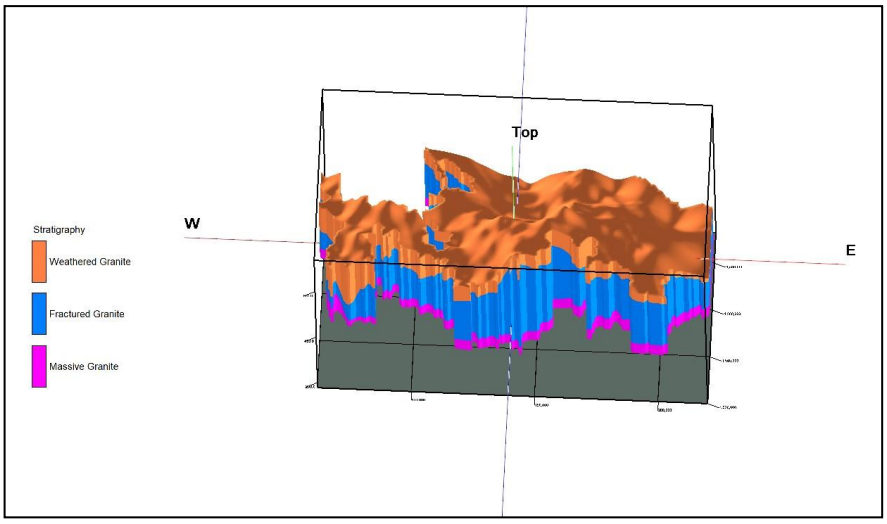

Fig.-3.1:3-D Model for Sri Sathya sai district.

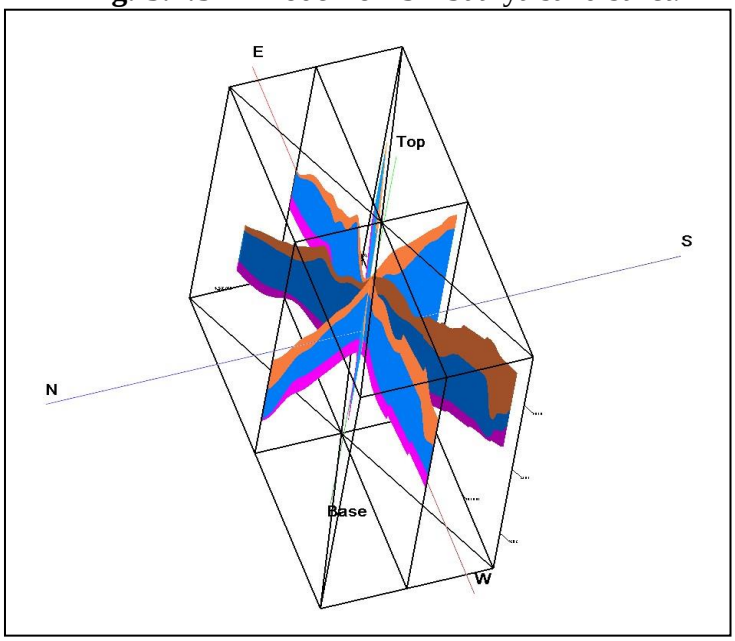

Fig.-3.2: Panel diagram- Sri Sathya Sai district.

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 (2 nos) are prepared in NE-SW and NW-SE, directions (**Fig. 3.3**).

