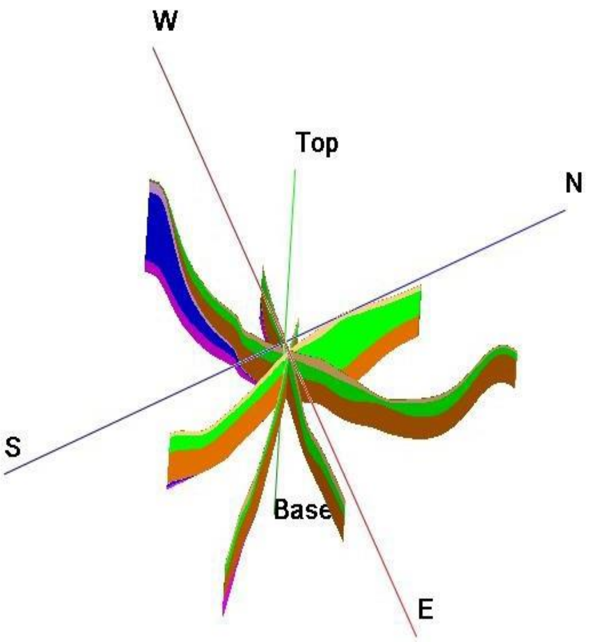
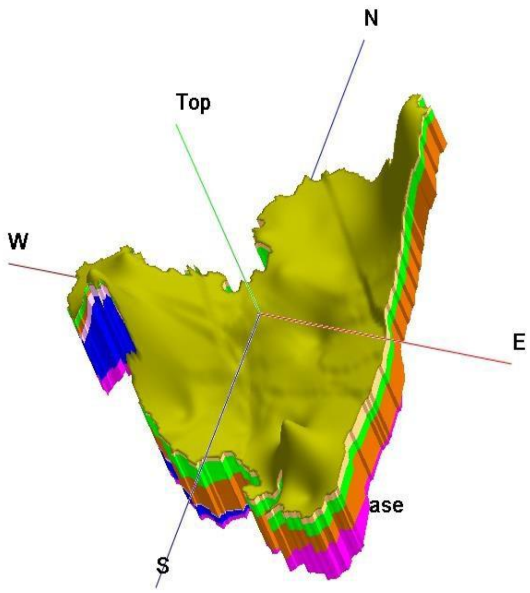
भारत सरकार
जल शक्ति मंत्रालय
जल संसाधन, नदी विकास और गंगा संरक्षण विभाग
केंद्रीय भूमिजल बोर्ड

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

REPORT ON
AQUIFER MAPPING FOR SUSTAINABLE MANAGEMENT OFGROUND WATER RESOURCES IN NANDYAL DISTRICT, ANDHRAPRADESH





CENTRAL GROUND WATER BOARD
SOUTHERN REGION
HYDERABAD
March 2023

REPORT ON

AQUIFER MAPPING FOR SUSTAINABLE MANAGEMENT OF GROUND WATER RESOURCES IN

NANDYAL DISTRICT, ANDHRA PRADESH

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Figures:

List of Tables:

Annexures:

AT A GLANCE

S.No.	Item		Particulars
1	Districts	:	Nandyal
2	Revenue Mandals (No.)	:	29
3	Villages	:	453
4	Geographical area	:	9681 km^2
5	Mappable area	:	7061 km^2
5	Population (2011 Census)	:	1687541
6	Population density (2011 Census)	:	184 persons/km^2.
7	Location	:	North latitude : 14°54'N16°9N East longitude : 77°38'E78°5E
8	Rainfall (Normal)	:	721.4 mm (Avg)
9	Geomorphology	:	Pediplain (61 %), Structural hills (13%), Pediments (6%), Floodplains (6%).
10	Major Rivers	:	Krishna, Kunderu (Tributary of Pennar) & its tributaries
11	Land Utilization (Ha) (2019-2020)	:	Forests - 31.8% Net Area Sown - 36.8% Current fallows - 9.2% Land put to non-agricultural uses - 8.2%
12	Soils	:	Montmorillontic, loamy-skeletal, mixed type and clayey-skeletal
13	Cropping Pattern (2019-2020) (Gross cropped Area: 4,06,534 Ha)	:	Kharif: Food crops-30%, food grains-26%, pulses-8%,paddy-12%, cotton-5% Rabi: Food crops-33%, food grains-32%, pulses-16%, paddy-7%
14	Irrigation	:	1. **Major project (completed):** Kurnool-Kadapa canal, Alaganuru Balancing Reservoir (ABR) 2. **Medium Projects**: Varadaraja Swamy Gudi Project (VRSP) 3. **Major Projects (ongoing):** NTR Telgu Ganga Project, Srisailam Right Bank Canal, Hundri Niva Sujala Sravanthi project, Galeru Nagari Sujala Sravanthi project

15	Prevailing Water Conservation/Recharge Practices	:	CD-2,221, PT-202 and Farm pond (FP) – 22,221
16	Geology	:	Shales, Quartzite, Limestone, BGC, Intrusives
17	Hydrogeological data points	:	343 hydrogeological data points (Exploration CGWB/SGWD: 124),VES: 111(CGWB), 49 well inventory.
19	Ground water yield (lps)	:	<0.1 to 6 lps (avg: 1.2 lps) in Granites and <0.1 to 10 lps (avg: 1.5 lps)in Metasediments. Deepest Fracture : 187.6 m at Chautkuru in Midtur mandal
20	Water Levels (2022) Depth to water levels (m bgl)	: :	1 8 3 wells Water table elevations during pre-monsoon season vary from156.9-536.5 m amsl and during post-monsoon season vary from 162-540.8 m amsl. Pre-monsoon season: 0.75 to 46.6 m bgl (average: 10.83 m bgl) Post-monsoon: 0.77 to 50.02 m bgl (average: 7.34m bgl).
21	Water Level Fluctuations (May V/s. November)	:	-7.83 to 37.65 m.bgl. Average rise of 4.49 m.
22	Long term water level trends (2011-21) (189 wells)	:	**Pre-monsoon:** Falling trends: 69% wells (0 m/yr to -2.3m/yr) Rising trends: 31% wells (0 to 2.6 m/yr) **Post-monsoon:** Falling trends: 24% wells (0 m/yr to -1 m/yr)Rising trends: 76% wells (0 to 2 m/yr)
23	Geophysical data (down to 200 m)	:	112 VES Weathered granite/Gneiss <100Ω m, Semi-weathered granite/Gneiss 60-350 Ω m, Fractured granite/Gneiss >350 Ω m. and < 150 ohm (Ω) m for the weathered Metasediments, 50-300 Ω m for underlying fractured Metasediments and > 300 Ω m for massive Metasediments.
24	Hydrochemistry	:	Total 111 GW samples Pre-monsoon (CGWB:57) Post-monsoon (CGWB:54)
24.1	Electrical Conductivity (µ Siemens/cm)	:	Pre-monsoon: 240-7920 µ Siemens/cm (avg:2223) in 45 % of the Area EC is within 1500 µ Siemens/cm. Post-monsoon: 107-6000 µ Siemens/cm(avg:1857.3)
24.2	Fluoride mg/l	:	Pre-monsoon: 0.15-2.21 mg/L, 82% of samples are fit forhuman consumptions. Post-monsoon: 0.1-2.95 mg/L

24.3	Nitrate mg/l	:	Pre-monsoon: 04-772 mg/L, 65 % of samples are unfit forhuman consumptions. Post-monsoon: 02-651 mg/L	
25	Conceptualization		Weathered zone (~25 m), Fractured zone (20-199 m)	
26	Aquifer Characterization	:	Weathered zone (~25 m). 10-20 m weathering occurs in 51% followed by < 10 m in 40% of area and deep weathering occurs in 9 % of area.	Fractured zone(25-196m.) Majority of fractures ~82% occurs within 60 m depth.
27	Aquifer wise Ground water yield	:	<0.1 to 1 lps. Avg:0.8 lps.	<0.1 to 6 lps. Avg: 0.75 lps. In Granites and <0.1 to 7 lps. Avg: 1 lps in Metasediments.
27.1	Transmissivity (m^2/day)	:	1- 14 m^2/day in Granites, upto 53 m^2/day in metasediments.	1- 910 m^2/day, in majority of wells it is < 30 m^2/day.
27.2	Specific Yield	:	< 1 to 2 %	-
27.3	Storativity	:	-	0.00001 to 0.0001
28	Ground water Resources (2022) MCM	:		
28.1	Net Dynamic ground water availability	:	768.8 MCM	
28.2	Gross GW Draft	:	143.2 MCM	
28.3	Provision for Domestic &Industrial use (2025)	:	6.264 MCM	
28.4	Average Stage of Ground water development (%)		19%	
28.5	Net GW Availability for future irrigation	:	625.63 MCM	
28.6	Categorization of mandals		Mandal wise it varies from 0% - 50.5% Safe:29 (all mandals)	
29	Major Ground Water Issues Identified	:	• Deep water levels (> 20 m bgl) are observed during pre monsoon season in 18 % of the area • Low yield (<1 lps) occurs in most of the area covering entire district. The yield from bore wells has reduced over a period of time. • Few mandals are fluorosis endemic where fluoride (geogenic) as high as 2.21 mg/L during pre-monsoon is found in ground water. • The high concentration of EC (> 3000 micro-seimens/cm) in 25 % of the area is observed during pre-monsoon (mostly in canal command area • High nitrate (> 45 mg/L) concentration due to anthropogenic activities isobserved in 55 % of samples during pre-monsoon. • High Uranium content >0.03 mg/L concentration in 14% of the area is observed during pre monsoon season	

30	Management Strategies	:	**Supply side measures** • To be taken up (Artificial Recharge Structure) : 111 ARS (CD : 66, CDRS : 6, PT : 30, PTRS : 9) • Water Conservation measures (WCM) Farm Ponds The size of form ponds can be 10 x 10 x 3 m. Total 9096 farm ponds are recommended (20 in each village in 453 villages) **Demand side measure** • Proposed micro Irrigation: ~22650 ha of additional land that can be brought under micro-irrigation . With this ~14.7 MCM of ground water can be conserved over the traditional irrigation practices. **Other measures** • Capacity building in power supply regulation (4 hour each in morning and evening) will increase the sustainability of wells • Laser leveling of irrigated land. • A participatory ground water management (PGWM) approach in sharing of ground water 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 ground water may be given to the concerned farmers. • The open stone quarries / abandoned quarries can be filled with soil and covered with vegetation; it will prevent further erosion and weathering of salts and minerals and also escalation of the salinity levels in aquifers. • Recommending to use of red mud pot to store potable household water in Fluoride contaminated areas to reduce the impact of fluorosis. • Recommend to cultivate high Ec tolerant crops like cotton, safflower, sesame etc. • Change in cropping pattern from water intensive paddy to irrigated dry crops like pulses and oil seeds are recommended, particularly in water stress areas. If necessary some regulatory rules may be framed and implemented. • In urban and rural areas the sewerage line should be constructed to arrest leaching of nitrate

31	Expected Results and Out come	:	• With the above interventions, the likely benefit would be the net saving of 17.73 MCM of ground water either through water conservation measures like adoption of drip and sprinkle irrigation and artificial recharge to ground water. Further stage of extraction would be controlled to avoid all the mandals of district to fall into semi-critical/critical category.

ABBREVATIONS

2D	:	2 Dimensional
3D	:	3 Dimensional
ARS	:	Artificial Recharge Structures
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

Nandyal district covering an area of 9681 km^2, receives an average annual normal rainfall of 721 mm of which SW monsoon 70% and north-east monsoon contributes 21% and rest by summer rainfall.

Administratively, the area is governed by 29 revenue mandals with 453 revenue villages. The population of the district is ~ 16.8 lakhs (2011 census) with average density of 184 persons/km^2.

The area is underlain by 97% Metasediments which include shales , quartzites, limestone and other 3% include banded gneissic complex. Pediplain is the major geomorphic feature (61% of area), followed by structural hills (13%), pediments (6%), flood plain (6%), Denudational hills, Structural valleys and channel fill, . The district is drained by river Kunderu, a major tributary of river Pennar, and bordered by River Krishna in north. The gross cropped area during 2019-20 is 4,06,354 ha. Forest occupies 32% of the total geographical area, waste lands and current fallow land occupies 9% of area. Main crops grown during Kharif (food crops-30%, food grains-26%, pulses-8%, paddy-12%) and during Rabi (food crops-33%, food grains-32%, pulses-16% and paddy-7%). The soils are majorly clayey soils and loamy soils.

The major irrigation projects completed in Nandyal district are Kurnool-kadapa canal, Alaganuru Balancing Reservoir. The ongoing major Galeru Nagari Sujala Sravanthi project. The medium irrigation projects in the district is Varadaraja Swamy Gudi Project. During the year 2019-20, which the major source in district for irrigation are canals (~50%) followed by bore wells (32%). Dugwell constitute 5% while Lift irrigation and Tanks constitute 6% . These projects are NTR Telgu Ganga Project, Srisailam Right Bank Canal, Hundri Niva Sujala Sravanthi project.

Ground water yield varies from <0.1 to 6 lps in Granite/Gneisses and <0.1 to 10 lps in metasediments. Majority of fractures occur within 100 m depth and deepest fracture is encountered at 175.8 m.bgl at, Burugula, Peapally mandal. Water levels are monitored through 124 wells during pre and post- monsoon seasons. The average DTWL varies from 0.75 to 46.6 m bgl (average: 10.83) and 0.77 to 50.02 m bgl (average: 7.34) during pre and post-monsoon season respectively. During pre-monsoon season 0-10 m water level range is more predominant (63% of area) followed by 10-20 and >20 m (16 % of area). During post-monsoon season 0-5 m water level is more predominant (61 % of area), followed by 5-10 m (20% of area) and 10-20 m (11% of are a). Water level fluctuation (May Vs Nov) data indicate water level vary from -7.83 to 37.65 m with average rise of 4.49m. The Long-term water level trend analysis for 10 years (2011-2021) is analysed and it is observed that during pre-monsoon season 69% wells shows falling trend (0 m/yr to -2.3 m/yr) and 31% wells shows rising trend (0 to 2.6 m/yr). During post-monsoon season 24% wells show falling trend (0 m/yr to -1 m/yr) and 76% wells shows rising trends (0 to 2 m/yr).

Geophysical data from 112 Vertical Electrial Sounding (VES) data (CGWB) reveals resistivity < 100 Ohm (Ω) m for the weathered granite/gneiss (1-30 m) , 60-350 Ω m for underlying fractured granite and > 350 Ω m for massive granite. Resistivity < 150 ohm (Ω) m for the weathered Meta-sediments (1-20 m), 50-300 Ω m for underlying fractured Meta- sediments (70-100m) and > 300 Ω m for massive Metasediments.

Total 111 ground water samples (Pre-monsoon:57 and Post-monsoon:54) were analysed for determining the suitability of ground water for drinking purposes. In 45% and 52% of the areas EC is in the range of < 1500 μ Siemens/cm during pre and post-monsoon seasons respectively. During pre-monsoon season, nitrate concentration in 65% of samples is beyond permissible limits of BIS (45 mg/l) and Fluoride concentration varies from 0.15 to 2.21 mg/l and found 82% of the samples within permissible limits of BIS (< 1.5 mg/l). During post- monsoon season, Nitrate concentration in 40% samples is within the permissible limits of 45 mg/L. The F concentration varies from
0.15 to 2.95 mg/l and in 17% of samples is beyond maximum permissible limit of BIS.

Based on 343 hydrogeological data points, aquifers from the area can be conceptualized into 2 no's namely 1. weathered zone (~25 m) and 2. fractured zone (25- 186 m). Weathered zone has gone dry in most of the area due to over-exploitation during pre-monsoon season. Weathered zone in the range of < 10 m occurs in 40 % of area, 10-20 m in 51 % of area, and deep weathering (> 20 m) in 9 % of area. Ground water yield of this zone varies from <0.1 to 1 lps (avg: 0.8 lps) in granites and from 0.01 to 4 lps (avg: 1.0 lps) in metasediments. Transmissivity varies from 1 to 14 m^2/day in Granites and upto 53 m^2/day in weathered metasediment aquifer. Fracturing zone varies from 25 to 175.8 (deepest fractureat Burugula, Peapally mandal). In 82% of the area fractures occur within < 60 m depth. It is observed that 60-100 m fractures occur in 10% while > 100 m fractures occur in 8% of area. Ground water yield varies from 0.01 to 6 lps (avg: 0.75 lps) and meta sediments vary from 0.01 to 7 lps (avg: 1 lps) . . The transmissivity varies from 1-910 m^2/day.

Net dynamic replenishable ground water availability as on 2022 is 768.8 MCM, gross ground water draft is 143.2 MCM, provision for drinking and industrial use for the year 2025 is 6.26 MCM and net available balance for future irrigation use is 625.63 MCM. The stage of ground water development is 19 %.

In terms of categorization, all 29 mandals are safe with stag of development <70%. Major issues identified are high fluoride concentration (>1.5 mg/L) occur in 18% & 17% of the samples during pre and post monsoon seasons , high concentration of EC (> 3000 micro-seimens/cm) in 25% & 14% of the area during pre and post monsoon seasons, deeper water levels (> 20 m bgl) in 18% of the area during pre monsoon seasons and low yield in most of the area. High nitrate concentration(>45mg/L) is observed in 55% of samples in pre monsoon season. High Uranium content >0.03mg/L is observed in 14% of the area in pre monsoon. Other issues identified are water marketing, change in cropping pattern etc.

The management strategies mainly include both supply side and demand side. The supply side measure includes ongoing work under state Govt. sponsored NEERU-CHETTU programme where silt has been removed from existing tanks. This will contribute ground water by recharge. Under supply side measures construction of artificial recharge structures in 7 mandals (Banganapalle, Dhone, Sanjamala, Kolimigundla, Owk, Bethamcherla and Peapally) which include 66 check dams, 6 check dams with recharge shafts, 30 percolation tanks and 9 percolation tank with recharge shafts. The expected volume to be recharged by these structure will be 3.031 MCM.

Under Water conservation measures, constructions of 9060 no.s of farm ponds are proposed in 453 villages.

Demand side measure includes bringing ~22650 ha of additional land (@50 ha/villagein 453 villages) under micro-irrigation. With this 14.7 MCM of ground water will be saved in both seasons by utilizing same units.

Other measure includes a participatory ground water management (PGWM) approach in sharing of ground water and monitoring resources on a constant basis along with effective implementation of the existing 'Water, Land and Trees Act' of 2002 (WALTA-2002). Subsidy/incentives on cost involved in sharing of ground water may be given to the concerned farmers. In urban and rural areas the sewerage line should be constructed to arrest leaching of nitrate. Recommending to use of red mud pot to store potable household water in Fluoride contaminated areas to reduce the impact to fluorosis. Uranium causes radio toxicity as well as chemical toxicity. Therefore in U contaminated areas installation of permeable reactive barrier (Ferric iron, phosphate) in Govt sponsored RO plants is recommended. Restrict use of extensive chemical fertilizers as it will eventually degrade soil and leach to join ground water which already has high salinity. Recommend to cultivate high Ec tolerant crops like cotton, safflower, sesame etc.

With the above interventions, the likely benefit would be the net saving of 17.73 MCM of ground water. This will keep the check on stage of ground water development so as to avoid the district to over exploit the ground water and sustainably use it in near future.

1. INTRODUCTION

Aquifer mapping is a multidisciplinary scientific approach wherein a combination of geologic, geophysical, hydrologic, and chemical analysis is applied to characterize the quantity, quality, and sustainability of ground water in aquifers. In the recent past, there has been a paradigm shift from "ground water development" to "ground water management". As large part of India particularly hard rock aquifers have become water stressed due to rapid growth in demand for water in response to population growth, irrigation, urbanization, and changing lifestyle. Therefore, in order to have an accurate and comprehensive micro-level picture of ground water in India, aquifer mapping in different hydro-geological settings at the appropriate scale is devised and implemented, to enable robust ground water 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. Varied and diverse hydro-geological settings demand precise and comprehensive mapping of aquifers down to the optimum possible depth at appropriate scale to arrive at the robust and implementable ground water management plans. The proposed management plans will provide necessary inputs and recommendations for ensuring sustainable management of ground water resources of district. Finally the aquifer maps and management plans will be shared with the Administration of Nandyal district, Andhra Pradesh state for its effective implementation.

1.1 Objectives

In view of the above challenges, an integrated hydro-geological study has been taken upto develop a reliable and comprehensive aquifer map and to suggest a suitable ground water management plan on a 1: 50,000 scale.

1.2 Scope of the study

The main scope of the study is summarised below.

- Compilation of existing data (exploration, geophysical, ground water level, and ground water quality) with geo-referencing information and identification of principal aquifer units.
- Periodic long-term monitoring of ground water regime (water levels and water quality) for creation of time series database and ground water resource estimation.

- Quantification of ground water availability and assessing its quality.
- To delineate aquifer in 2-D and 3-D along with their characterization on a 1:50,000 scale.
- Capacity building in all aspects of ground water development and management through information, education, and communication (IEC) activities, information dissemination, education, awareness, and training.
- Enhancement of coordination with concerned central/state govt. organizations and academic/research institutions for sustainable ground water management.

1.3 Study Area

Nandyal District lies between the northern latitudes of 14 °54’9’’N to 16 °9’4’’N and eastern longitudes of 77 °38’54’’E to 78 °55’47’’E located in the south-west of Andhra Pradesh in (Fig 1.1). This district is bounded on the north by Krishna Rivers as well as Nagarkurnool (Old Mahabubnagar) district of Telangana State, on the south by Kadapa and Anantapur districts on the west by the Kurnool district and on the east by Prakasam district. The district population with 1687541 as per 2011 Population Census and population density of 184 persons/km^2 ,with geographical extent of 9154 Sq. Kms. Administratively the district comprises of 3 Revenue Divisions, 29 Revenue Mandals, 26 Mandal parishads, 5 Municipalities, 1 Nagar Panchyat, 453 Gram Panchayats and 417 Revenue Villages.

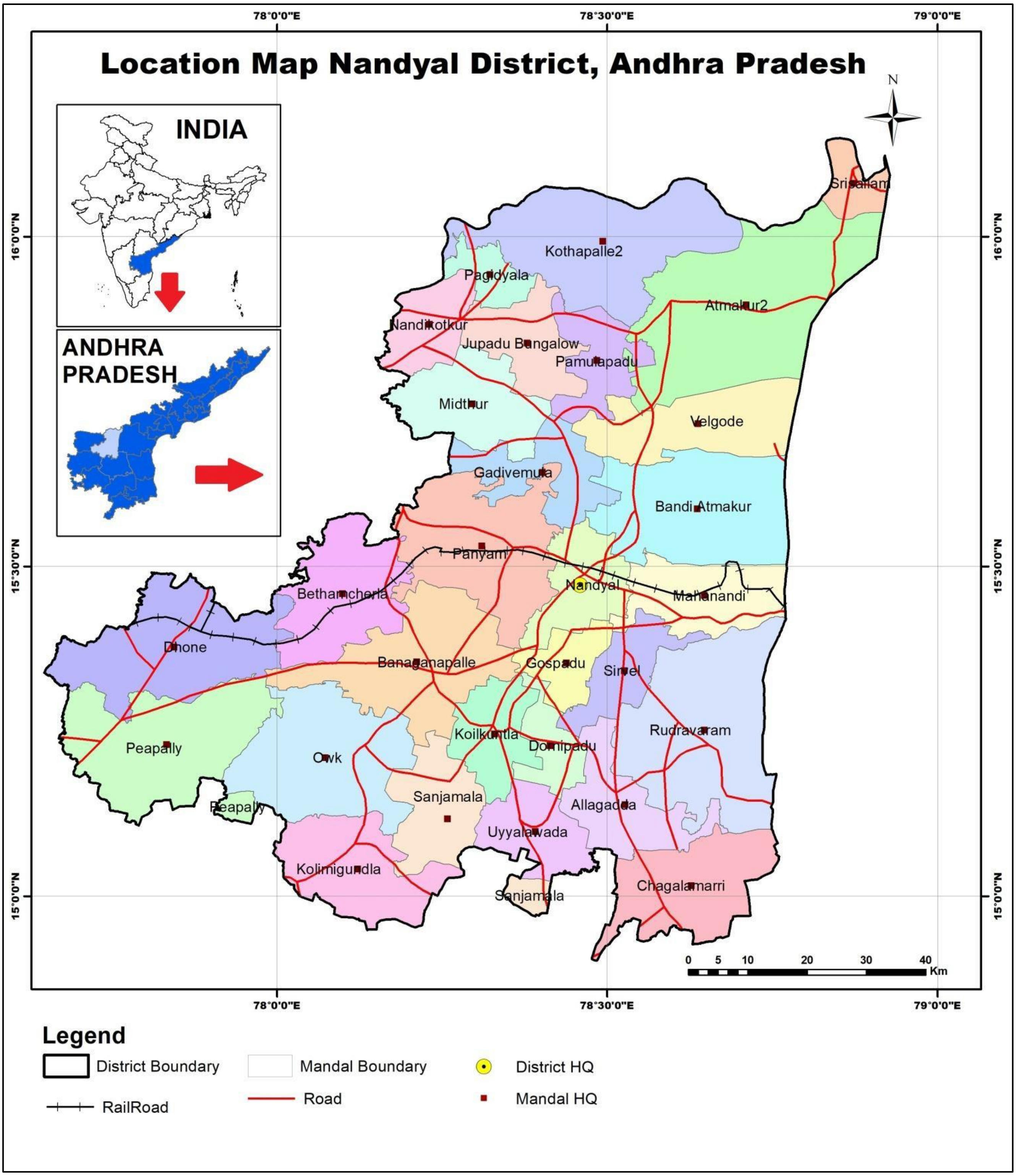


Fig.1.1 Location map of Nandyal District, Andhra Pradesh

1.4 Climate and Rainfall

The climate of the district is characterised by tropical wet and dry climate, characterized by year round high temperatures. Nandyal gets rainfall from both the South West monsoon as well as the North East monsoon. June to October is usually the monsoon period. The December is the coldest month and tempreture varies between 17.8° C an 30.5°C while May is the hottest month and tempreture varies between 25° C an 40° C. SW monsoon contributes 70% while retreating monsoon (NE) contributes 21% season and rest by winter and summer rainfall. Generally Rainfall increases from west to eastern part of district. As per the IMD rainfall data, during the year 2022, it received annual rainfall of 721.4 mm. The trend of decadal rainfall of the district shows negative slope value suggesting that annual rainfall is declining every year.

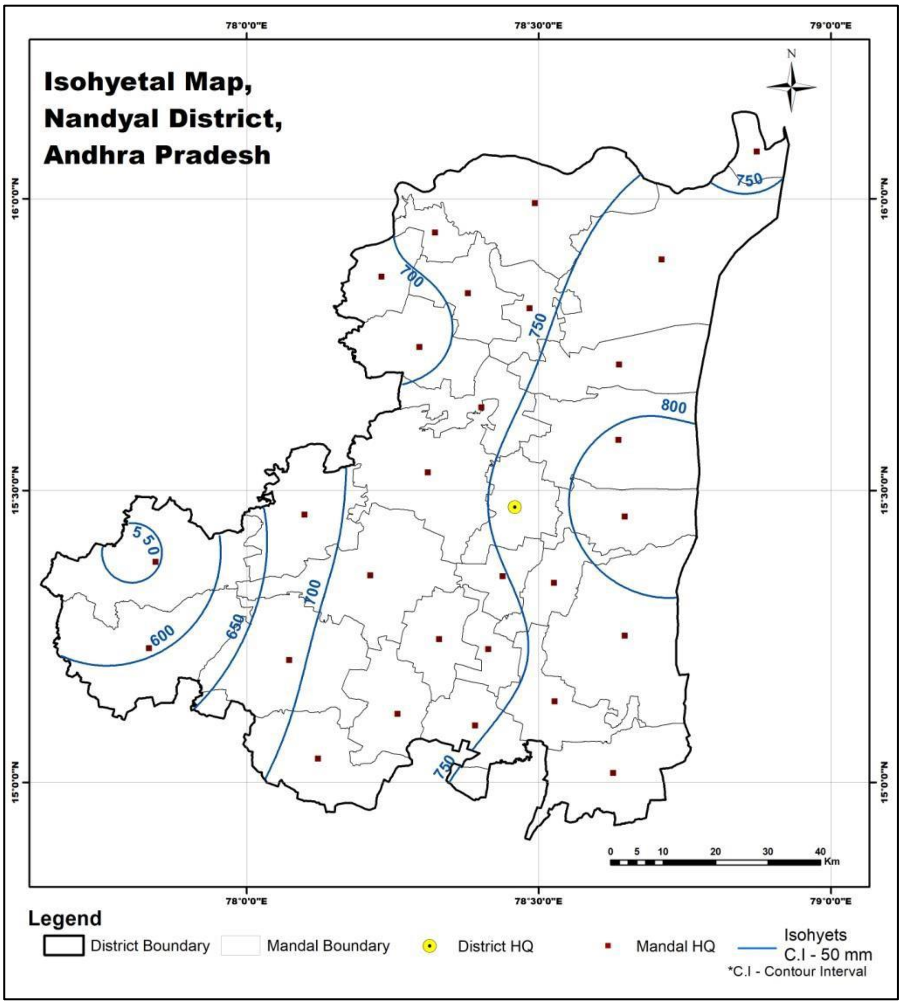


Fig.1.2 Isohyetal map of Nandyal District

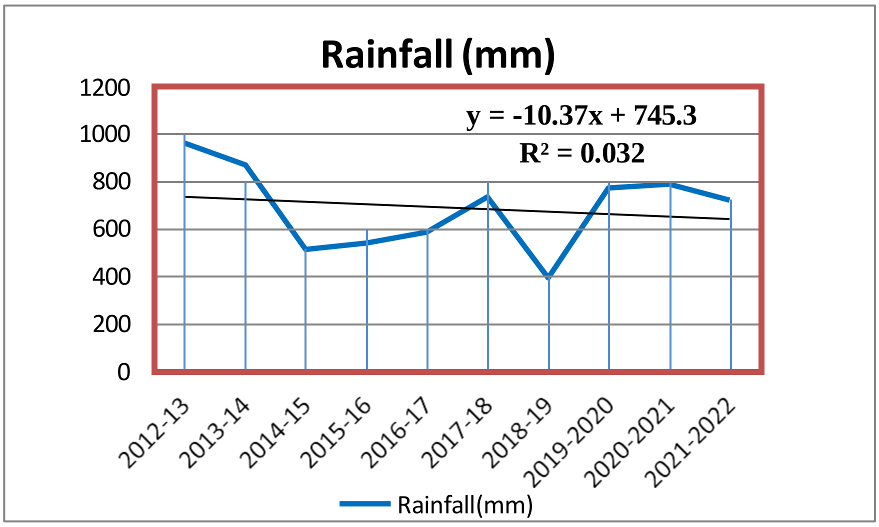


Fig.1.3 Decadal rainfall graph of Nandyal District

1.5 Geomorphological Set up

Physiographically the district posseses very undulating topography with two major distinctive topographic units identified as midlands and highlands. Nallamalas and Erramalas are the two important mountain ranges in the district. As the eastern part of the district is bordered by Nallamala Hills (part of Eastern Ghats), with nearly N-S alignment, also parallel to Coromandel Coast can be considered as highlands along with Erramalas, which roughly divide the district into two. Majority of the area comes under midlands, i.e. area west of the Nallamala Hills. The major slope of the district is towards south, but in northern part of the district the slope is towards north. The major landforms covered in the district are pediplain, bordered by Structural hills on eastern side. The other landforms include Residual Hills, Pediment, Plateau, Channel fill, Flood plain.

Major Hydrogeomorphic Features in District	Description	Significance in Ground water Prospecting	% of area covered
Pediplain	An extensive plain formed by the coalescence of pediments.	Moderate	61
Pediment	Gently sloping smooth surface of erosional bedrock with thin veneer of detritus	Moderate to Poor	6
Structural Hill	Linear or arcuate hills exhibiting definite trend	Poor to Nil	13

	lines. structurally controlled with complex folding, faulting, criss-crossed by numerous joints/fractures which facilitate some infiltration		
Flood Plain	Very gently sloping plain of alluvial sediments with more than 50 meter of thickness	Excellent	6
Channel Fill	The sediment infill of a channel, produced either by the accretion of sediment transported by water flowing through the channel, or by the infilling of an abandoned channel.	Good	2

Table 1.1 Hydrogeomorphic units in relation with ground water prospecting

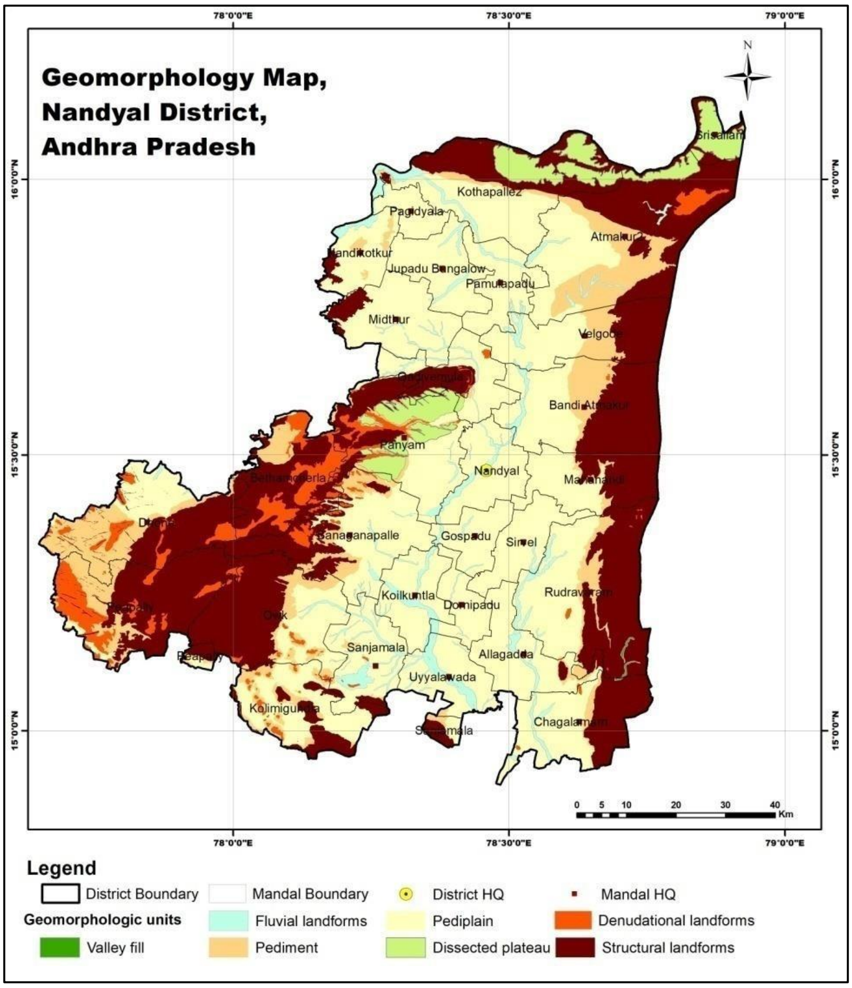


Fig.1.4 Geomorphology map of Nandyal District

1.6 Drainage

Kunderu river, a tributary of Penna is the major stream flowing in N-S direction in the district. It flows through Midthur, Gadivemula, Nandyal, Gospadu, Koilakuntla, Dornipadu and Chagalamarri mandals and then enters Kadapa district. Nandyal district is also bounded by Krishna River in the North; which also act as natural boundary between Telangana and Andhra Pradesh. Topographical analysis of the area has brought to light the dendritic patterns of the major rivers. Dendritic pattern drainage is commonly seen in the flat lying rocks and in areas where the preferential zones of structural weakness are minimal. The tributaries joining the major rivers are showing parallel pattern in some area. The drainage pattern is mostly dendritic to sub dendritic of higher order streams, however at places parallel to sub parallel pattern is also observed which indicates that the drainage of particular area is controlled by topography, i.e. steep slopes with some relief. Some lower order streams which overlain BGC has very little control of topography as they exhibit rectangular drainage pattern suggesting structural weakness beneath. A significant decrease in the drainage density from highland to midland is observed in the basin (from east to west of district). The area with low drainage density indicates possibility of high recharge (central liner portion of the district). The whole eastern margin of the district and west to central west portion has high drainage frequency as compared to central part of the district which suggests high runoff and low recharge in the area. Hence lowland and midland area is good sites for recharge structures.

1.7 Land use and cropping pattern

Out of the total geographical area of 968100 ha, agriculture and forest are the prominent land use aspects in Nandyal district which forms 36.68 % and 31.88 % of total area respectively. The gross cropped area during the year 2019-20 is 4,06,534 ha and net sown area is 3,56,840 ha, remaining agricultural land was kept fallow. The gross area cropped during Khariff season is 2,29,446 ha and the major crops sown in khariff are paddy fields, bajra, maize, chillies, turmeric, cotton and oil seeds; while The gross area cropped during Rabi season is 1,77,088 ha and the major crops sown in grown during rabi season are paddy ,jowar, pulses, oilseeds and tobacco.

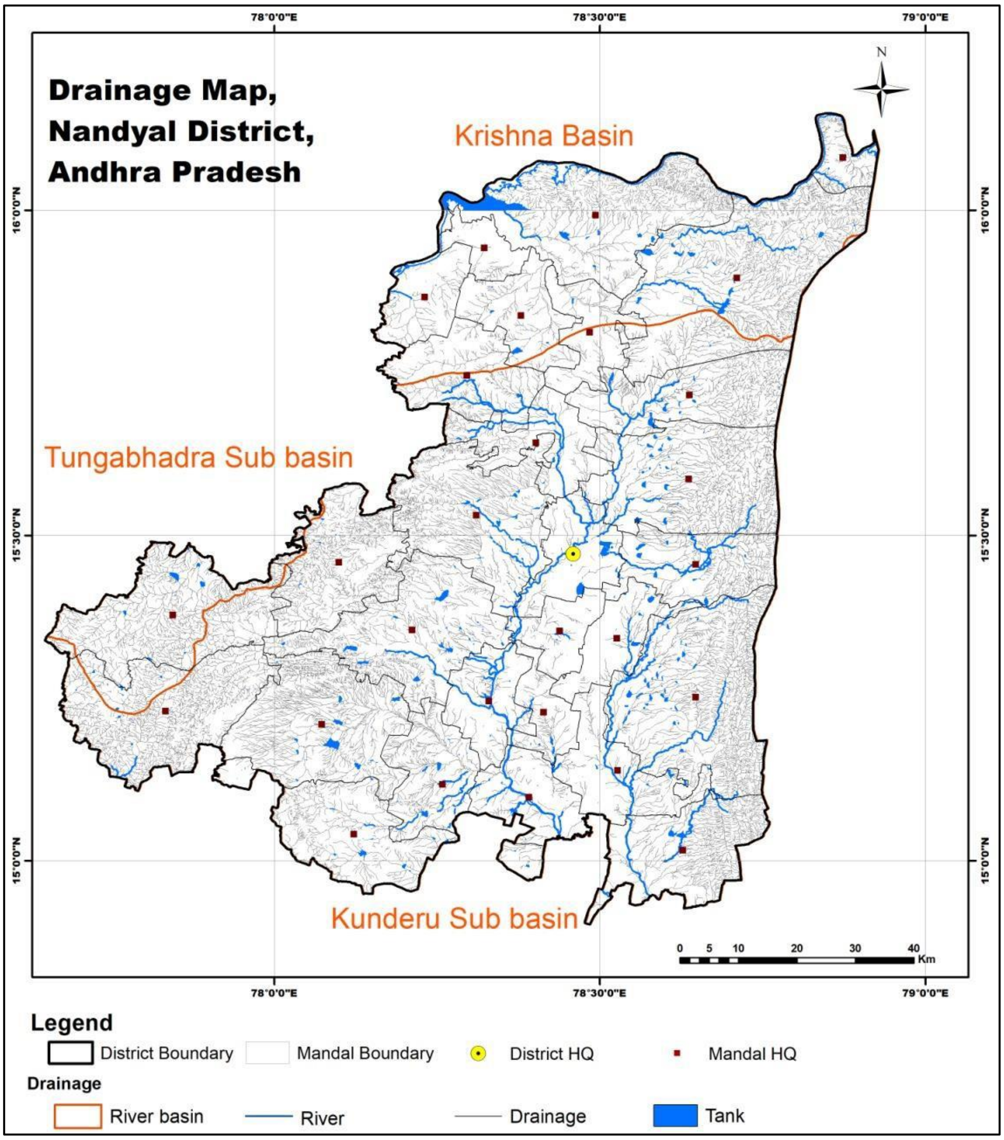


Fig.1.5. Drainage map of Nandyal district

Land Utilization	Area (Ha)	% of Geographical Area
Forests	308607	31.88
Barren & uncultivable land	74986	7.75
Land put to non-agricultureal uses	79528	8.22
Cultivable waste	19729	2.04
Permanent pastures and other grazing lands	523	0.05
Land under miscellaneous tree crops & groves	790	0.08
Current fallows	89041	9.20
Other fallow lands	38016	3.93
Net Area Sown	356840	36.86
Total geographical area	**9681 00**	**100**

Table 1.2. Land utilization of Nandyal District (2019-2020)