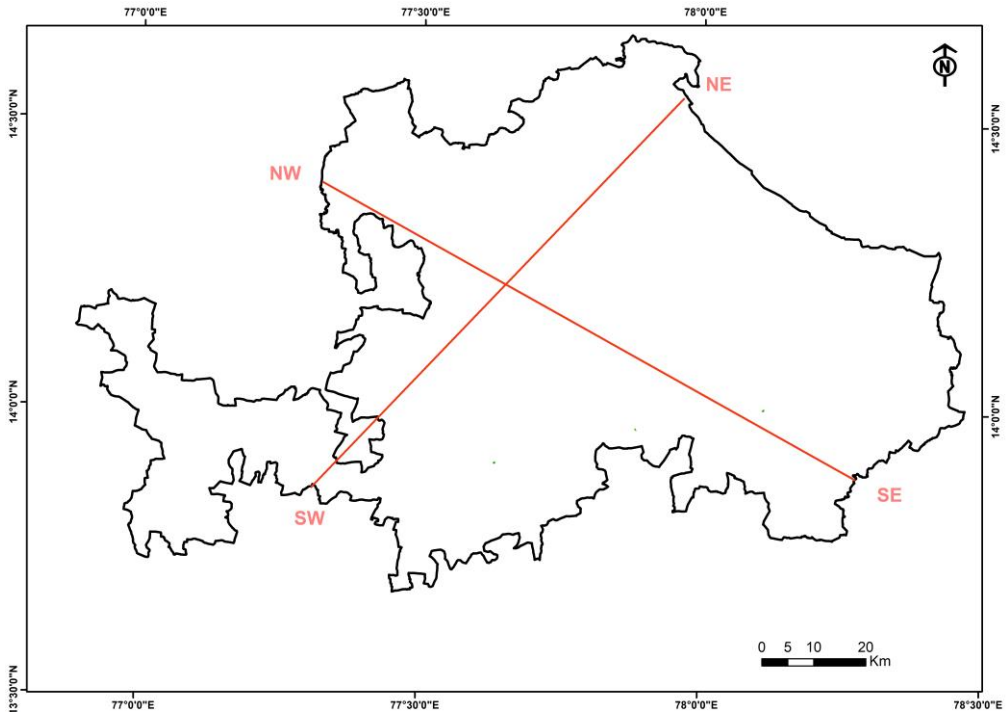

Fig.-3.3: Map showing orientation of various hydrogeological sections.

3.2.1 North East-South West Section: The section drawn vertically along the NE-SW direction covering distance of ~160 kms (Fig.3.4a). It depicts less fractured zone in north easter parts and in southern wester parts of the section. The central parts of the section show more weathering and fractures.

3.2.2 North-West and South-East Section: The section drawn along the NW-SE direction covering distance of ~110 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.