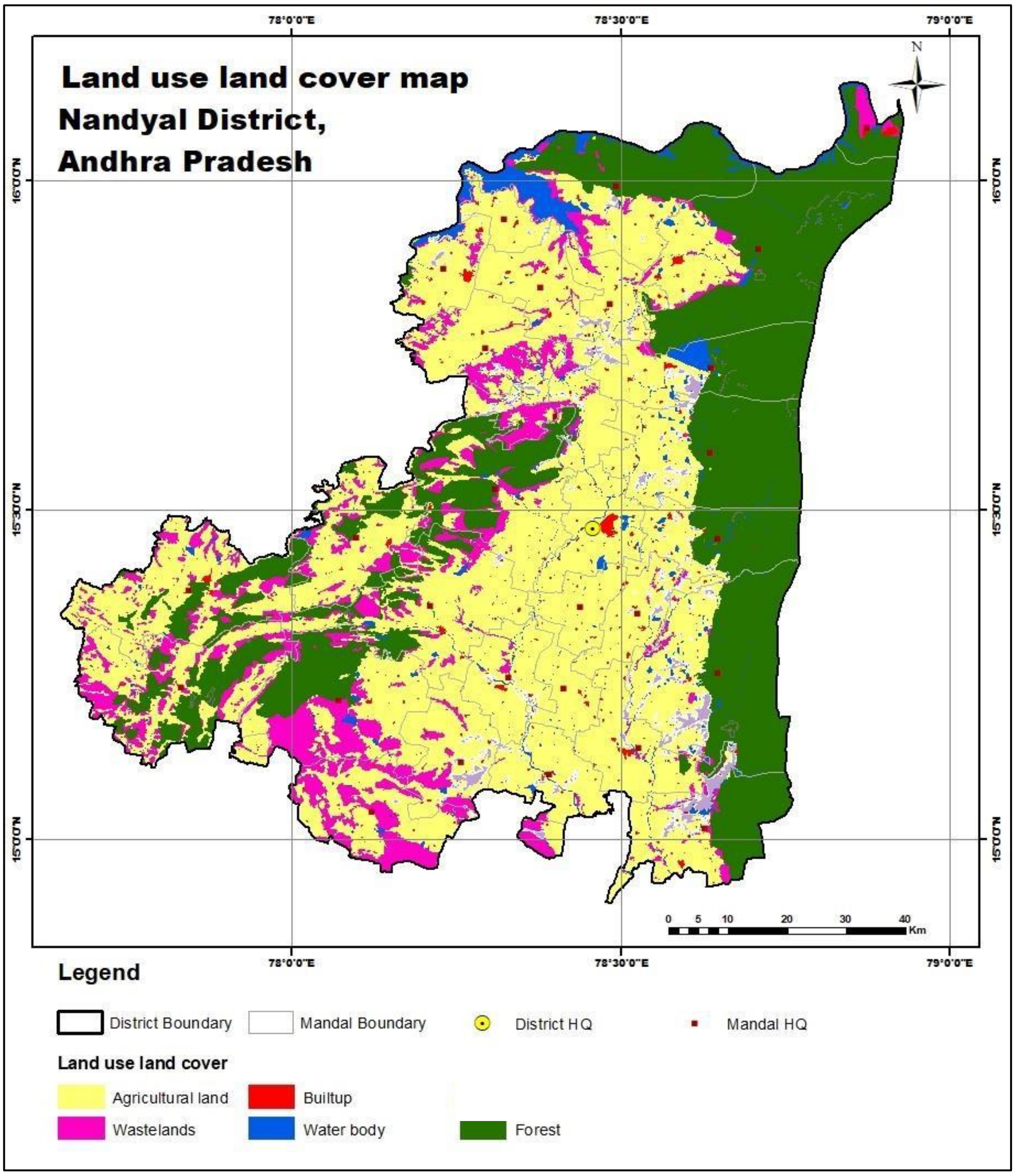


Fig.1.6 Land use land cover map of Nandyal district

Crops	Rabi (ha)	Kharif (ha)
Paddy	34551	69967
Jowar	34206	7802
Bajra	508	1798
Maize	9569	28078
Pulses	84890	46781
Food Grains	164225	157423
Chillies	69	7156

Turmeric	1128	7225
Food crops	169153	178597
Cotton	0	30612
Oilseeds	6312	19564
Tobacco	1338	20
Non food Crops	7935	50849

Table.1.3. Crops harvested in Rabi vs Khariff

Source : Handbook of statistics of Nandyal District

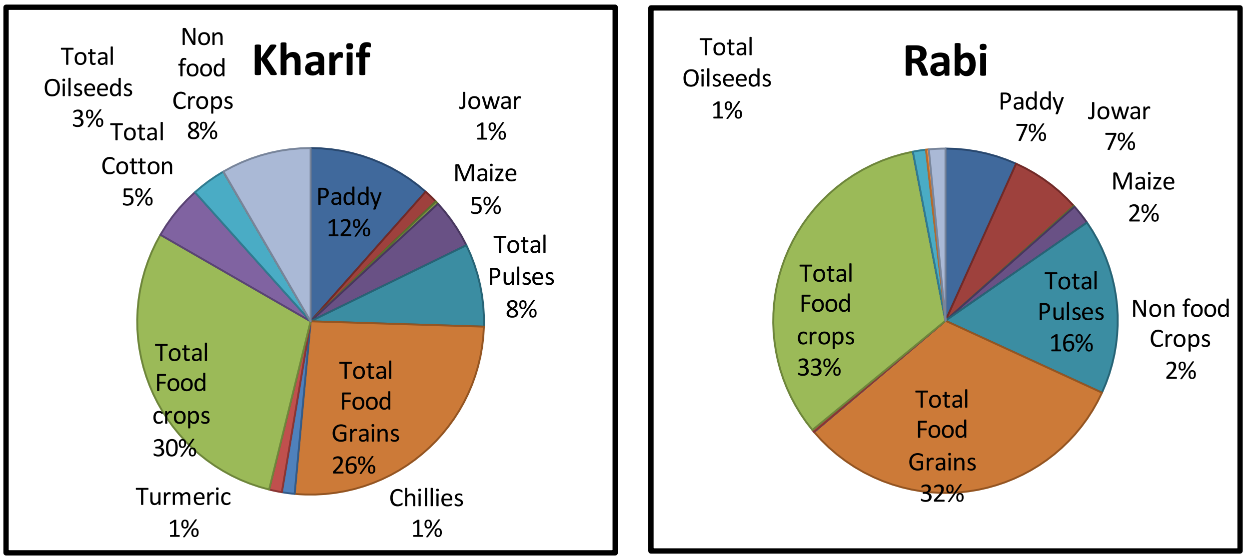
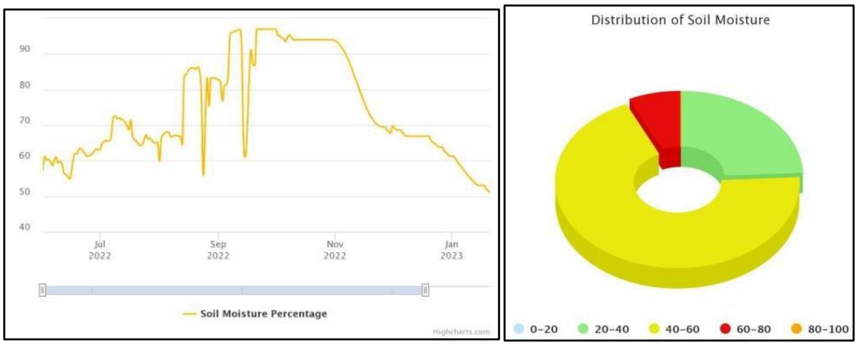


Fig. 1.7 Pie diagram showing cropping pattern trend during Kharif and Rabi

1.8 Soils

The major types of soil in the district include fine, montmorillontic, loamy-skeletal, mixed, clayey-skeletal and very fine, montmorillonitic. The montmorillonitic soil is confined to drainage of the low lying streams of Kunderu River. The Erramalas and Nallamala ranges are characterized by clayey soils with rock fragraments, therefore clayey-skeletel. Loamy-skeletal is also observed in Nallamala hills. Highlands of the ranges have rock lands with little soil. Soil moisture for the months May to Nov is shown in graphical form. It increases from month of may to November indicating its direct relation to SW monsoon. Soil moisture range of 40-60% covers around 68% of the district area followed by 20-40% moisture which covers 24% of the geographical area. As the major soil type is montmorillontic (Clayey) it has tendency to absorb and hold more moisture due its small numerous pore spaces.



Source : https://apwrims.ap.gov.in/mis/soilmoisture

Fig. 1.8. Distribution of Soil moisture

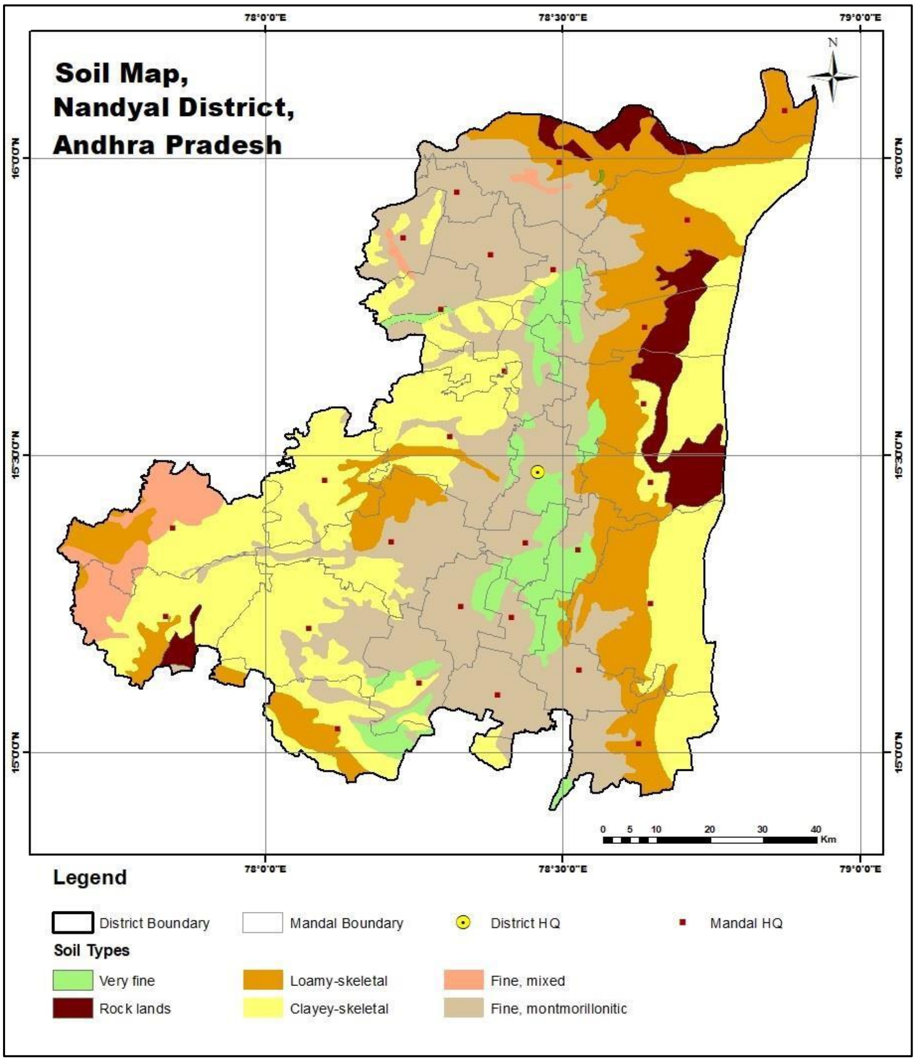
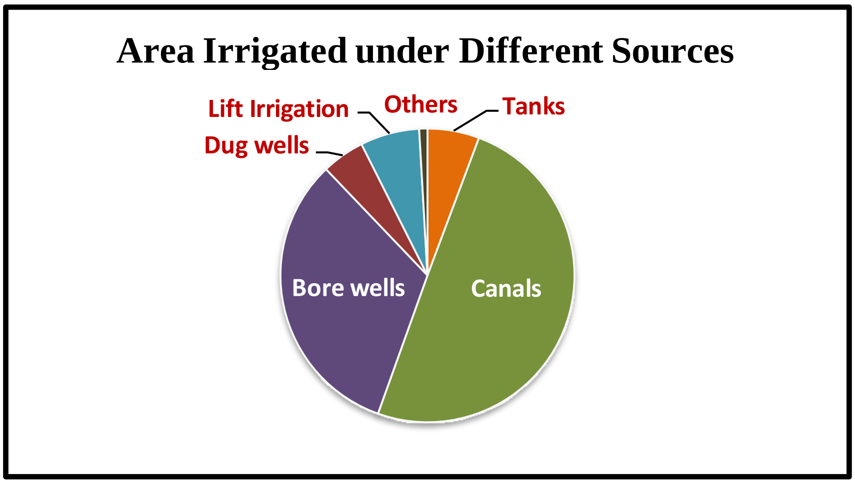


Fig. 1.9. Soil map of Nandyal district

1.9 Irrigation:

The KC.Canal (Kurnool - Cuddapah Canal) is 130 years old major irrigation system which takes off from right flank of Anicut constructed across Tungabhadra River near Sunkesula Village in Kurnool district. The mandals benefitted under KC Canal are

Nandikotkur, Pagidyal, Jupadu bunglow, Pamulapadu, Velugodu, Gadivemula, Bandi Atmakur, Mahanandi, Nandyal, Gospadu, Sirivella, Rudravaram, Allagadda, Chagalamarri, Dornipadu, Uyyalawada and Koilakuntla. Sivabhashyam Sagar Project (Formerly known as Varadaraja Swamy Gudi Project) is a Medium Irrigation Project constructed across Munimadugula Vagu which is a hill stream which takes its origin in the Srisailam hill ranges of Nallamala forest . It joins Bhavanasi River which in turn is a tributary of Krishna River. The dam site is at Kottalachervu village about 18 Kms North of Atmakur town in Kurnool District.Telugu Ganga Project is an inter-state Project formulated to irrigate 5.75 lakh acres in drought prone areas of Rayalaseema and uplands of Nellore District in Andhra Pradesh by utilising 29 TMC of Krishna flood flows and 30 TMC of Pennar flood flows. Further with a view to provide drinking water to the Chennai city, the three Krishna basin states of Andhra Pradesh, Karnataka and Maharashtra have agreed to spare 5 TMC each from their respective shares of Krishna waters totals to 15 TMC to meet the requirements. The Srisailam Right Bank Canal (S.R.B.C) Scheme was formulated to irrigate an ayacut of 1,90,000 acres to benefit the chronic drought prone areas in 82 villages of Nandyal, Panyam, Banaganapalli, Owk, Koilakuntla, Vuyyalwada and Sanjamala mandals of Nandyal district (1,57,422 Acres) and 18 villages of Jammalamadugu mandal of Kadapa district (32,578 Acres). Hundri Niva Sujala Sravanthi Irrigation Project is contemplated to utilise 40 tmc of floodwater of river Krishna near Malyala village Nandikotkur mandal of Nandyal district from the foreshore of Srisailam Reservoir by lift and gravity to provide irrigation facilities to an extent of 6.025 lakh acres Kharif ID, and also drinking water facility for about 33 lakh people in drought prone districts of Rayalaseema.



Source : Handbook of statistics of Nandyal District

Fig. 1.10. Irrigated area – Sources of water

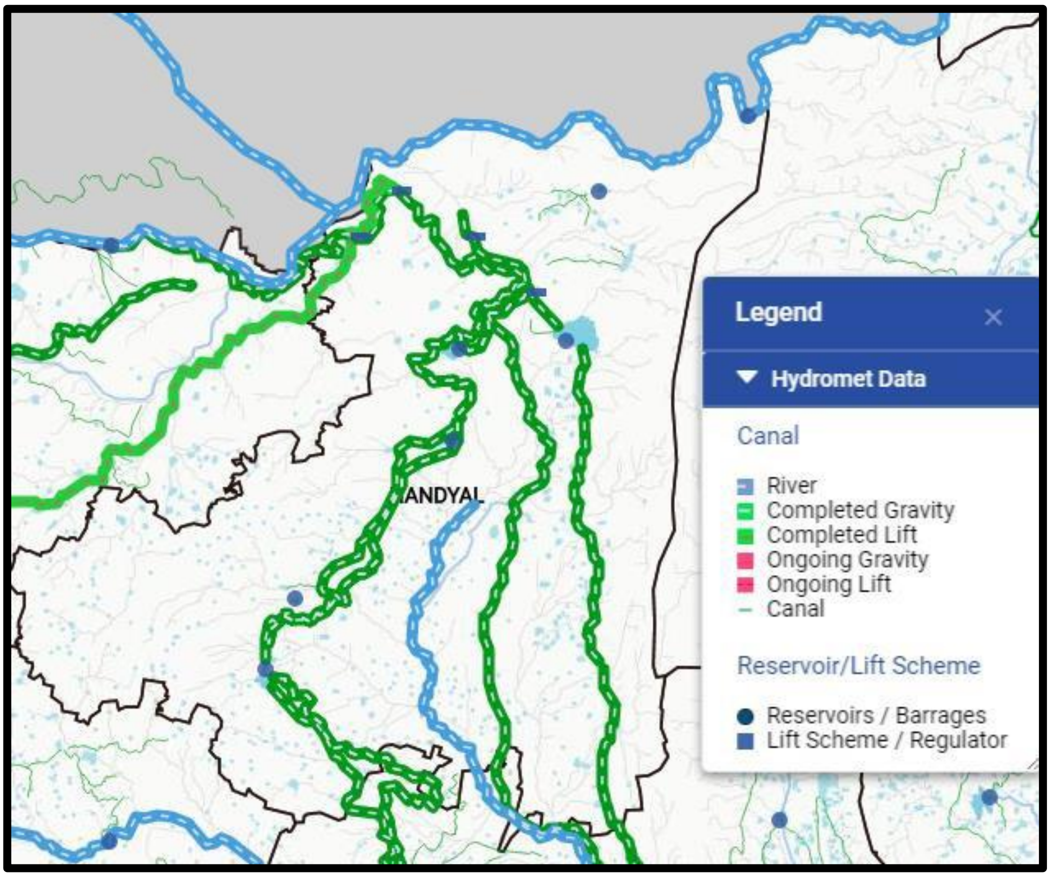


Fig.1.11. Major Canal systems in Nandyal district

Under Lift irrigation the Contemplated ayacut of Nandyal district is 48,401.98 acres. During the year 2019-20, 1,26,673 Ha area was irrigated from surface water and 79,479 Ha irrigated by ground water. Ground water contributes 39% of irrigation and surface water 61%.

In Nandyal district, irrigated area has sources from dugwells, borewells, canals, lift irrigation, and tanks, of which the major source in district for irrigation is canals (~50%) followed by bore wells (32%). Dugwell constitute 5% while Lift irrigation and Tanks constitute 6% each.

Irrigation projects benefited in district	
Major Irrigation projects Completed	1. Kurnool - Cuddapah Canal
	2. Alaganuru Balancing Reservoir (ABR)

Medium Irrigation ongoing projects	1. Varadaraja Swamy Gudi Project (VRSP)
Major Irrigation ongoing projects	1. NTR Telugu Ganga Project (TGP)
	2. Srisailam Right Bank Canal (SRBC)
	3. Hundri Niva Sujala Sravanthi Irrigation Project(HNSS)
	4. Galeru Nagari Sujala Sravanthi Irrigation Project

Table.1.4. Irrigation projects in Nandyal district

1.10 Geology

The area is underlain by various rock types that belong to Late Archaean or Early Proterozoic era which are succeeded by rocks of Dharwarian age and both are traversed by dolerite dykes. The older rocks are overlain by rocks of Cuddapah Super group and Kurnool Group belonging to Middle and Upper Proterozoic Age. The Archaeans comprise the Peninsular Gneissic Complex, represented by granite, granodiorite, granite-gneiss and migmatite. The metasediment rocks of Cuddapah and Kurnool Group include mostly shales, quartzites, limestones and dolomites. The recent alluvium is confined to the major stream and river courses like Krishna and Kunderu.

	Age	**Group**	**Formation**
Kadapa Super Group	Neo - Proterozoic	Kurnool Group	Nandyal Shale
			Koilkuntla limestone
			Painam quartzite
			Owk shale
			Narji limestone
			Banganapalle quartzite
	Meso – Proterozoic	Nallamalai Group	Srisailam quartzite
Peninsular Gneissic Complex (Basement)			

Table.1.5. Stratigraphic succession in Nandyal district

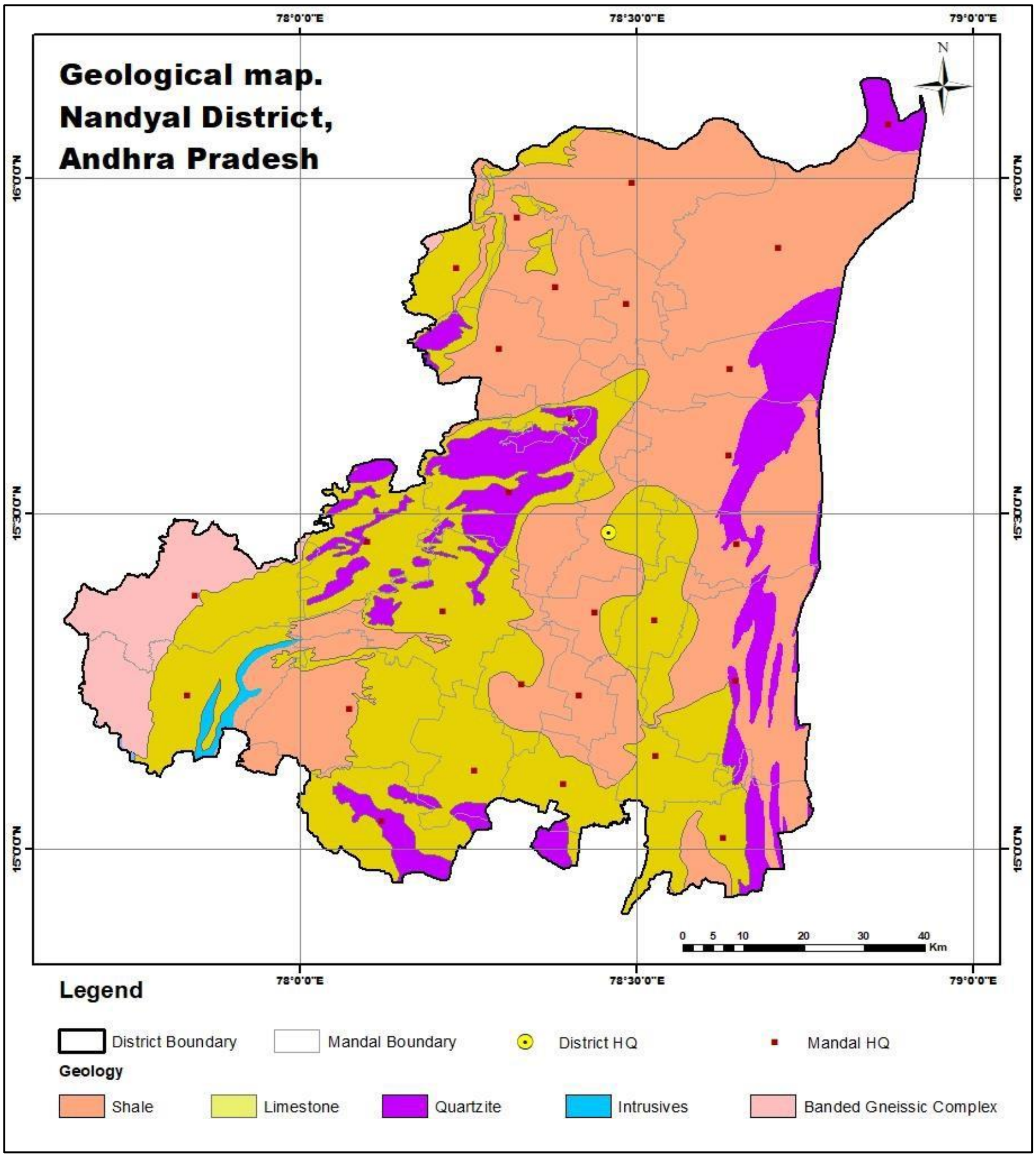


Fig.1.12. Geological map of Nandyal district

2. DATA COLLECTION AND GENERATION

Collection and compilation of data for aquifer mapping studies are carried out in conformity with the Expenditure Finance Committee (EFC) document of XII plan of CGWB encompassing various data generation activities (Table-2.1). The historically available data of Geology, Geophysics, Hydrogeology, and Hydrochemistry generated under various studies by CGWB through Systematic Hydrogeological studies, Reappraisal Hydrogeological studies, Ground Water Management studies, Exploratory drilling, and special studies have been utilized for data gap analysis, along with the data collected from various State and Central government departments.

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

Sr. No.	Activity	Sub-activity	Task
1.	Compilation of existing data/ Identification of Principal Aquifer Units and Data Gap	Compilation of Existing data on ground water	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.
		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.
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 subsurface geoelectrical and gravity data generation	Vertical Electrical Sounding (VES), borehole logging, 2-D imaging etc.
		Hydrological Parameters on ground water 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 ground water 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 Hydrochemical 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.

The aquifer geometry for shallow and deeper aquifer has been established through hydro geological studies, exploration, surface and subsurface geophysical studies in the district. The data used for the integration and interpretation are discussed in detail in following section:

2.1 Hydrogeological Studies

Hydrogeology is concerned primarily with mode of occurrence, distribution, movement and chemistry of ground water occurring in the subsurface in relation to the geological environment. The occurrence and movement of water in the subsurface is broadly governed by geological frameworks i.e., nature of rock formations including their porosity (primary and secondary) and permeability. The principal aquifer in the area is granites gneisses, shales, limestone and quartzites and the occurrence and movement of ground water in these rocks is controlled by the degree of interconnection of secondary pores/voids developed by fracturing and weathering. Based on 203 hydrogeological data points hydrogeological map has been prepared.

2.1.1 Ground water occurrences and movement:

Ground water occurs under unconfined and semi-confined/confined conditions and flows downward from the weathered zone into the fracture zone. The main aquifers constitute the weathered zone at the top, followed by a discrete anisotropic fractured/fissured zone at the bottom, generally extending down to 200 m depth. The storage in granite rocks is primarily confined to the weathered zone due to overexploitation, mainly for irrigation purpose, has resulted in desaturation of weathered zone at many places. The thickness of weathered zone generally extends upto 10 m. in most of the granitic area. Ground water in fractured zone is developed through construction of shallow/deep bore wells. Ground water in metasediments occurs under water table conditions in weathered portion of the formation and the thickness of weathered portion is around 10 mbgl. Ground water in fractured zone is developed through construction of deep bore wells down to a depth of 300 mbgl. At present, extraction is mainly through boreholes of 60-100 m depth, with yield between <0.3 and 7 litres/second (lps). ~ 87 % of fractures occur within 100 m depth and deepest fracture is encountered in granites at a depth of 175.8 m in Burugula (Peapally mandal). The weathering depth is generally restricted to 30~35m in most of the areas indicating that aquifer 1 is uniform throughout the district, while the depth of fracture encountered in rocks varies distinctively and ranges from ~25 to ~190m indicating that aerial extent of aquifer 2 is not uniform and varies place to place. It also suggests varied geology beneath the ground surface. The graphical representation of depth of weathering and depth of fracture is shown in Fig.2.1

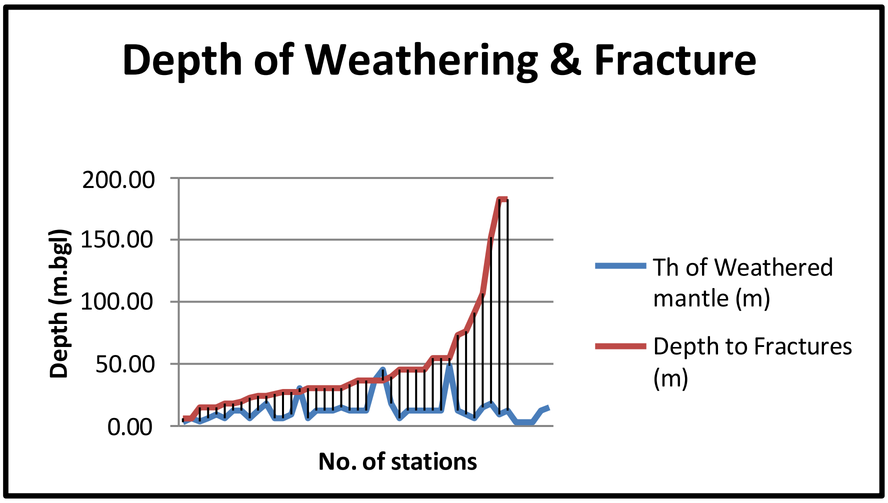


Fig.2.1.Comparison of depth of weathering and fracture

2.1.2 Exploratory Drilling:

As on 31/03/2022, CGWB drilled 11 bore wells (exploratory, observation and piezometers) in the district. Out of these 08 wells were drilled in metasediment area and 03 wells were drilled in granitic area. Data analysed from CGWB wells indicates deepest fracture was encountered at 175.8 m.bgl at Burugula , Peapally mandal . In the district, there are 79,479 wells (DW: 12017 and BW:67462). Of which wells used for irrigation purpose counts 76,706.

2.1.3 Ground Water Yield:

Ground water yield of granitic aquifers varies from <0.1 to 6 lps (avg: < 1 lps) and metasediment aquifers varies from <0.1 to 10 lps (avg: 1.5 lps). 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 Level

National Hydrograph Monitoring stations of CGWB and SGWD has been utilized for Aquifer Mapping studies. 17 dug wells and 6 peizometers are presently monitored by CGWB and 101 piezometers by SGWD. CGWB wells are being monitored four times (January, April, August and November) in a year whereas; the monitoring wells of State Ground Water Department

(SGWD) are being monitored every month. These ground water monitoring wells data were used in order to understand the spatio-temporal behaviour of the ground water regime.

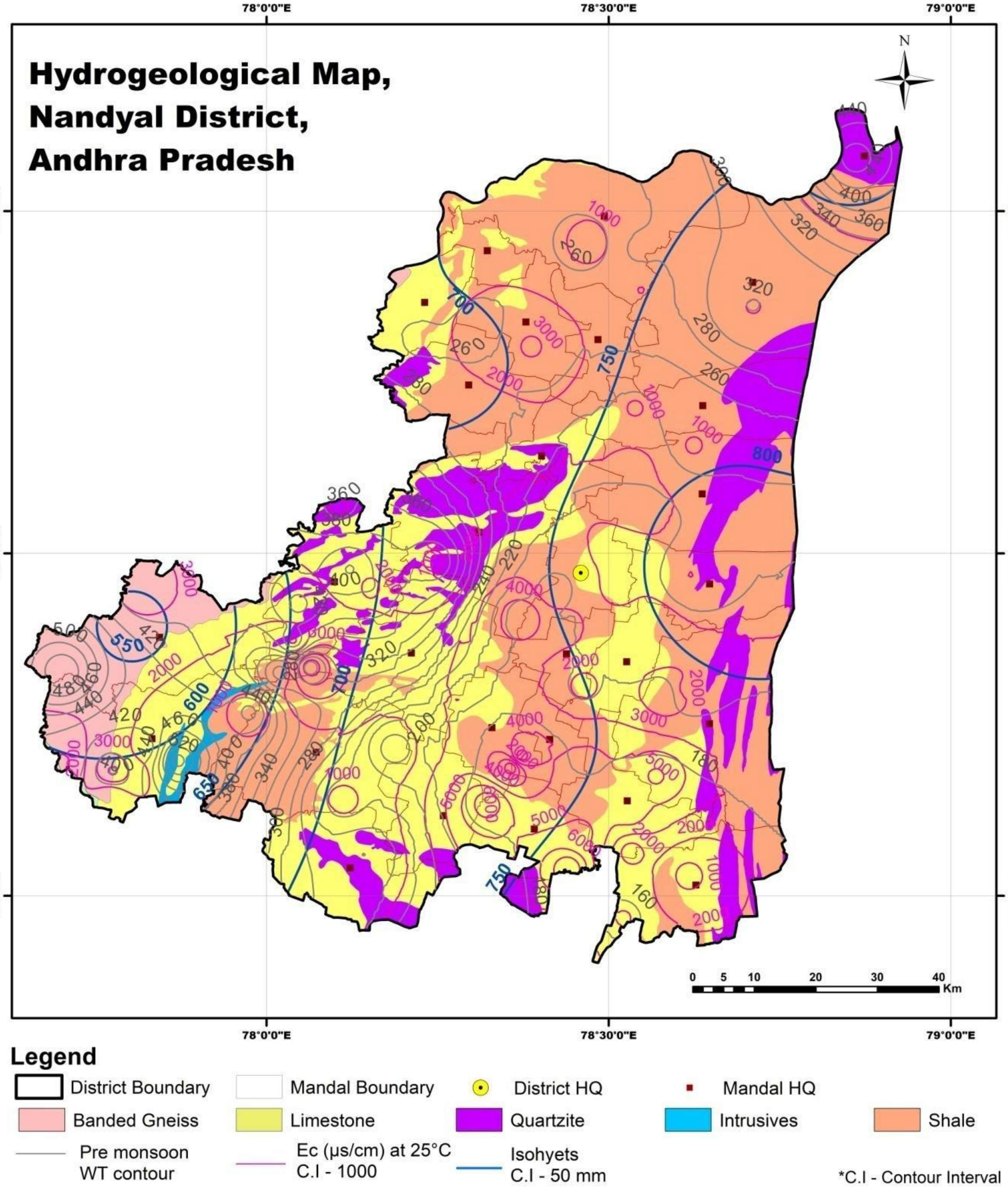


Fig.2.2. Hydrogeological map of Nandyal district

2.3 Hydro chemical Studies

Water quality data of CGWB and SGWD wells has been utilized for understanding the spatial variation of quality in the district. A total of 114 (pre-monsoon and post-monsoon) ground water monitoring well data of Central Ground Water Board, Andhra Pradesh State Ground Water Department and Andhra Pradesh Rural Water Supply (mostly tapping combined aquifers Aq-1 and aq-2) has also been utilized to understand the chemical characteristics of ground water. Parameters namely pH, EC (in µS/cm at 25 ° C), TH, Ca, Mg, Na, K, CO_3, HCO_3, Cl, SO_4, NO_3 and F were analyzed.

2.4 Geophysical Studies

Geophysical data of VES and profiling are used to extract information on the weathered thickness, fracture depth, thickness of fracture in hard rock area. For the interpretation of the aquifer geometry geophysical data in conjunction with the available ground water exploration data has been utilised. The data from 112 Vertical Electrical Soundings (VES) employing the Schlumberger electrode configuration with the maximum electrode separation (AB) of 400 meters has been used for the aquifer mapping studies. The data was processed and interpreted by IPI2Win software developed by Moscow State University, after marginally modifying the manually interpreted results in corroboration with geology and hydrogeology.

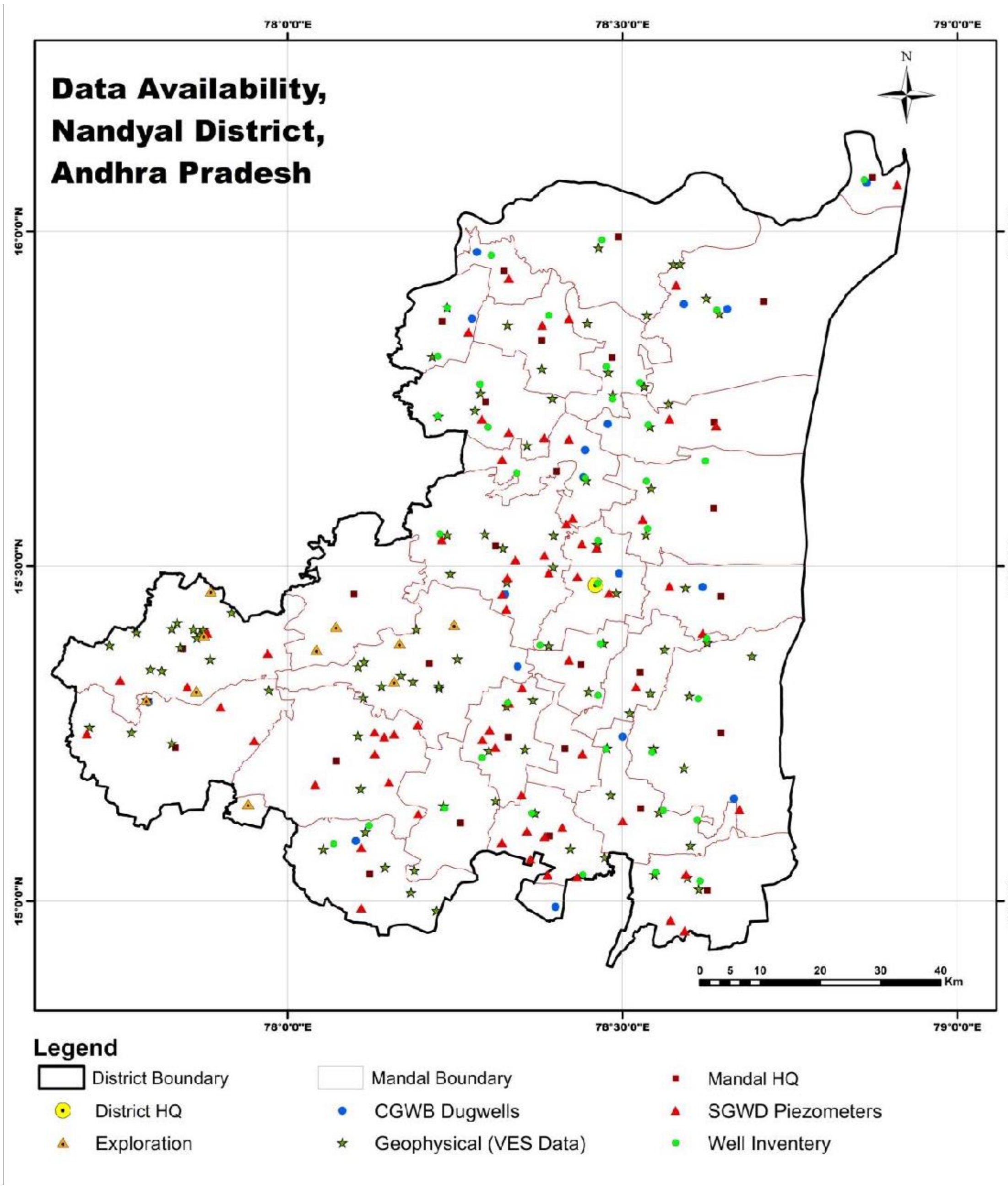


Fig. 2.3.Data availability of Nandyal District

2.5. Ground water Level Scenario

2.5.1 Depth to ground water level

Pre-monsoon season: The depth to water level scenario for pre-monsoon was generated by utilizing water level data of 183 wells (159 dug wells, 24 bore wells). The pre-monsoon depth to water levels ranges between 0.75m bgl (Uyyalawada) to 46.6 mbgl (Midthur).The depth to water levels of Nandyal district can be divided into 6 zones; where the shallow water levels are towards the north-eastern part of the district and gradually getting deeper towards western part of the district. The shallow water levels i.e. 0 to 2m bgl measured in May is observed in NE part of the district which include only 1 mandal

(Srisailam) (out of 29 mandals). The mandals with deeper water level of >20 mbgl are Kothapalle, Nandikotkur, Jupadu Bungalow, Midthur and Bethamcherla. All these 7 mandals are situated in western part of the district. However, in some mandals there is wide variation in water levels as there are different stations in same mandals where the water level is very shallow and even >30 mbgl represented by Nandyal, Kothapalle, Jupadu Bunglow, Bethamcherla and Peapally. The post-monsoon depth to water levels ranged between 0.77m bgl to 50.02m bgl in Gospadu and Nandi Kotkur mandals respectively. More than ~50% of the district has water levels measured from 2 to 5 m in month of November. When compared the water levels of same stations in pre monsoon and post monsoon period, it was observed that there has been fluctuation in water levels in month of May as compared to November; also 84% of the station has rise in water levels while 16% of the stations has falling water level as compared to pre monsoon period to that of post monsoon period. It indicates that saturation percentage of water in aquifer is increased in November due to percolation of rainwater in ground surface.