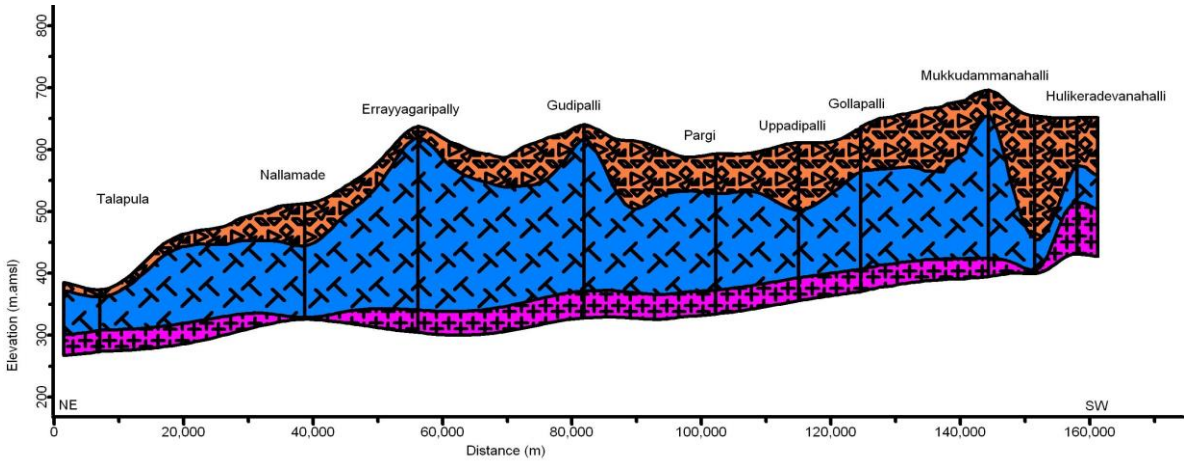

Fig-3.4 a: North East to South West (NE-SW) Section

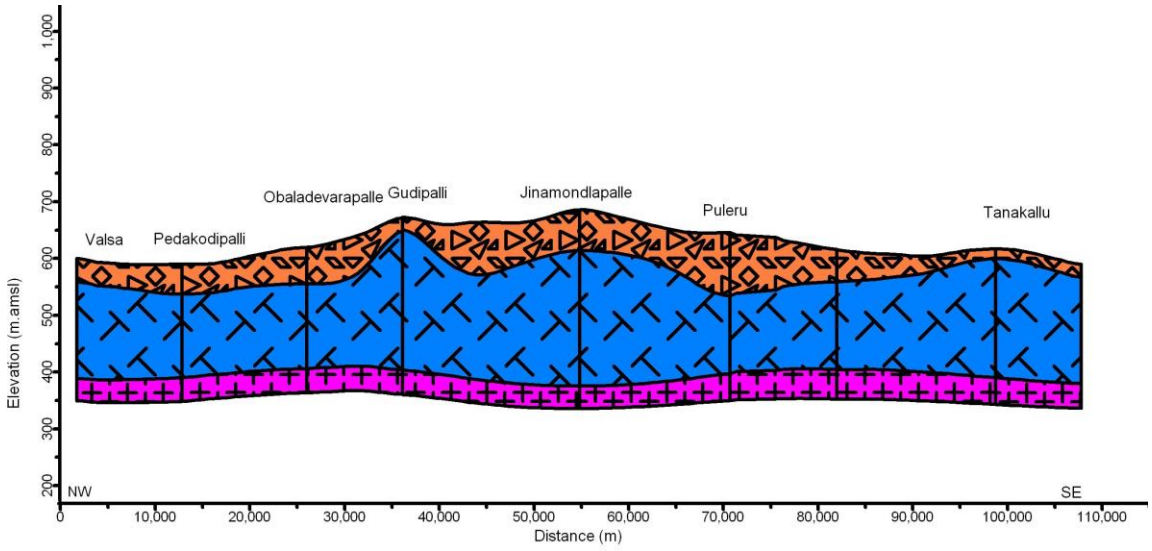

Fig-3.4 b: North West to South East (NW-SE) Section

3.3 Aquifer Characterization

3.3.1 Weathered zone:

In granite depth of weathering varies from 5-25 m (avg: 9.30m) and in gneisses it ranges from 6-21 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 western part of the district (Fig.3.5). Ground water yield from weathered granite/gneiss aquifer ranges from <0.1 to 4.5 lps (avg: 1.5 lps).