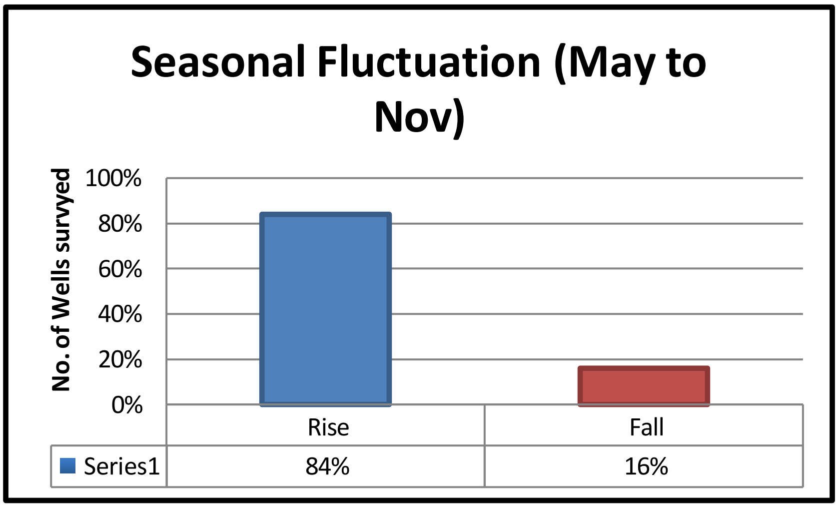


Fig. 2.4. Seasonal fluctuation (May to nov) of Nandyal District

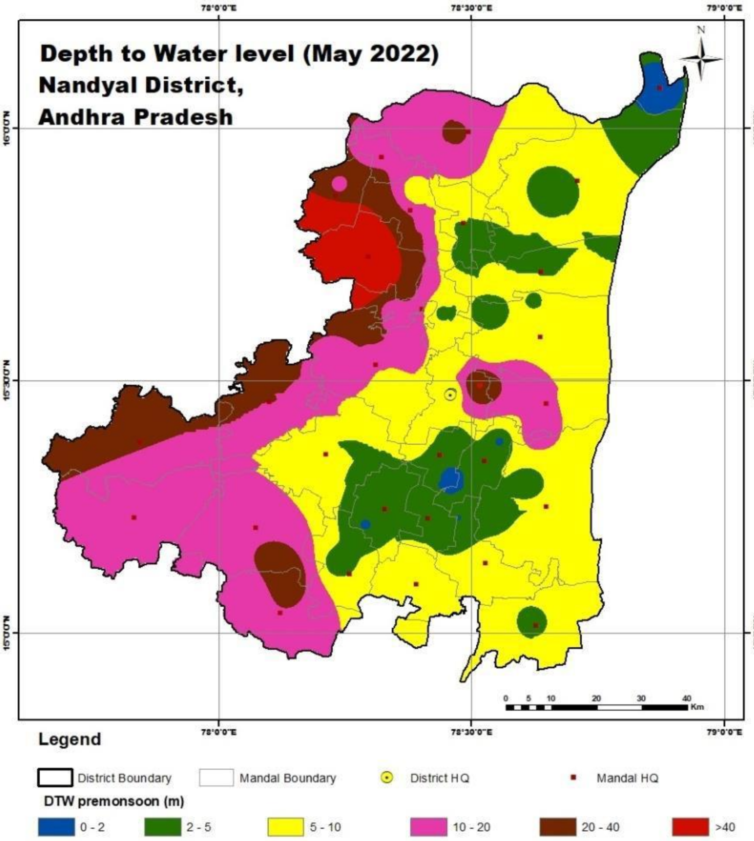


Fig. 2.5. Depth to water level (May 2022) of Nandyal District

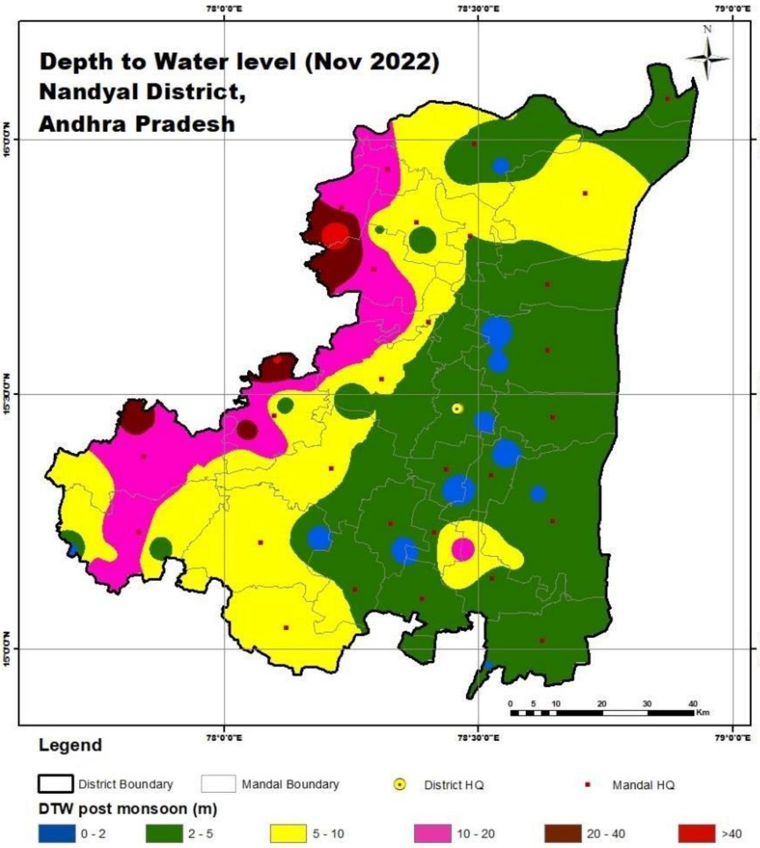


Fig. 2.6. Depth to water level (Nov 2022) of Nandyal District

2.5.2 Water Table Elevation

The water table elevation map was prepared to understand the ground water flow directions. The water table elevation ranges from 150 to 550 m amsl during pre-monsoon period. The regional ground water flow is mainly towards Kunderu river i.e. towards SSE direction. However, in northern part of district there is localized basin divided by water divide which roughly underlies parts of Srisailam Dam Reservoir and Krishna river.

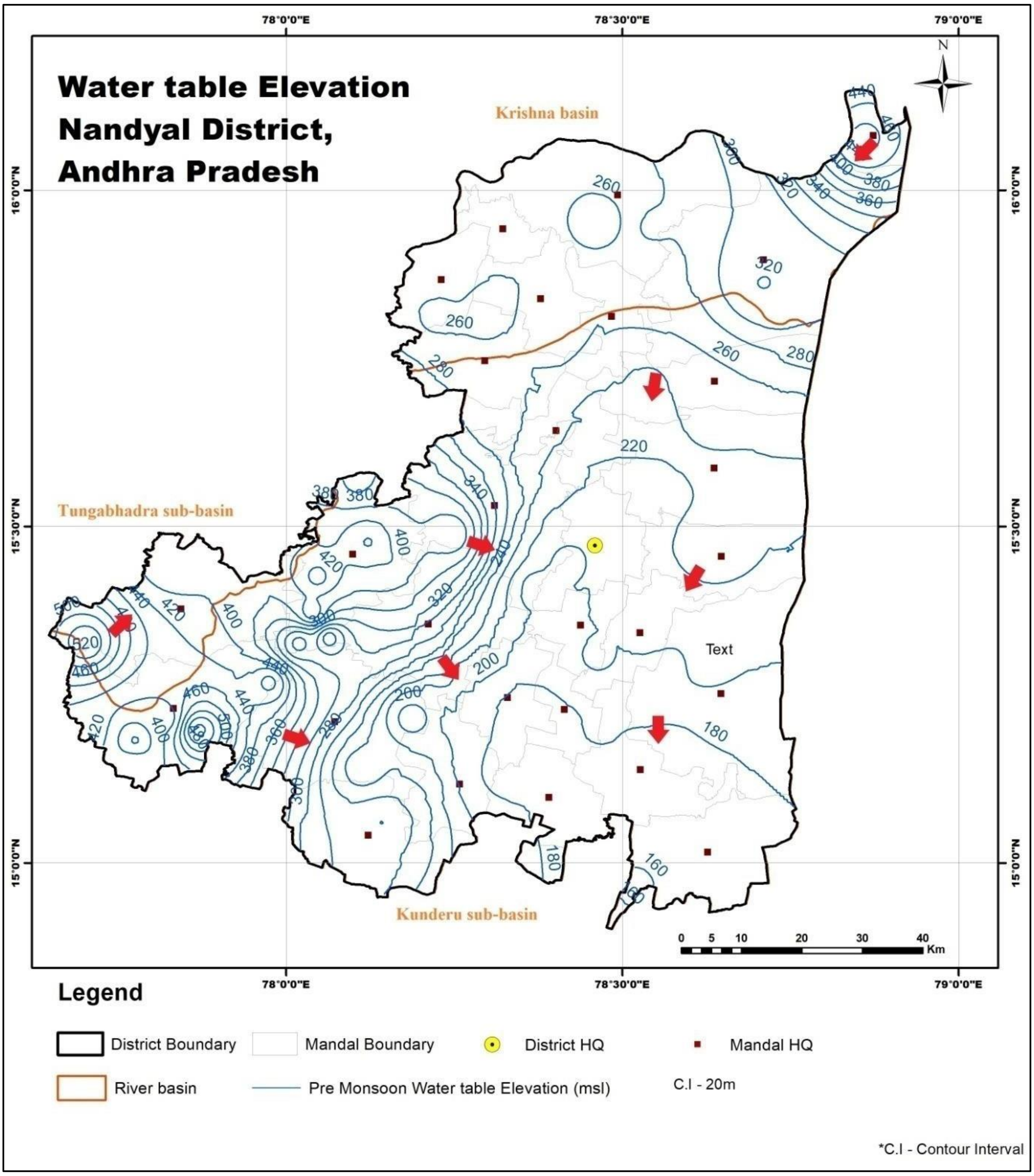


Fig. 2.7. Water table elevation map of Nandyal District

2.6 Long term water level trends :

Trend analysis for the last 10 years (2013-2022) is studied from 189 hydrograph stations of CGWB and SGWD. It is observed that during premonsoon season 69% of wells shows falling trend (max fall: 2.3 m/yr) and 31% wells shows rising trend (max rise: 2.6m/yr). During post-monsoon season 24% wells show falling trend (maximum fall: 1 m/Yr) and 76% wells shows rising trends (max rise: 2 m/yr).

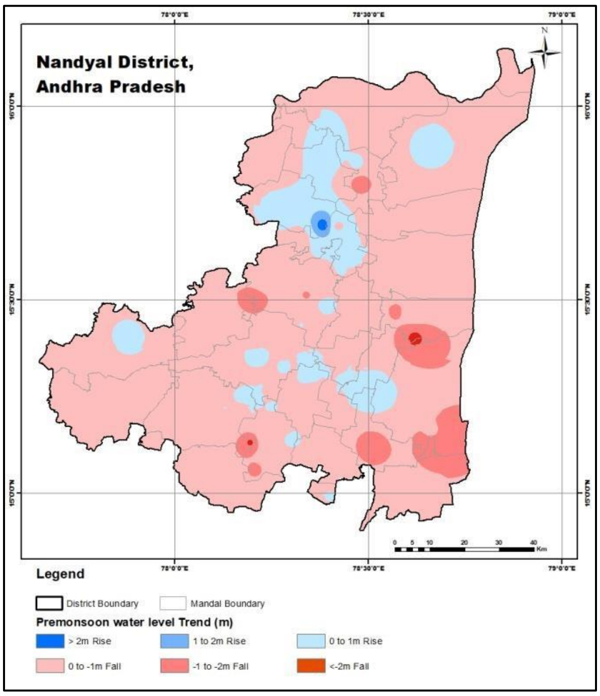


Fig.2.8. Decadal water level trend (2011-2021) pre-monsoon trend

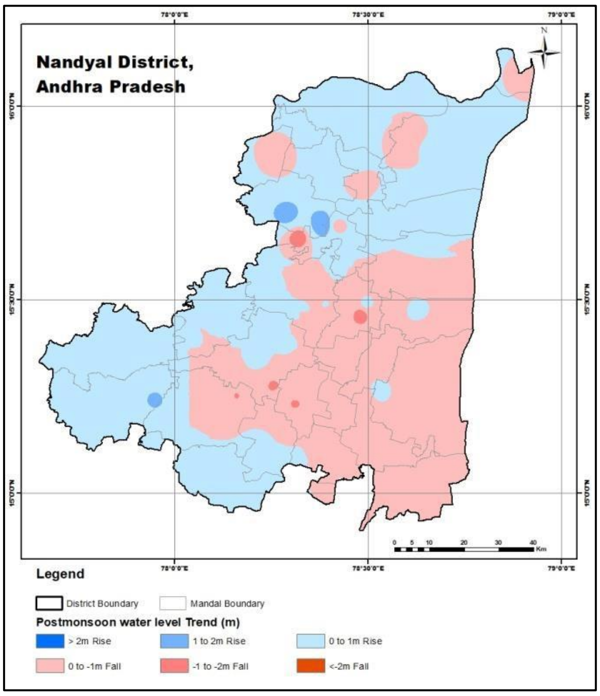


Fig.2.9 Decadal water level trend (2011-2021) post monsoon trend

2.7 Ground Water Quality

2.7.1 Pre monsoon - Ground water from the area is mildly alkaline to alkaline in nature with pH in the range of 6.75-7.83 (Avg:7.34). The Total Hardness ranges between 125 mg/l to 1700 mg/l at Srisailam and Reddivari Jambuladinne respectively. Average total hardness in Nandyal district is 495 mg/l , which is above acceptable limit of 200 mg/l but under permissible limit of 600 mg/l in case of no other alternate source of water. Electrical conductivity varies from 240-7920 (Avg: 2223)µ Siemens/cm. In 45% of area, EC is within 1500 µ Siemens/cm, in 31% area, it is 1500-3000 µ Siemens/cm and in 22 % area, it is > 3000 µ Siemens/cm. Nitrate concentration varies from 4 to 772 mg/L in 65% of samples is beyond permissible limits of 45 mg/L . Fluoride concentration varies from 0.15-2.21 mg/L and 82 % of samples are within permissible limits of BIS and rest is beyond permissible limit of 1.5 mg/L. High fluoride concentration is observed mostly in Dhone, Peapally, Judapu Bungalow, Bethemcherla and Velgode. High Uranium content >0.03 mg/L concentration in 14% of the area is observed in Gulamaliabad, Yalluru, Muthaloor, Ayyalur ,Reddivari Jambuladinne, Kotha Buruju, Venkatapuran, Gudipadu during pre monsoon season (measured by fluorimeter, nonstandard method)

2.7.2 Post monsoon - Ground water from the area is mildly alkaline to alkaline in nature with pH in the range of 6.70-7.93 (Avg:7.23). The total hardness observed is between 50 mg/l to 2000 mg/l at Srisailam and Gulamaliabad respectively. Average total hardness in Nandyal district is 523 mg/l , which is above acceptable limit of 200 mg/l but under permissible limit of 600 mg/l in case of no other alternate source of water. Electrical conductivity varies from 107-6000 (Avg: 2223)µ Siemens/cm.. Nitrate concentration varies from 02 to 651 mg/L. Fluoride concentration varies from 0.15-2.95 mg/L

2.7.3 Analysis-

The water quality data show a wide array of parameter changes within the Nandyal district in the postmonsoon and pre-monsoon periods . The data analysis shows the average pH value, EC, TDS of the water samples during post monsoon period is usually less than the pre-monsoon period. The reduction in values of pH, Ec and TDS during the post monsoon period shows, precipitated water is infiltrating the soil cover to reach the underlying aquifer. Henceforth, reducing the concentrations of total dissolved solids and also the suspended solids in the ground water .This phenomenon could primarily due to the dilution of the ground water with rainwater which had been received by the aquifer in the monsoon season. However average Total hardness of the district is increased from 495 mg/l to 523 mg/l which may suggest that the infiltrated water entering the aquifer is being affected by several anthropogenic activities.

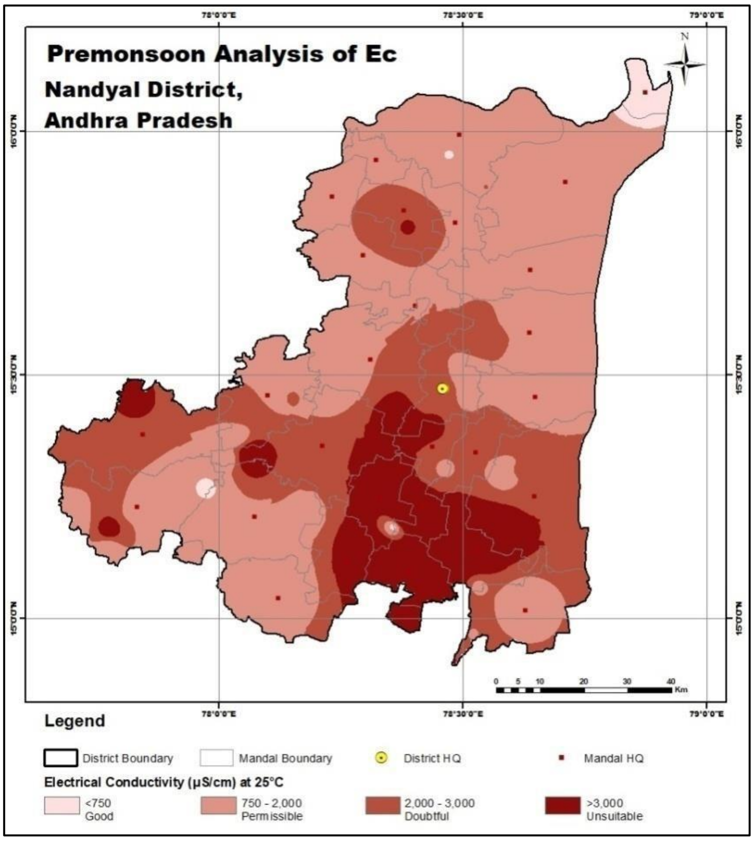


Fig. 2.10. Distribution of Electrical conductivity (Pre monsoon) of Nandyal District

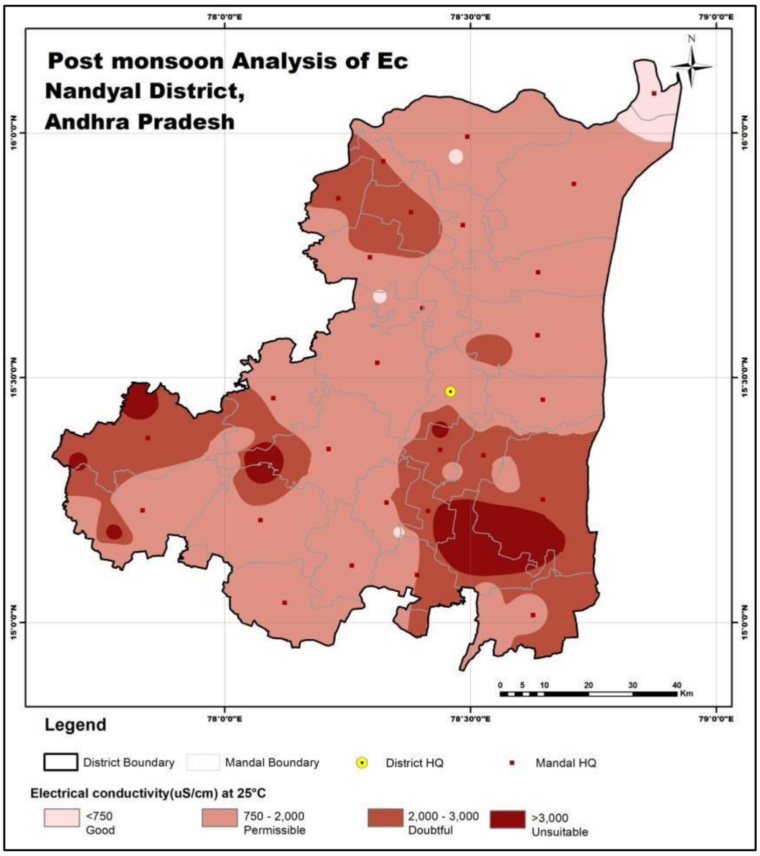


Fig. 2.11. Distribution of Electrical conductivity (Post monsoon) of Nandyal District

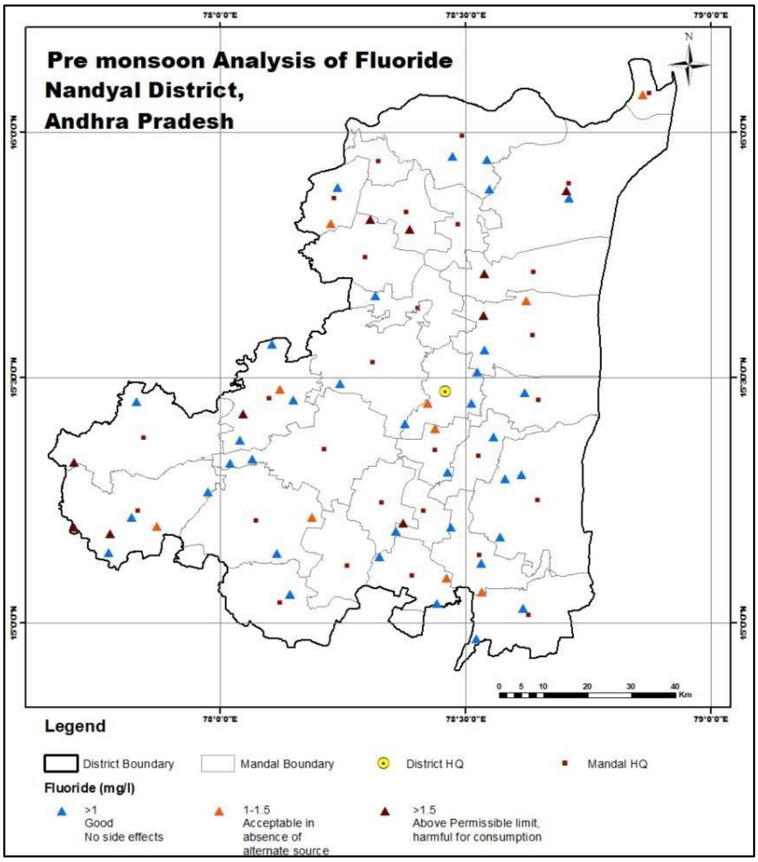


Fig. 2.12. Distribution of Fluoride (Pre monsoon) of Nandyal District

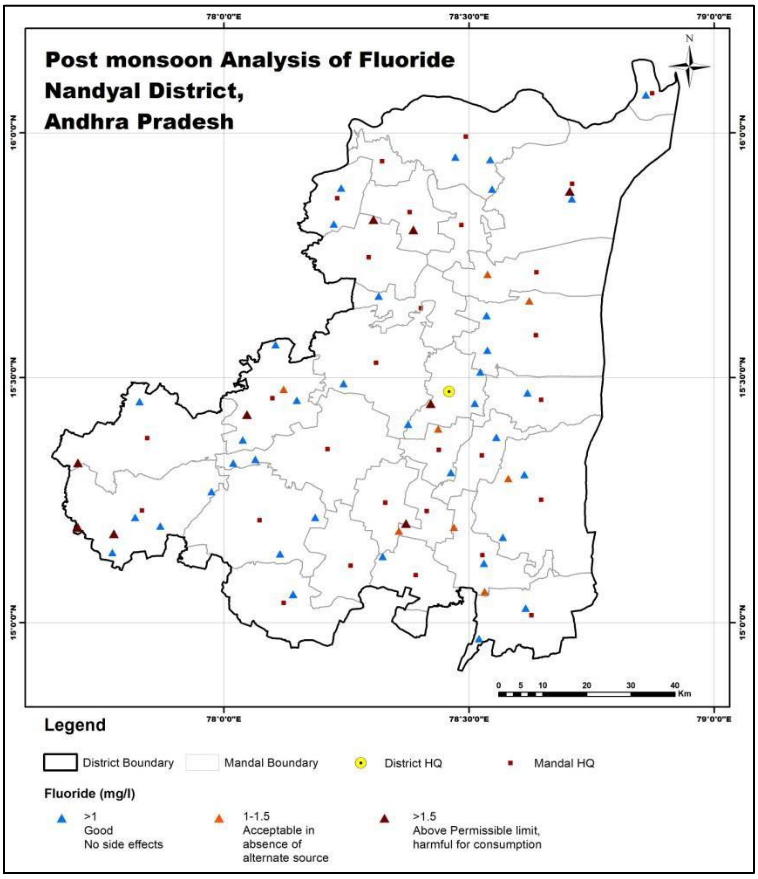


Fig. 2.13. Distribution of Fluoride (Post monsoon) of Nandyal District

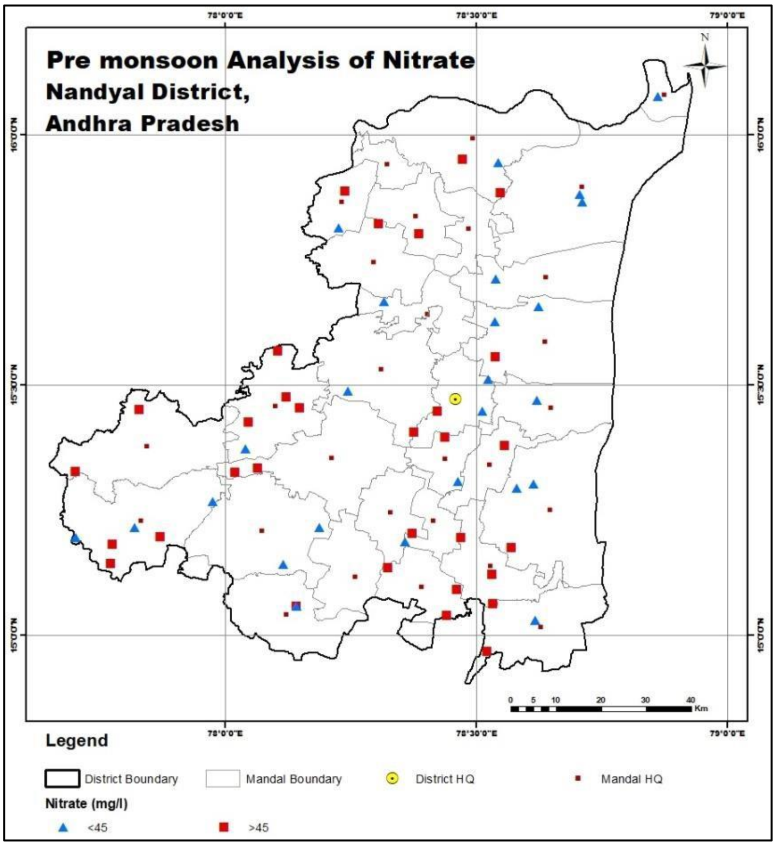


Fig. 2.14. Distribution of Nitrate (Pre monsoon) of Nandyal District

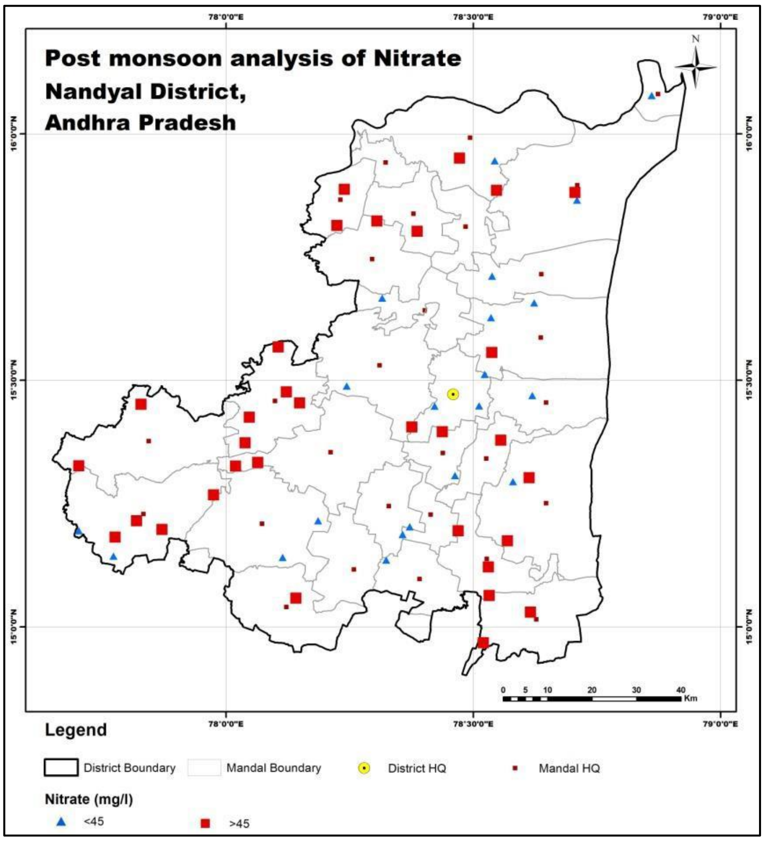


Fig. 2.15. Distribution of Nitrate (Post monsoon) of Nandyal District

Classification of Ground water based on EC values (Pre-monsoon- 2022)				
Sr.No	**Water Quality Type**	**Ec in µS/cm**	**No of Samples**	**% of Samples**
1	Low Salinity water	<750	5	9
2	Medium Salinity Water	750-2000	20	35
3	High Salinity Water	2000-3000	11	19
4	Very High Salinity Water	>3000	21	37
Total			**57**	**100**

Table2.2. Classification of GW based on Ec in district

A total 114 (Pre-monsoon and post-monsoon) wells data of Central Ground Water Board (mostly tapping combined aquifers Aq-1 and Aq-2) has been utilized to understand the chemical characteristics of ground water. Parameters namely pH, EC (in µS/cm at 25 ° C), TH, Ca, Mg, Na, K, CO_3, HCO_3, Cl, SO_4, NO_3 and F were analyzed.

2.7.4 Piper Tri-linear Diagram:

A Piper diagram is a graphical representation for presenting water chemistry data to help in understanding the sources of the dissolved constituent salts in water. This procedure is based on the fact that cations and anions in water are in such amounts to assure the electroneutrality of the dissolved salts, in other words the algebraic sum of the electric charges of cations and anions is zero.

The samples of Nandayal district falls under three major geochemical facies, they are Mixed type, Mg-HCO_3 type and Na-Cl type. Samples those who have Mg-HCO_3 type and positioned in extreme left of central shaped diamond indicates presence of weak acids exceed strong acids and alkaline earths exceeds alkalies. While Na-Cl type which are to extreme right of the piper plot indicates they have strong acids more as compared to weak acids and alkalies exceeds alkaline earth. As we do not observe any one dominant geochemical facies of the samples analysed, it may be concluded that the water contains cations and anions from varied geological formations such as limestone, shale, quartzites and BGC. As there is absence of one geochemical facies it may suggest that there is no control of geo hydrochemistry of any particular rock type or all the rocks have contribution to control the geo hydrochemistry of ground water in Nandyal district.

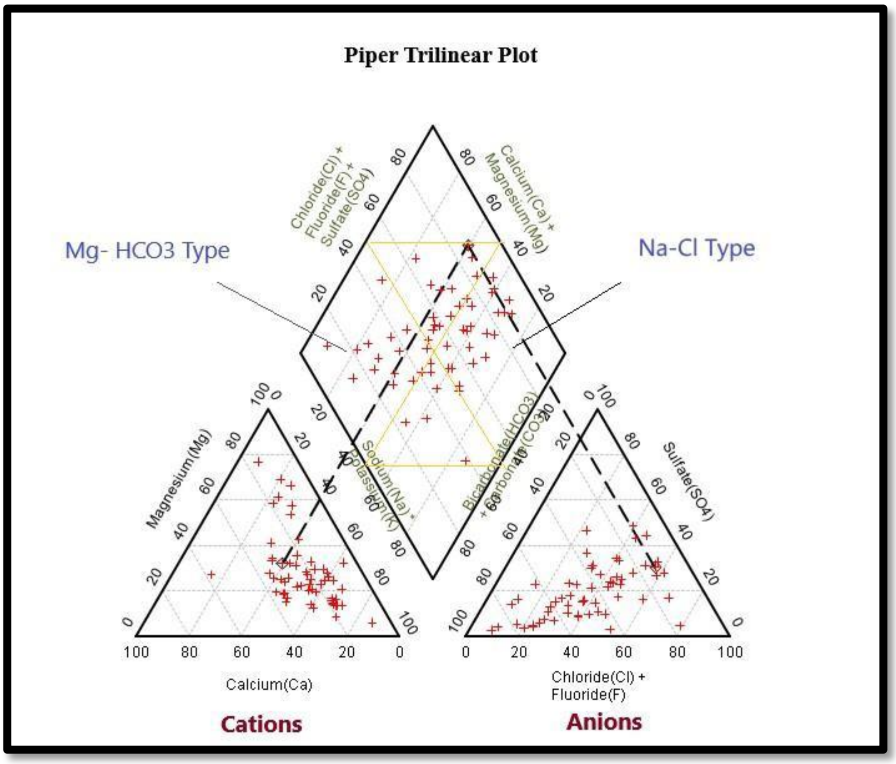


Fig.2.16. Piper plot of water samples collected in Nandyal district.

2.7.5. US Salinity Diagram :

The USSL diagram explains the combined effect of sodium hazard and salinity hazard while classifying the irrigation water. The USSL diagram is a plot between sodium hazards (SAR) on the Y-axis versus salinity hazard (EC) on the X- axis (i.e., log scale) which allows water to be grouped into 16 classes.

SAR allows assessment of the state of flocculation or of dispersion of clay aggregates in a soil. Sodium and potassium ions facilitate the dispersion of clay particles while calcium and magnesium promote their flocculation. The behaviour of clay aggregates influences the soil structure and affects the permeability of the soil whose directly depends the water infiltration rate.

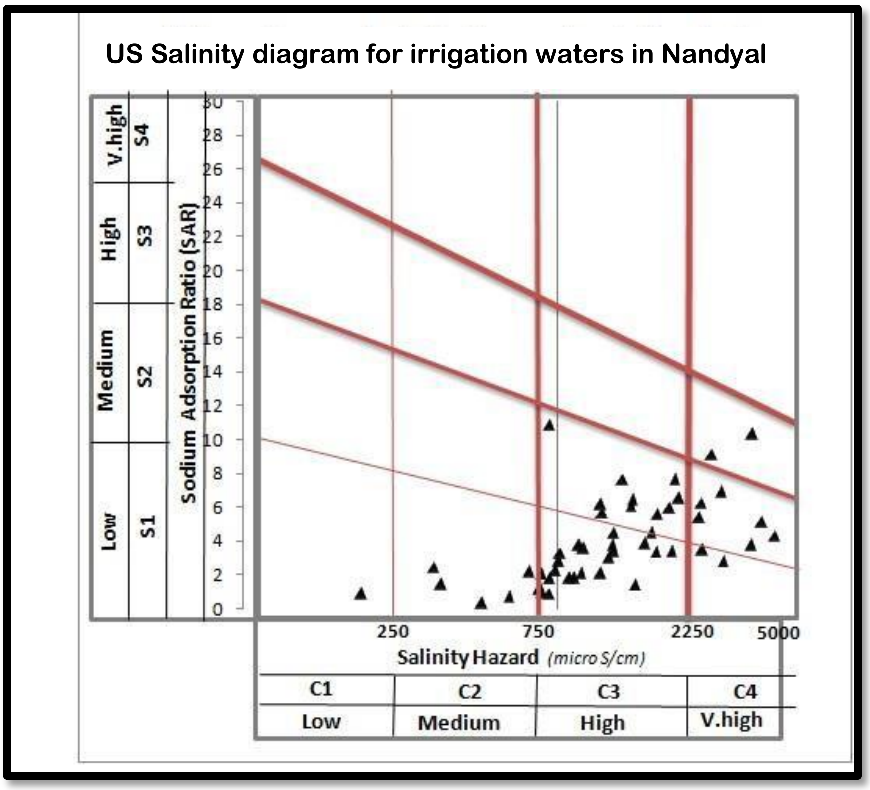


Fig.2.17. Graphical representation of SAR and EC in Nandyal district

In the diagram C1S1 class is most excellent, C2S1 is good for irrigation. But in Nandyal district out of 57 water quality samples only 7 sample falls under this categories, rest are either doubtful or unsuitable as they fall in C3S1, C3S2, C4S1, C4S2 and C4S3. Out of which C4S3 is most hazardous for irrigation. C4S2 waters are useful only on well drained soils with low cation exchange capacity and can be used satisfactorily on coarse textured soil with good permeability. These waters will present appreciable sodium hazard in fine textured soils with high cation exchange capacity especially under low leaching condition. Mandals with C4S2 waters include Dhone, Peapally, Judapu Bunglow, Uyyalawada, Bethamcherla, Bandi Atmakur and Midthur.

3. DATA INTERPRETATION, INTEGRATION AND AQUIFER MAPPING

3.1 Conceptualization of aquifer system in 3D

Conceptualization of 3-D hydrogeological model was carried out by interpreting and integrating representative 343 data points (both hydrogeological and geophysical down to 200 m) for preparation of 3D map, fence diagram and hydrogeological sections. The data 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 Nandyal district and hydrogeological sections.

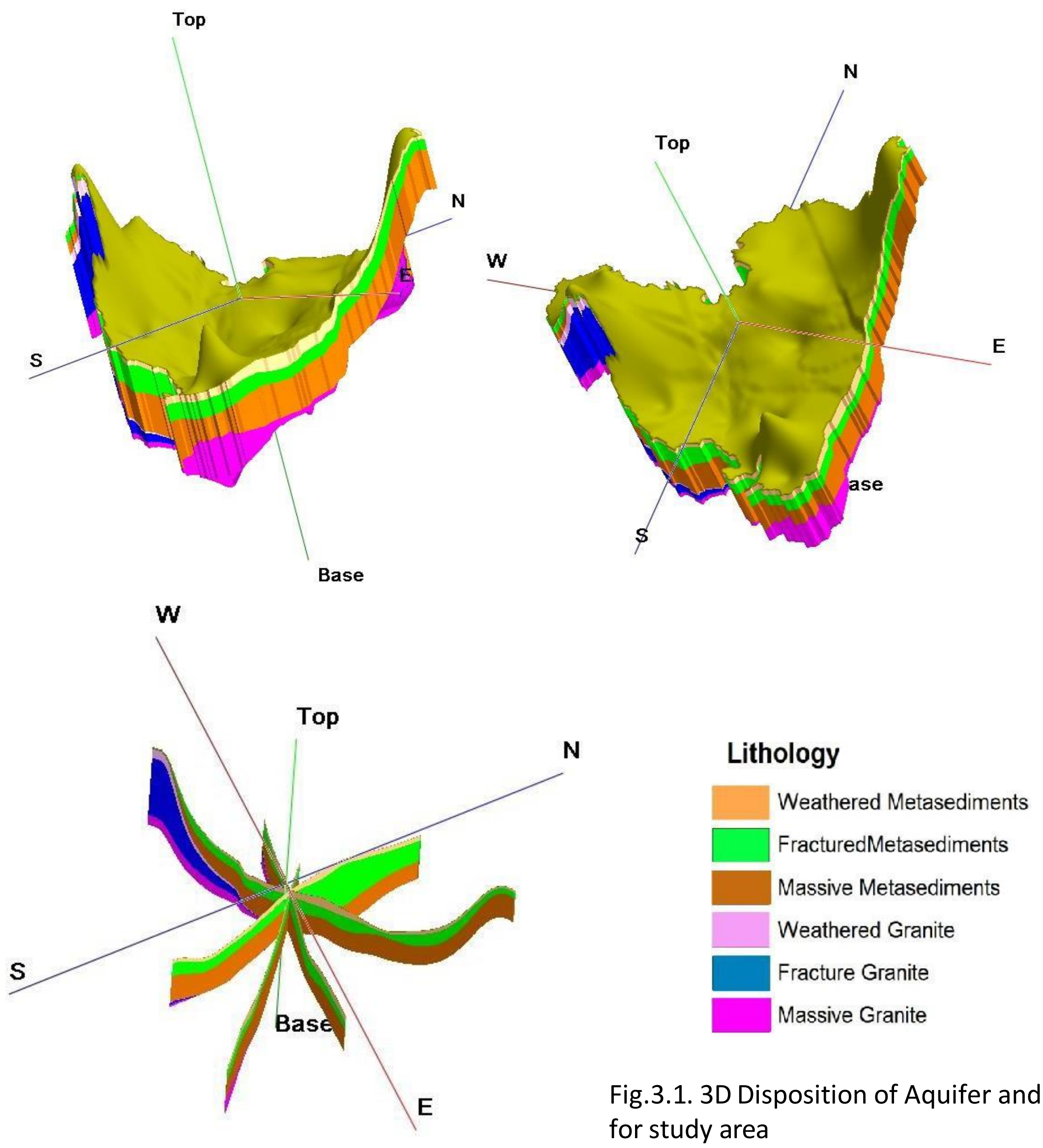


Fig.3.1. 3D Disposition of Aquifer and Fence diagram for study area

Aquifers were characterized in terms of potential and quality based on integrated hydrogeological data and various thematic maps. Weathered zone is considered up to the maximum depth of weathering and first fracture encountered (below weathered depth) generally down to ~25 m depth and the fractured zone (fractured granite) is considered up tothe depth of deepest fracture below weathered zone (~25-195 m).

3.2 Hydrogeological Sections

Hydrogeological sections are prepared in NW-SE and SW-NE directions.