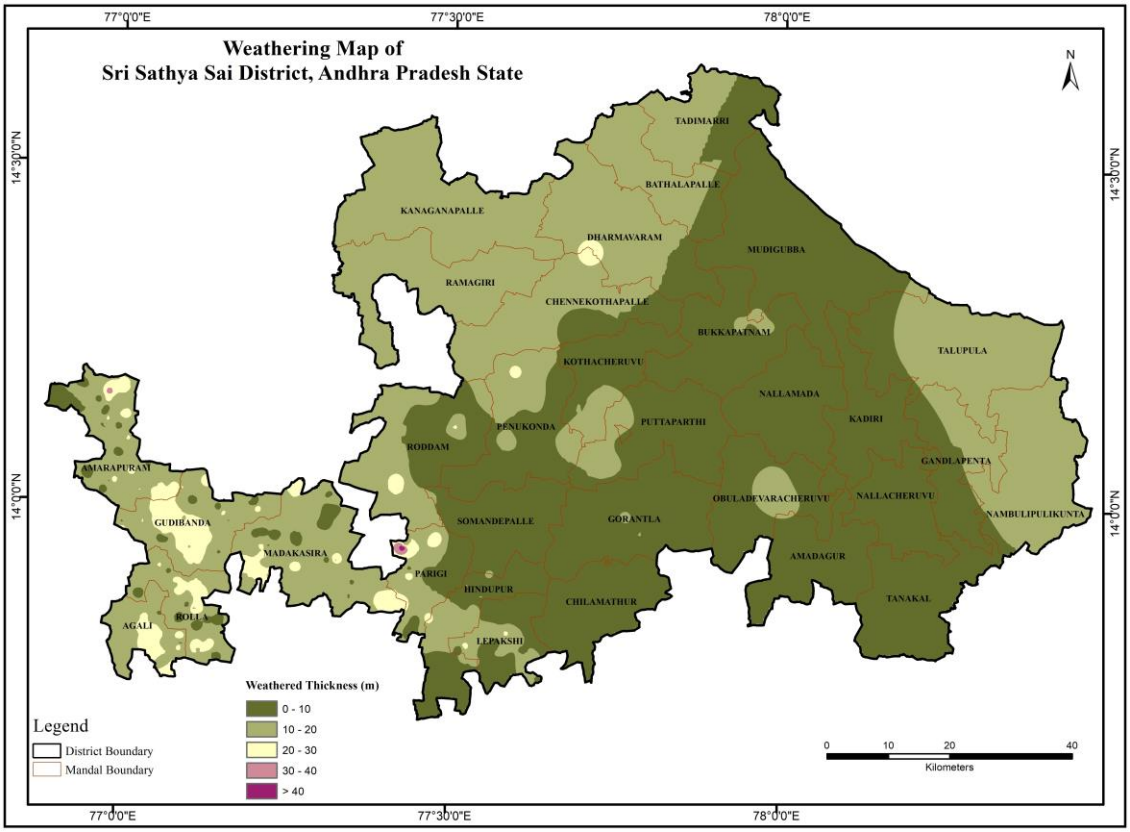

Fig.3.5: Thickness of weathered zone-Sri Sathya Sai district, A.P.

3.3.2 Fractured zone:

In Granite depth of fracturing varies from 4.4-157 m and deepest fracture is encountered at 157 m (Kanaganapalle). In gneisses it ranges from 5.5-60 m. The depth of fracture map is presented in Fig. 3.6. ~ 80% of fractures occur within 100 m depth and rest occur below this depth (Fig.3.7). Ground water yield from fractured Granite varies from 0.2 to 12 lps and gniesses it ranges from 0.1 to 5 lps.

The combine transmissivity (T) in weathered and fracture zone in granite aquifer it ranges from 1 to 222 m^2/day and in gneisses it varies from 6 to 232 m^2/day. The combine storativity (S) in weathered and fracture zone in granite aquifer it ranges from 0.0001 to 0.0013 and in gneisses it varies from 0.0001 to 0.025.