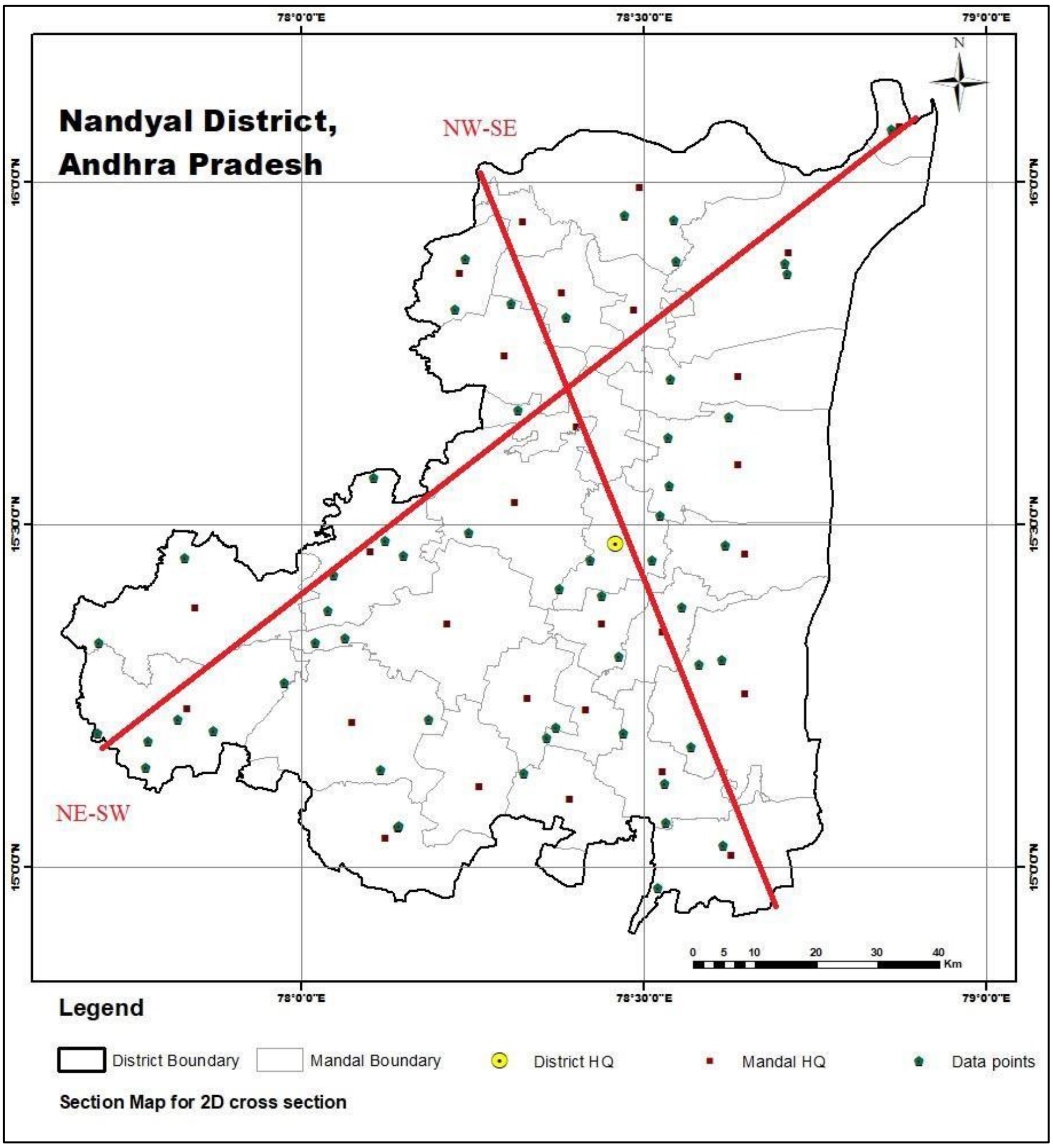


Fig.3.2. Map showing orientation of Hydrogeological cross section in NW-SE & NE-SW direction

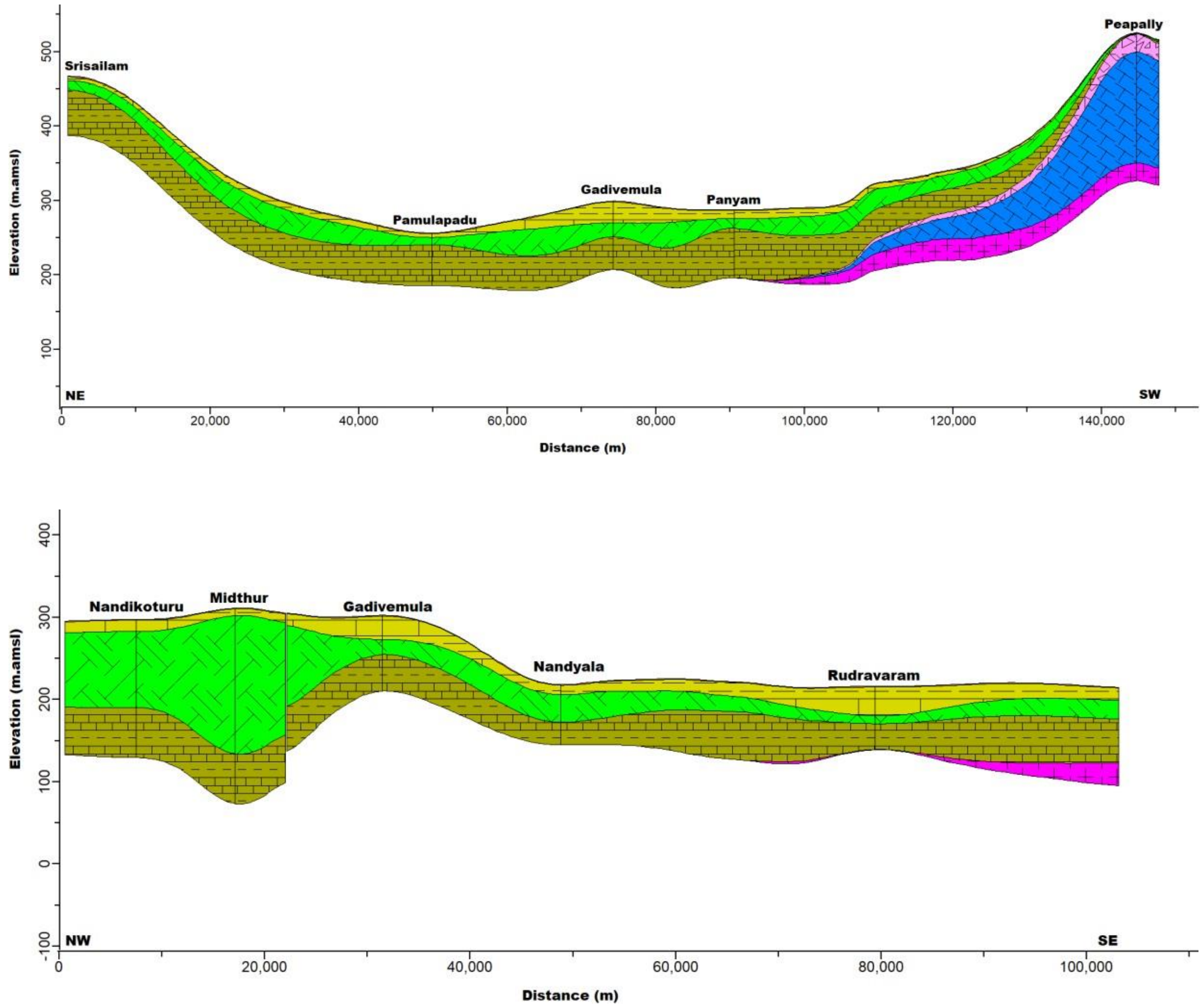
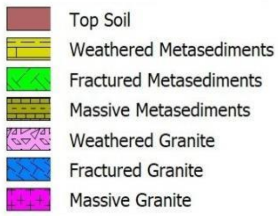


Fig:3.3. Hydrogeological cross section in Nandyal district.

1. NE – SW
2. NW - SE



3.2.1 North East and South West section: The section drawn along the NE-SW parts covers a distance of ~145 kms. It depicts thick weathered zone in the central part of the district which underlies Kunderu River and thick fracture zone of granite observed at Peapally. A `U‘ shaped basin can be observed with high ridges on Srisailam and Peapally areas. The north eastern ridges are represented by high lands of meta sediments while the south westen areas have high ridges of gneissic complex.

3.2.2 North West and South East section: The section drawn along the NW-SE parts covers a distance of ~100 kms. It depicts thick fractured zone in meta sediments at Midthur (NW part of district). Thick weathered zone can be observed in central-south east areas.

3.3 Aquifer Characterization:

3.3.1 Weathered zone:

The top weathered zone (~25 m) consisting of upper saprolite (~13 m) and lower sap rock (13- 25m.) varies from meagre to 17 m.bgl in granitic formation and meagre to 62 m. in metasediments. It has gone dry in considerable part due to overexploitation. Spatial distribution of weathered depth zone is given in Fig. 3.4. Thickness of weathered zone is in the range of 10-20 m in most part of area covering ~51% of area, shallow weathering (< 10 m) occurs in 40 % of the area and deep weathering (> 20 m) occurs in rest of the area. Shallow weathering mostly seen in granitic areas along the NE and central part of the district. Ground water yield from weathered granite/gneiss aquifer varies from <0.1 to 1 lps (avg: 0.8 lps) in granites and from 0.01 to 4 lps (avg: 1.0 lps) in metasediments. The transmissivity varies from 1-14 m^2/day in granites and upto 53 m^2/day in weathered metasediment aquifer.

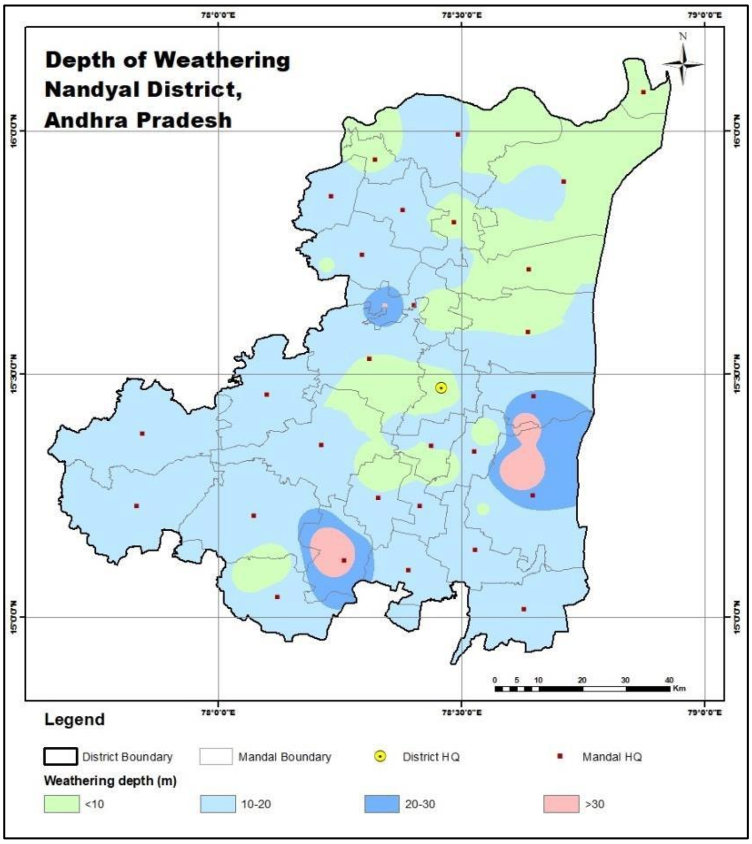


Fig. 3.4. Weathered zone thickness in Nandyal District

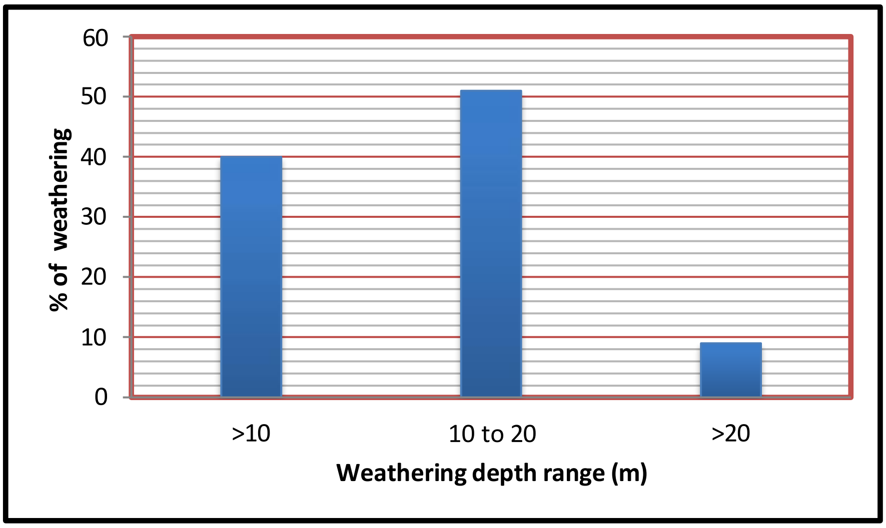


Fig. 3.5.. Graphical representation of weathering thickness in Nandyal district

3.3.2 Fractured zone:

Ground water is extracted mainly through bore wells of 30 to 250 m depth from fractured zone (~20 to 199 m). Based on CGWB wells data, it is inferred that fractures in the range of < 60 m depth are more predominant (82 % of the area), 60 - 100 fractures occur in 10 % and 100 - 150 m. fractures occur in 8 % of area respectively and deep fractures in the range of

> 150m. occur mostly in Midthur mandal .

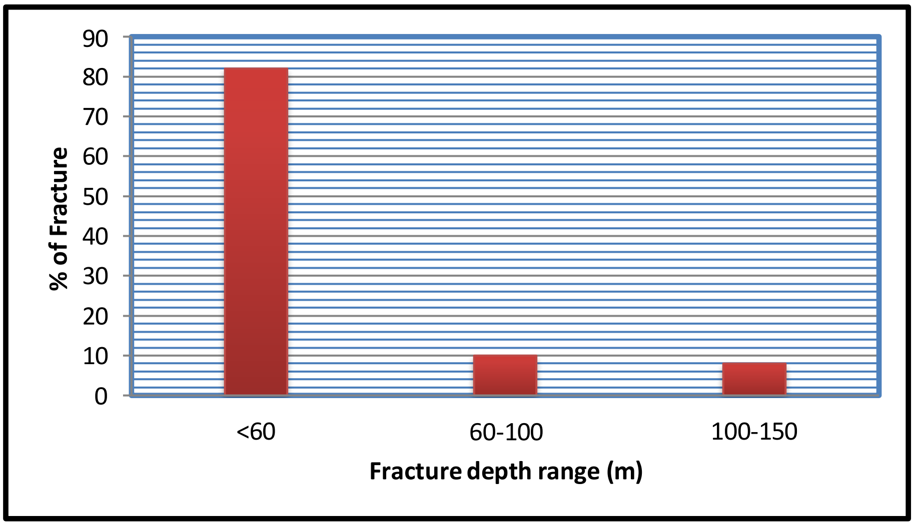


Fig. 3.6. Graphical representation of fracture depth in Nandyal district

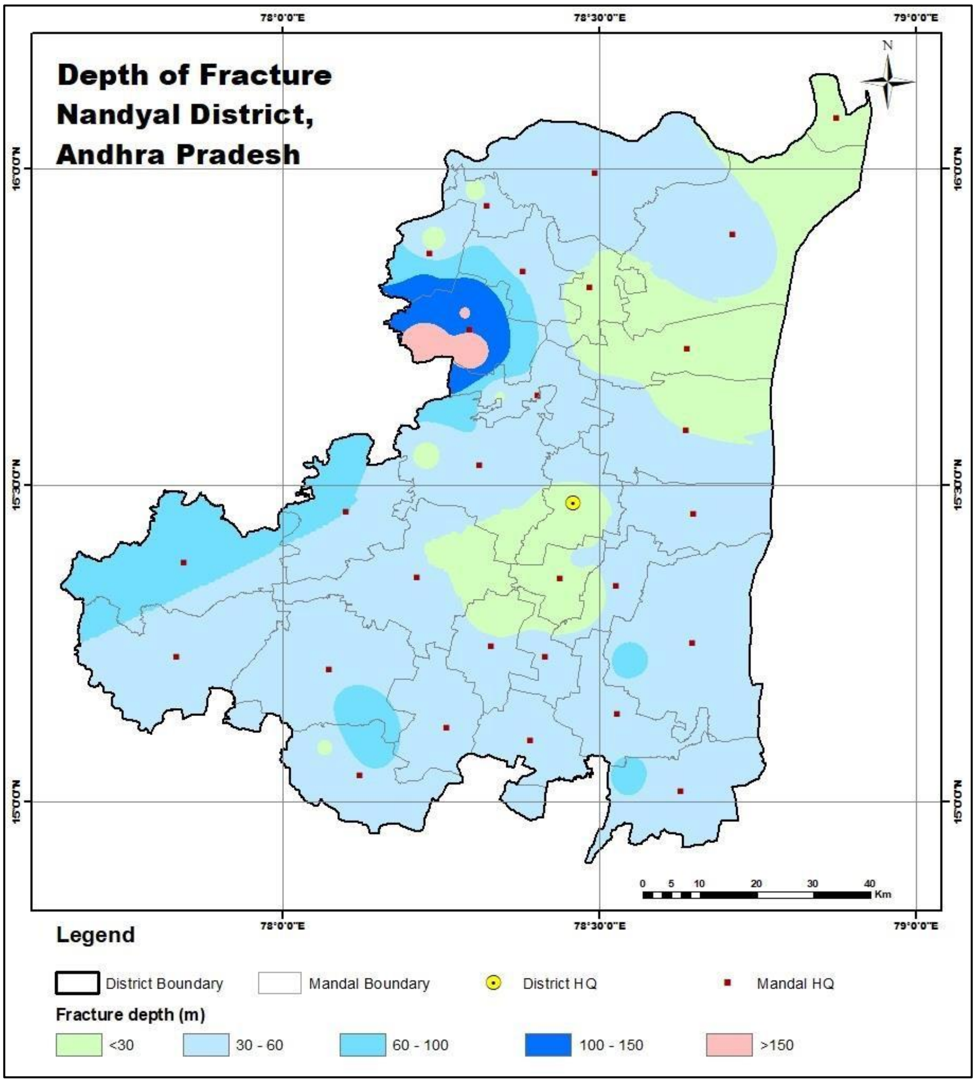


Fig. 3.7. Depth to fracture map of Nandyal District

Analysis of occurrence of fractures reveal that majority of fractures (~90 %) occur within 100 m depth. Ground water yield of fractured granite/gneiss varies from 0.01 to 6 lps (avg: 0.75 lps) and meta sediments vary from 0.01 to 7 lps (avg: 1 lps) . Wells located in the command area have higher yield (1-3 lps) and sustains for more hours of pumping as compared to non-command area where yields are relatively low and sustains for 2-3 hrs. The transmissivity varies from 1-910 m2/day. Storativity of the fracture zone varies from 0.0001 to 0.00001.

4. GROUND WATER RESOURCES (2022)

In hard rocks, for practical purpose it is very difficult to compute zone wise (aquifer wise) ground water resources, because the weathered zone (WZ) and fractured zone (FZ) are inter-connected with fractures/joints and fractured zone gets recharged through weathered zone. Therefore, it is very difficult to demarcate the boundary between two aquifers; hence the resources are estimated considering entire area as a single aquifer system. Village wise dynamic and in-storage ground water resources are computed as per the guidelines laid down in GEC 2015 methodology. While computing the in-storage resources, the general depth of deepest fractures in the area, pre-monsoon water levels and 2% of granular zone (depth below pre-monsoon water level and down to deepest fracture depth in the village) is considered. Summarized mandal wise resources are given in Table no. 4.1. The total ground water resources estimated for Nandyal district is 625.6 MCM.

Resources As per GEC 2022	**MCM**
Dynamic (Net GWR Availability)	**768.8**
• Monsoon recharge from rainfall	226.56
• Monsoon recharge from other sources	426.02
• Non-Monsoon recharge from rainfall	0.62
• Non-monsoon recharge from other sources	156.13
Gross GW Draft	**143.2**
• Irrigation	136.96
• Industrial	1.284
• Domestic	4.98
Provision for Drinking and Industrial use for the year 2025	4.99
Net GW availability for future use	625.63
Stage of GW Extraction (%)	**19%**

Table.4.1.Ground Water Resources 2022 for Nandyal district

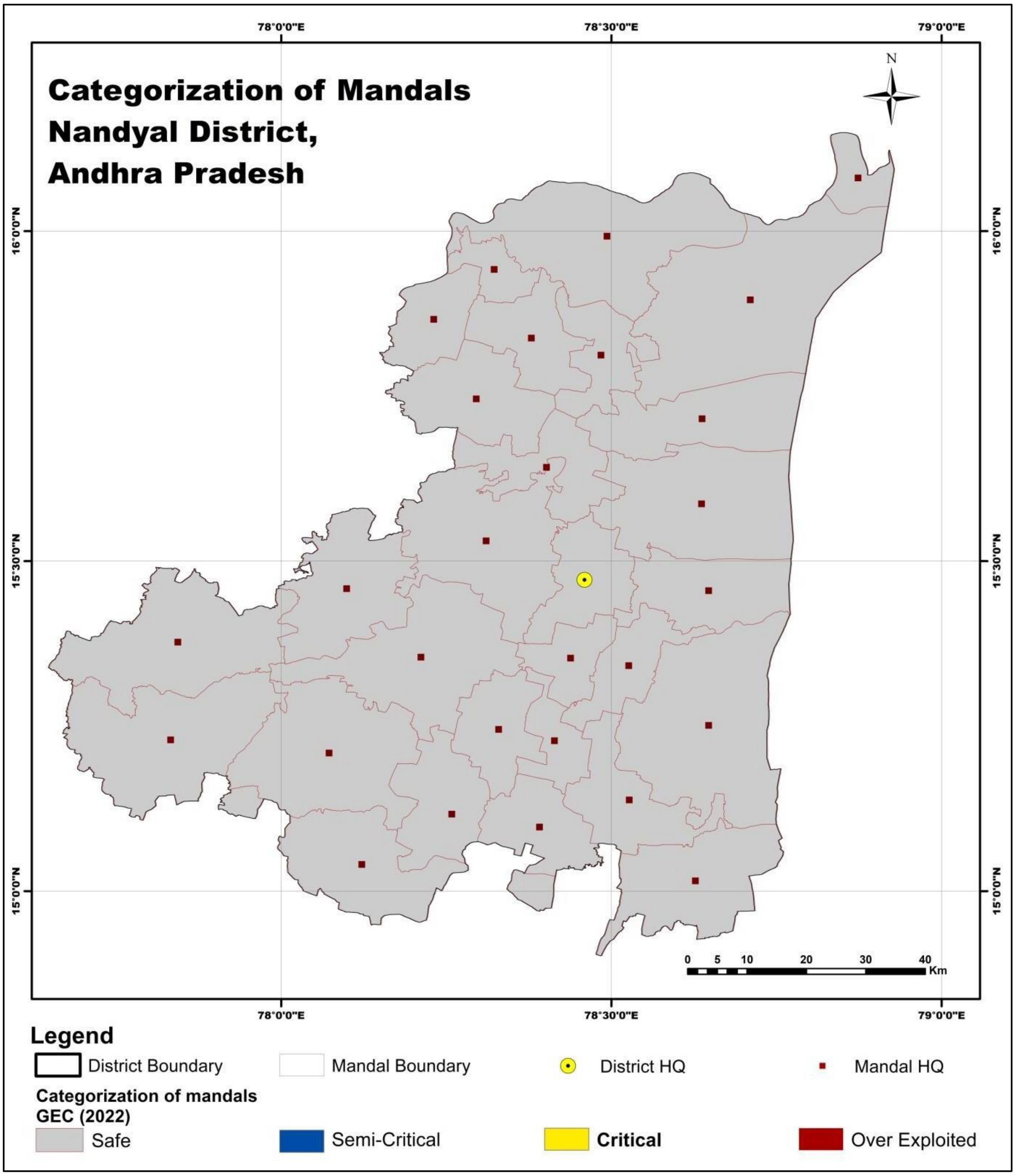


Fig. 4.1. Categorization of mandals of Nandyal District

5. GROUND WATER RELATED ISSUES AND REASONS FOR ISSUES

5.1 Issues

Deep water levels

1. Deep water levels (> 20 m bgl) are observed during pre monsoon season in 18 % of the area

Sustainability

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

Pollution (Geogenic and Anthropogenic)

3. Few mandals are fluorosis endemic where fluoride (geogenic) as high as 2.21 mg/L during pre-monsoon is found in ground water. The high fluoride concentration (>1.5 mg/L) occur in 20% samples during pre-monsoon season.