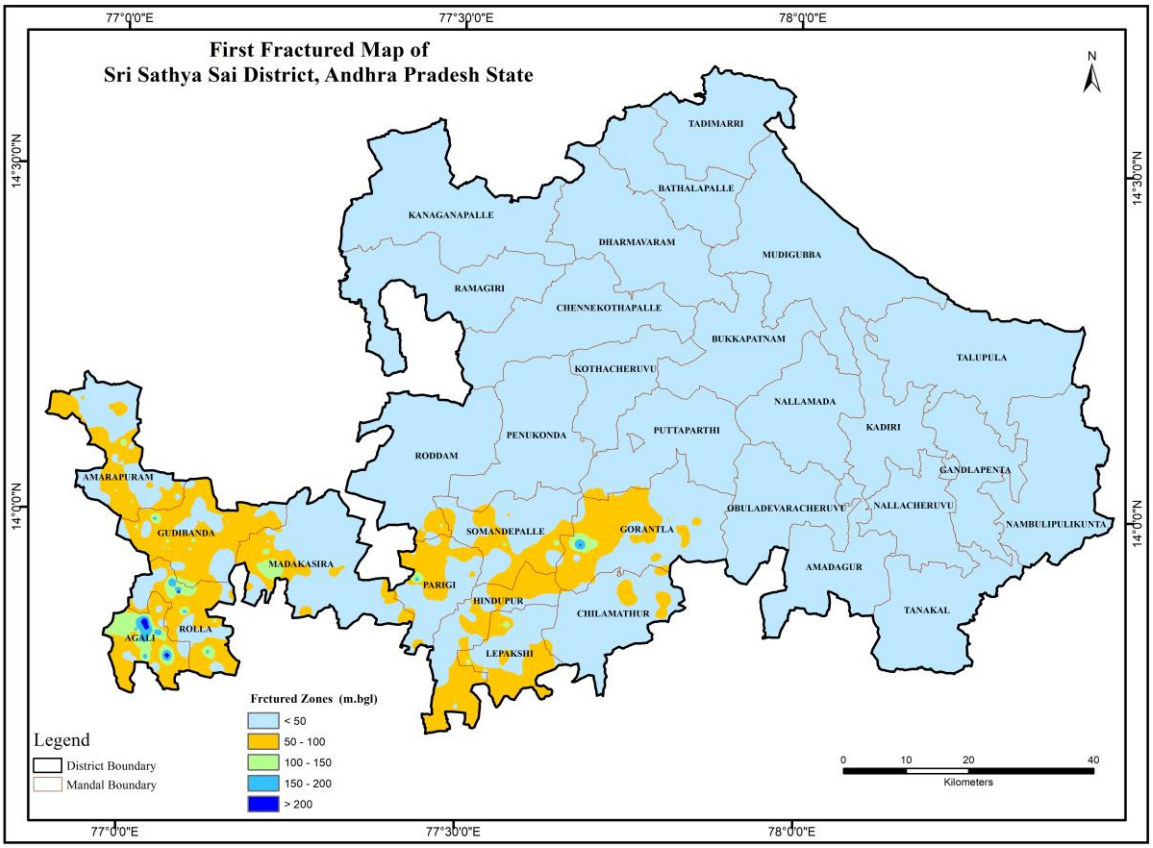

Fig.-3.6: Depth of fractured zone (m bgl).

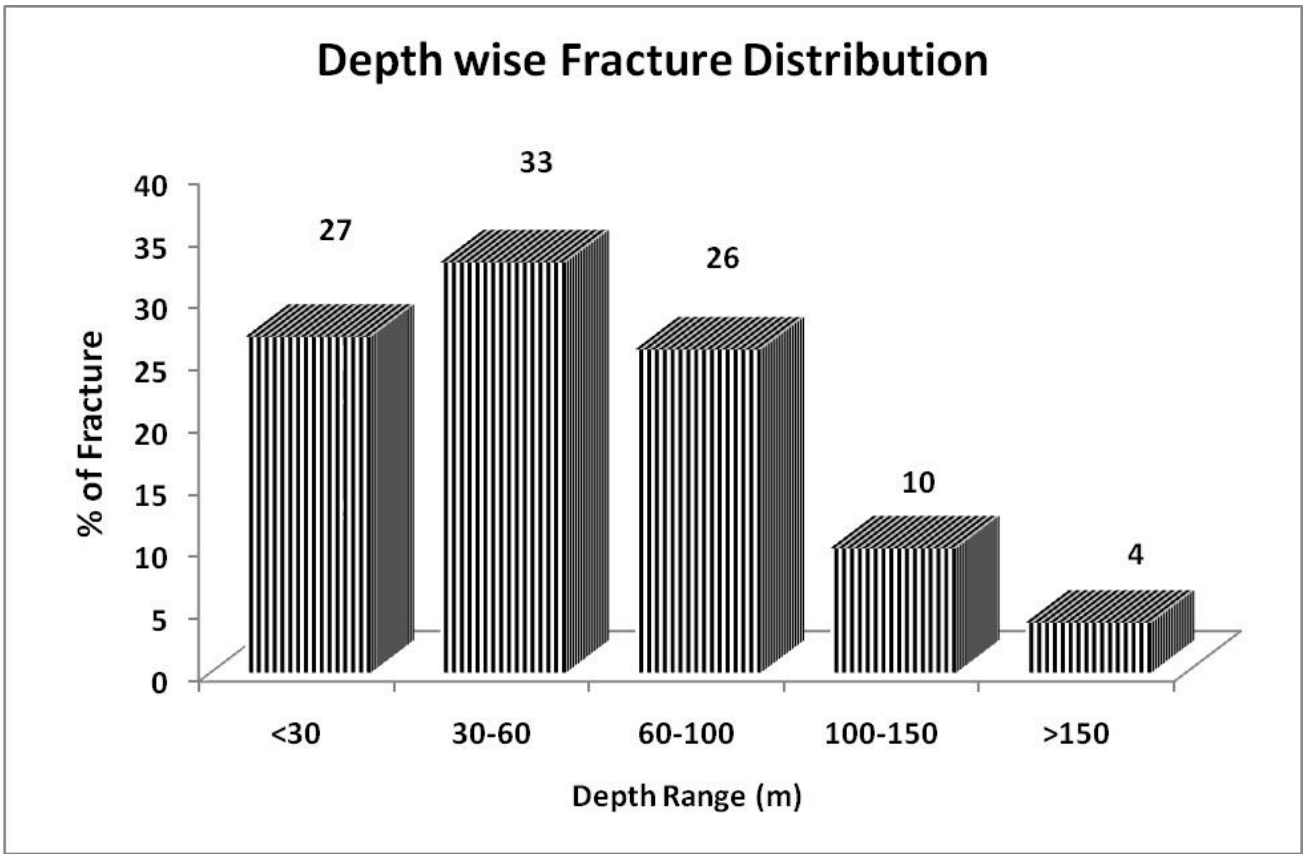

Fig.-3.7: Depth wise distribution of fractures in Sri Sathya Sai district.

4.0 GROUND WATER RESOURCES (2023)

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

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

As per 2023 GEC report, the net dynamic replenishable groundwater availability is 1121.28 MCM, gross ground water draft for all uses 630.57 MCM, provision for drinking and industrial use for the year 2025 is 111.19 MCM and net annual ground water potential available for future irrigation needs is 561.21 MCM. Out of 32 mandals 04 mandals falls in over-exploited category. 1 in critical category, 3 in semi critical category and rest 24 in safe category. Mandal wise Stage of Ground Water Extraction varies from 19 % (Bukyapatnam) to 161% (Gandlapenta).

Table-4.1: Computed Dynamic, Ground Water resources, Sri Satya Sai district Andhra Pradesh State .

Parameters	**Resources (GEC 2023) in MCM**
As per GEC 2023	MCM
Dynamic **(Net GWR Availability)**	**1121.28**
• Monsoon recharge from rainfall	432.46
• Monsoon recharge from other sources	312.70
• Non-Monsoon recharge from rainfall	5.95
• Non-monsoon recharge from other sources	429.17
• Provisional for natural discharge	59.01
Gross GW Draft	
• Irrigation	540.79
• Domestic and Industrial use	89.78
Provision for Drinking and Industrial use for the year 2025	111.19
Net GW availability for future use	561.21
Stage of GW Exraction (%)	56.24
Categarization of mandals	Over-Exploited:04; Critical :01; Semi Critical:03 Safe:24 Mandal wise Stage of GW extraction varies from 19 % (Bukyapatnam) to 161% (Gandlapenta)

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 4.0 mg/L is found in groundwater. The high fluoride concentration (>1.5 mg/L) occur in 22 samples (31 %.).

2. High nitrate (> 45 mg/L) due to anthropogenic activities is observed in 38 % samples (27 nos).

3. The high concentration of EC (> 3000 micro-seimens/cm) in 7 samples (1 %) is observed during pre-monsoon season of 2022 falling in Talupula, Amadagur, Nallacheruvu, O D Cheruvu, Kadiri and Madakasira mandals.

Deep water levels

4. Deep water levels (> 20 m bgl) are observed during pre -monsoon season in 05 % of the area.

5. Out of 29 wells analyzed, 13 wells and 03 wells shows falling trends in pre and post-monsoon season in the last 10 years (max fall 1.52 and 0.15 m/yr) respectively.

Sustainability

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

Unscientific construction of ARS

7. In most of the villages ARS are constructed unscientifically where there was no surplus runoff water available. In order to fill these structures additional 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 5272 MCM of unstaturated volume (below the depth of 5 m) is avaialable during post-monsoon season of 2022 having 105 MCM of recharge potential (considering 2% specific yield). This can be utilized for implementing management strategy.

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 4.79 MCM of silt from existing 829 (minor irrigation tanks and Percolation tanks) are taken under state Govt. sponsored NEERU-CHETTU programme has created additional surface storage. This will contribute ~ 1.44 MCM to groundwater (considering 30% of recharge) and with this additional ~240 ha land can be brought under irrigated dry (ID) crops in tank ayacut.

To be taken up

Artificial Recharge structures:

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). 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.

- In district there is recharge potential 105 MCM, 144 MCM Utilizable Yield (uncommited Runoff) and 33 MCM of volume is available for considering Recharge.
- About 5400 artificial recharge structures were constructed (PTs:1502, CDs:3898) in 349 villages.
- Artificial recharge structures are recommended for 50% of the utilizable yield in the intermittent areas.
- About 201 artificial recharge structures (159 mini PT's with 1.5 fillings with a unit cost of Rs 20 lakhs each and 42 CD's with recharge shafts with 6 fillings with a unit cost of Rs. 15 lakhs each) with a total cost of 38.10 Crores can be taken up.
- After effective utilization of this yield, there will be 3.43 MCM of groundwater recharge with 100% recharge efficacy.
- Roof top rainwater harvesting structures should be made mandatory to all Government buildings (new and existing).

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 farm ponds can be 10 x 10 x 3 m. Total 9220 farm ponds are recommended (20 in each village in 461 villages) with total cost of 23.05 crores.

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

- 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 61.15 crores (excluding the cost involved in HNSS project), the likely benefit would be the net saving of 6.20 MCM of ground water. This will bring down the stage of ground water Extraction by 0.31 % (from 56.20 % to55.92 %).

Acknowledgment

The authors thank Shri Dr. Sunil Kumar Ambast, Chairman, and Smt. T. S. Anitha Shyam Member (South) of the Central Ground Water Board, Govt. of India and Shri G Krishnamurthy, Regional Director, and Smt Rani V. R. Scientist-D of this office for encouragement. The authors acknowledge State Ground Water Department and Rural Water Supply department, Govt of Andhra Pradesh for making available of field data. Authors also thank the Executive Engineer and his drilling crew of CGWB, for carrying out the exploration activity.

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Annexure – I

Proposed Recharge Structure in district.

Mandal	Village	Existing No. of Check Dams	Existing No of Percolation Tanks	Proposed Check Dams	Proposed Percolation Tanks
AGALI	MADHUDI	4		0	1
AGALI	NARASAMBUDI	25	1	0	2
AGALI	P.BYADIGERA	15		0	2
AGALI	AGALI	9		0	2
AMADAGUR	CHEEKIREVULAPALLE	2		0	1
AMADAGUR	AMADAGUR	23	4	0	4
AMADAGUR	THUMMALA	19	1	0	6
AMADAGUR	KARIMIREDDIPALLE			2	1
AMADAGUR	LOKOJIPALLE			2	1
AMARAPURAM	BASAVANAHALLI	8		0	3
AMARAPURAM	AMARAPURAM	14	3	0	4
AMARAPURAM	TAMMEDAHALLI	7	3	1	2
AMARAPURAM	HALUKURU	6	1	1	3
CHILAMATHUR	KODUR	7	5	0	1
GORANTLA	MANDALAPALLE	17	7	0	1
GORANTLA	PULERU	14	2	0	1
GORANTLA	BUDILI	20	11	0	2
GORANTLA	GORANTLA	19	2	0	3
GORANTLA	MALLAPALLE	8	2	1	3
GUDIBANDA	MORUBAGAL	20	3	0	2
GUDIBANDA	GUDIBANDA	26	1	0	4
HINDUPUR	MANESAMUDRAM	3		0	1
HINDUPUR	KOTNUR			1	1
KADIRI	CHIPPALAMADUGU			1	1

Mandal	Village	Existing No. of Check Dams	Existing No of Percolation Tanks	Proposed Check Dams	Proposed Percolation Tanks
KADIRI	YERRADODDI	1		2	2
KOTHACHERUVU	POTHULAKUNTA	5	2	0	1
KOTHACHERUVU	BYRAPURAM	5	1	0	2
KOTHACHERUVU	BANDLAPALLE	16	1	0	4
LEPAKSHI	SIRIVARAM	21	2	0	1
LEPAKSHI	MANEPALLE	14	1	0	2
MADAKASIRA	KALLUMARRI	12	5	0	2
MADAKASIRA	TIRUMALADEVARAHALLI			1	1
MADAKASIRA	GOVINDAPURAM	3	8	2	0
MADAKASIRA	C.KODIGEPALLE	1	3	2	1
MUDIGUBBA	THAPPETAVARIPALLE	7	0	0	2
MUDIGUBBA	MALLEPALLE	16	3	0	4
NALLACHERUVU	NALLACHERUVU	9	1	0	2
PARIGI	PYDETI	6	0	0	1
PARIGI	SASANAKOTA	5	0	0	1
PARIGI	VITTAPALLE	6	0	0	1
PARIGI	KODIGENAHALLI	6	0	0	2
PARIGI	UTAKUR	11	0	0	2
PARIGI	BEECHIGANIPALLE	30	1	0	3
PARIGI	MODA	14	0	0	3
PARIGI	PARIGI	12	2	0	4
PARIGI	SHO. BEEREPALLE			1	0
PARIGI	GANAPATHIPALLE			1	1
PARIGI	SIREKOLAM			2	2
PENU KONDA	SETTIPALLE	23	8	0	1
PENU KONDA	PENUKONDA(PT)	28		0	2
PENU KONDA	NAGALURU	9		0	4

Mandal	Village	Existing No. of Check Dams	Existing No of Percolation Tanks	Proposed Check Dams	Proposed Percolation Tanks
PENU KONDA	CHERLAPALLE			2	2
PENU KONDA	KONDAMPALLE			3	2
PUTTAPARTHI	KOTHAPALLE	10		0	4
PUTTAPARTHI	JAGARAJUPALLE			1	1
RAMAGIRI	MOTARCHINTALAPALLE	15	4	0	2
RODDAM	CHERUKUR	11	4	0	1
RODDAM	CHINNAMANTHUR	8		0	1
RODDAM	NALLUR	12		0	2
RODDAM	PEDDAMANTHUR	20		0	2
RODDAM	R. LOCHARLA	6		0	3
RODDAM	KALIPI	11		0	5
RODDAM	BUCHARLA	1		1	2
RODDAM	NARANAGEPALLE	2	4	2	1
RODDAM	CHOLEMARRI	4	1	2	2
RODDAM	MOLAKALACHERUVU			5	4
ROLLA	KAKI	14		0	2
ROLLA	ROLLA	54		0	7
ROLLA	TUBINAKUNTA			1	0
SOMANDEPALLE	BRAHMASAMUDRAM	7	3	0	1
SOMANDEPALLE	CHALLAPALLE	9		0	1
SOMANDEPALLE	EDULABALLAPURAM	7		0	1
SOMANDEPALLE	JULUKUNTA	6		0	1
SOMANDEPALLE	MAGECHERUVU	5		0	1
SOMANDEPALLE	PANDIPARTHI	14		0	1
SOMANDEPALLE	CHALAKUR	13		0	2
SOMANDEPALLE	CHENNAPURAM			1	0
TADIMARRI	PEDDAKOTLA	5		0	1

Mandal	Village	Existing No. of Check Dams	Existing No of Percolation Tanks	Proposed Check Dams	Proposed Percolation Tanks
TANAKAL	BONTHALAPALLE	14	3	0	2
TANAKAL	GURRAMBAILU			1	1
TANAKAL	VENKATRAYANIPALLE			1	1
TANAKAL	TANAKAL	12	20	2	0