4. The high concentration of EC (> 3000 micro-seimens/cm) in 25 % of the area is observed during pre-monsoon (mostly in canal command area).

5. High nitrate (> 45 mg/L) concentration due to anthropogenic activities is observed in 55 % of samples during pre-monsoon.

6. High Uranium content >0.03 mg/L concentration in 14% of the area is observed during pre monsoon season (measured by fluorimeter, nonstandard method)

Water Marketing

7. Water marketing is present in most of the mandals and people are buying RO filtered water due to high EC. Most of the villages have their own filter system provided by government and they charge minimum , however in mandal headquarters there are many private filter plants

Fig.5.1. Various water filter plants (govt/private) in district

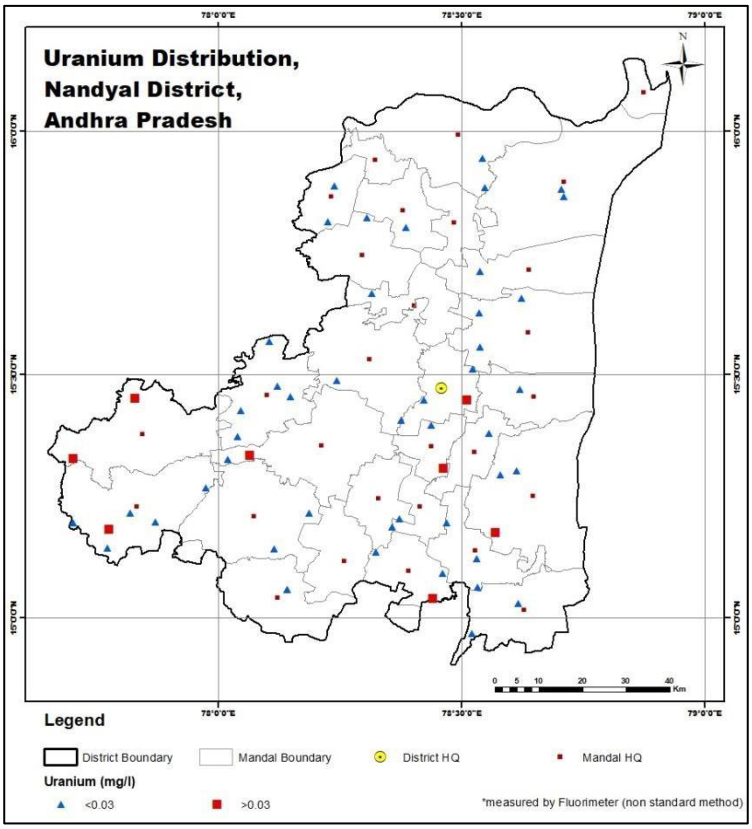


Fig.5.2. Distribution of Uranium (Pre monsoon) in Nandyal District

5.2 Reasons for Issues

Over-exploitation and Deep water levels

1. Over-extraction, low rainfall, paddy cultivation during Rabi season and limited artificial measures.
2. Dewatering in Limestone Quarry, lowers the water table changing ground water flow directions

Sustainability

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

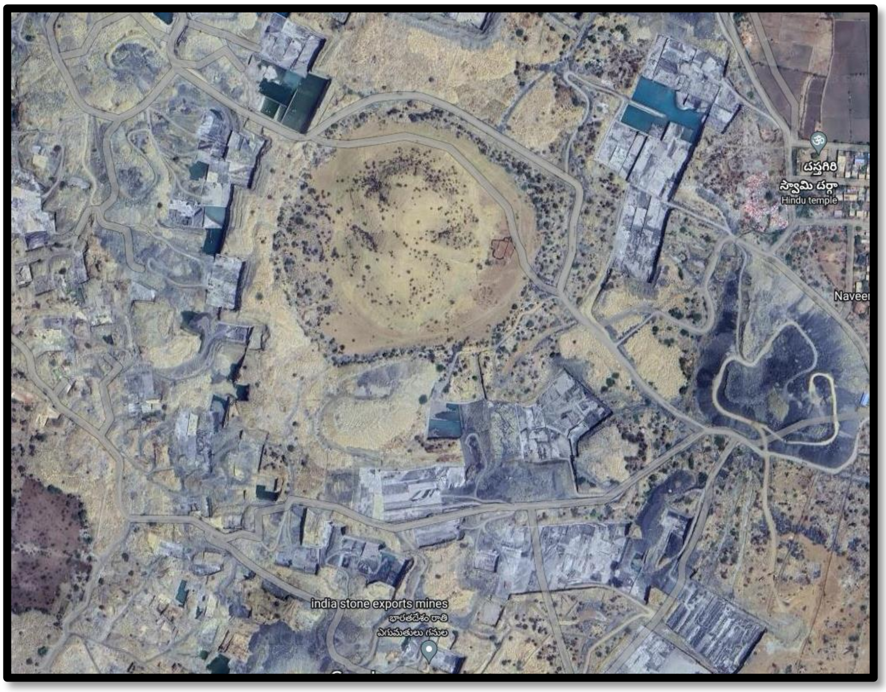


Fig. 5.3.Satellite image of limestone quarries around Owk, Nandyal

Geo-genic pollution (Fluoride)

4. Higher concentration of fluoride in ground water is attributed due to source rock, rock water interaction where acid-soluble fluoride bearing minerals (fluorite, fluoroapatite) gets dissolved under alkaline conditions.
5. Higher residence time of ground water in deeper aquifer

Anthropogenic pollution (Nitrate)

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

Others

8. Long-term water–rock interaction within the stone quarries and its solid waste, dissolved ions and salt from these stone quarry rocks are released out and then accumulated in the ground water aquifers in the region results in high TDS.

6. MANAGEMENT STRATEGIES

High dependence on ground water coupled with absence of augmentation measures has led to a steady fall in water levels and de-saturation of weathered zone in some parts, raising questions on sustainability of existing ground water 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 (75%) of fractures occur within 100 m depth. 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 ground water.

6.1 Management plan

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

In the target areas of district 13739 MCM of unsaturated volume (below the depth of 3 m) is available during post-monsoon season, having 274.78 MCM of recharge potential (2%). This can be utilized for implementing management strategy.The study suggests notable measures for sustainable ground water management, which involves a combination of various measures given below.

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

6.1.1 Supply side measures:

The supply-side management of ground water resources can be done through the artificial recharge by computing surplus runoff available within river sub-basins and also by repairing, renovation and restoration of existing tanks.

6.1.2 Artificial Recharge Structures (To be taken up)

The areas feasible for construction of recharge structures has been demarcated based on the analysis of post-monsoon depth to water level data and existing data on artificial recharge structures constructed under various schemes of MGNREGA and by Rural Development department, Govt. of Andhra Pradesh. The availability of unsaturated volume of aquifer was computed by multiplying the area feasible for recharge and unsaturated depth below 3 mbgl. The recharge potential of aquifer is calculated by multiplying the unsaturated volume with specific yield of the aquifers (0.02 for hard rock).

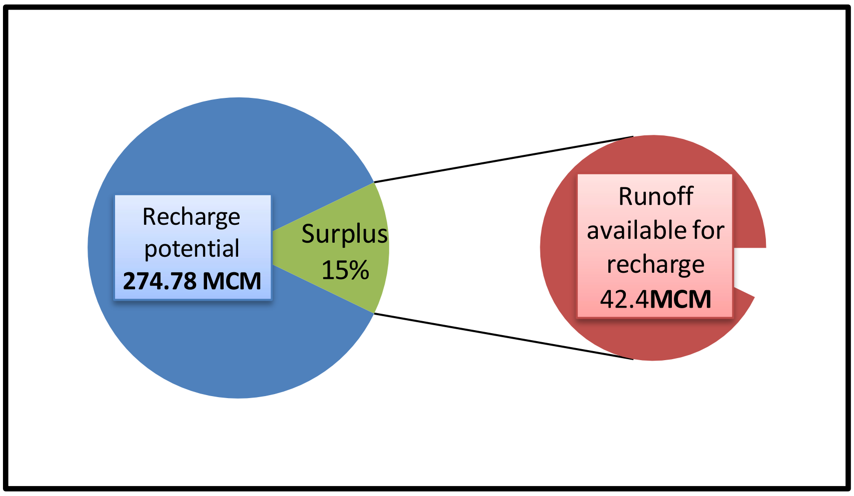
The source water availability is estimated from the rainfall and run-off correlations. The runoff was calculated by taking into account of normal monsoon rainfall of the mandal and corresponding runoff yield from Strangers table for average catchment type. Out of the total run-off available in the mandal, only 20% is considered for recommending artificial recharge structures in intermittent areas.

The storage required for existing artificial recharge structures by State Govt. departments under MGNREGS schemes is deducted to find the available surplus run-off for recommending the additional feasible artificial recharge structures. 50% of the available surplus run-off is considered for the recommendation of artificial recharge structures, as the remaining 50 % is recommended for implementing water conservation measures in recharge areas through MGNREGS.

As the stage of ground water development in the district is 19 % and all 29 mandals are falling in safe category as per the GEC 2022 estimation, the artificial recharge structures are not proposed for entire district. Total 7 mandals have deeper water levels in post monsoon season (Benganapalle, Sanjamala, Dhone, Kolimigundla, Owk, Bethamcherla and Peapally) . Areas where water level is shallow are not considered for recharge, because it may lead to water logging condition which in turn would affect the yield of agricultural crops. Also area covered under forests, hilly terrain where slope exceeds 20 degrees, human settlements are not taken into consideration as recharge structures are not feasible in these areas . Three mandals have decadal water level more than 15m i.e Banganapale, Dhone and Peapally hence recharge structures with shafts are proposed in those areas for more effective percolation at greater depths to increase the saturation percentage of aquifer. Hence, mandals with deeper water levels are considered for constructing ARS.

Proposed Artificial Recharge Structures	
Total geographical area of district (sq.km)	9686.15
Area feasible for recharge (sq.km)	2299.17
Unsaturated Volume (MCM)	13739
Recharge Potential (MCM)	274.78
Surplus run-off available for recharge (MCM)	42.4
PROPOSED ARTIFICIAL RECHARGE STRUCTURES	
Percolation Tanks with/without RS (@ Av. Gross Capacity=0.007 MCM*2 fillings = 0.0140 MCM)	30+9
Check Dams with/without RS (@ Av. Gross Capacity=0.007 MCM* 5 fillings = 0.035 MCM)	66+6
Total volume of water expected to be recharged (in MCM)	3.031

Table.6.1. Proposed ARS in Nandayal district

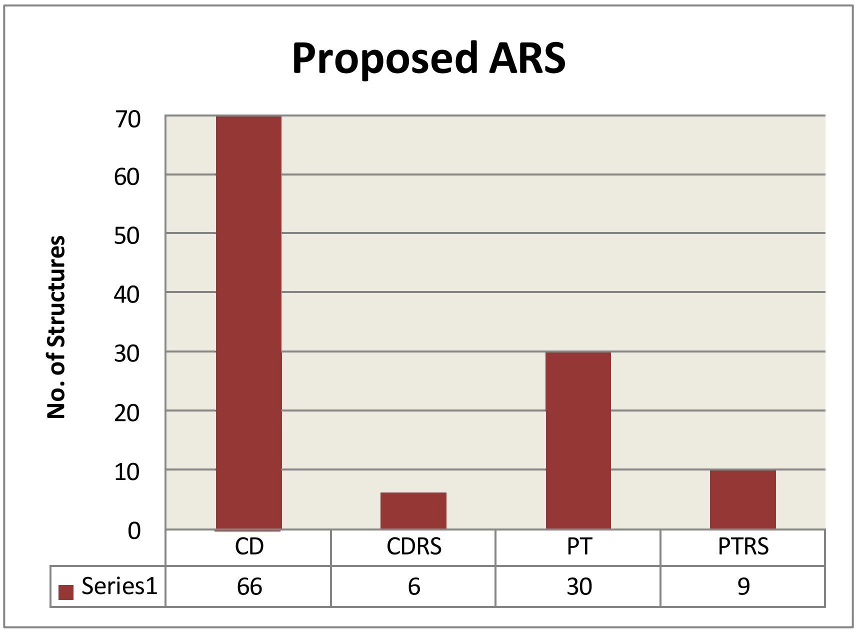


The total unsaturated volume (below the depth of 3 m) available for artificial recharge is 13739 MCM, having 274.78 MCM of recharge potential (2%). The available surplus run-off can be utilized for artificial recharge through construction of percolation tanks, check dams with recharge shafts at suitable sites. The number of percolation tanks, and check dams are decided based on the number of suitable streams available in the district. Thus, after taking into consideration all the factors, only 42.4 MCM of surplus water is available for recharge, which is given in table 6.1. This surplus water can be utilized for constructing 72 check dams and 39 percolation tanks at suitable sites. The amount of recharge from these artificial recharge structures was calculated by considering 0.0140 MCM per percolation tanks and 0.035 MCM per check dam.*(The locations recommended for checkdams and percolation tanks on map are tentative with subject to field verification)*

- After effective utilization of this yield, there will be 3.031 MCM of ground water recharge with new structures.
- All existing artificial recharge structures are to be desilted and maintained properly.
- Roof top rainwater harvesting structures should be made mandatory to all Government buildings.

6.1.3 Other supply side measures:

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



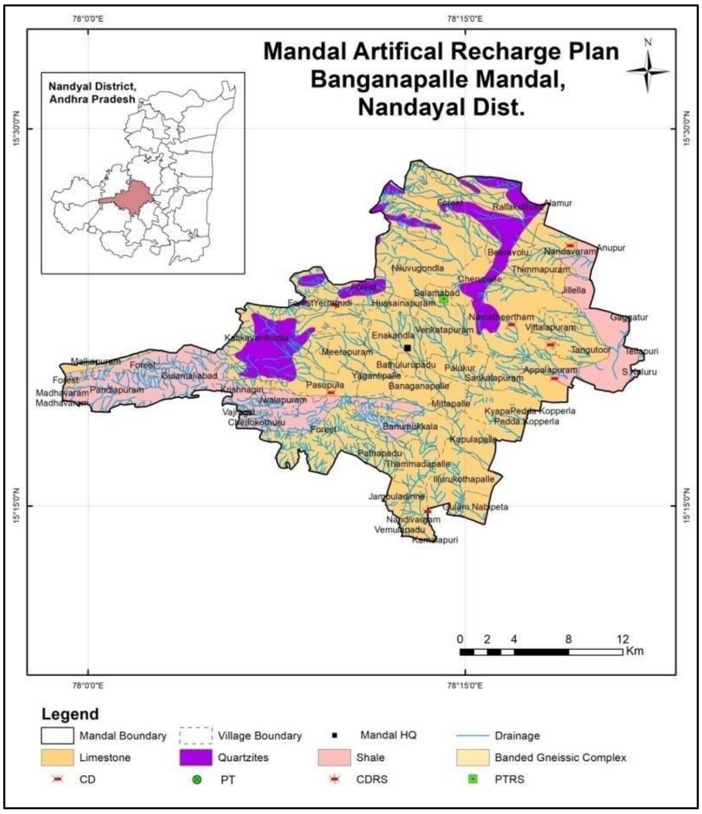


Fig. 6.1.Preferable locations proposed for ARS in Banganapalle mandal

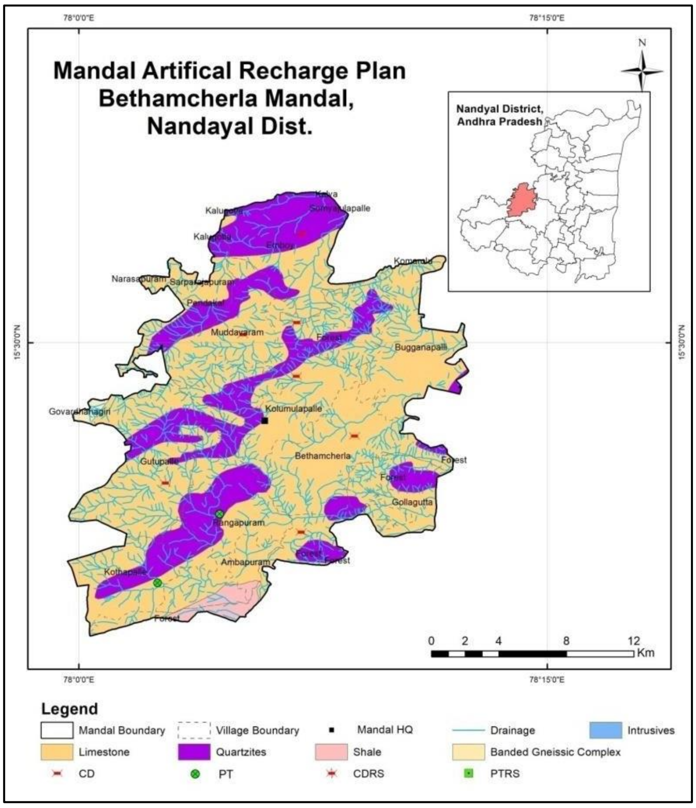


Fig. 6.2.Preferable locations proposed for ARS in Bethamcherla mandal

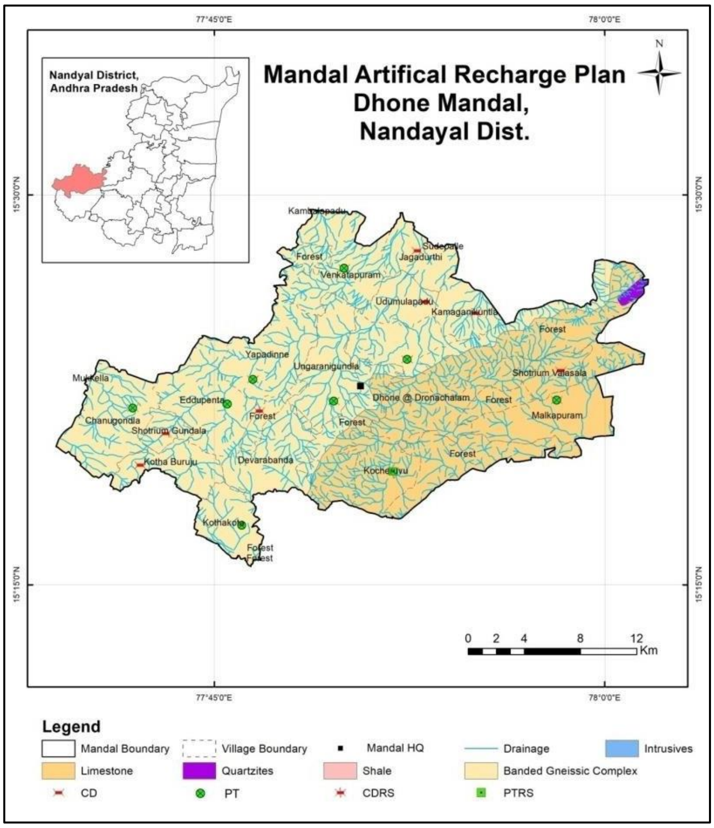


Fig. 6.3.Preferable locations proposed for ARS in Dhone mandal

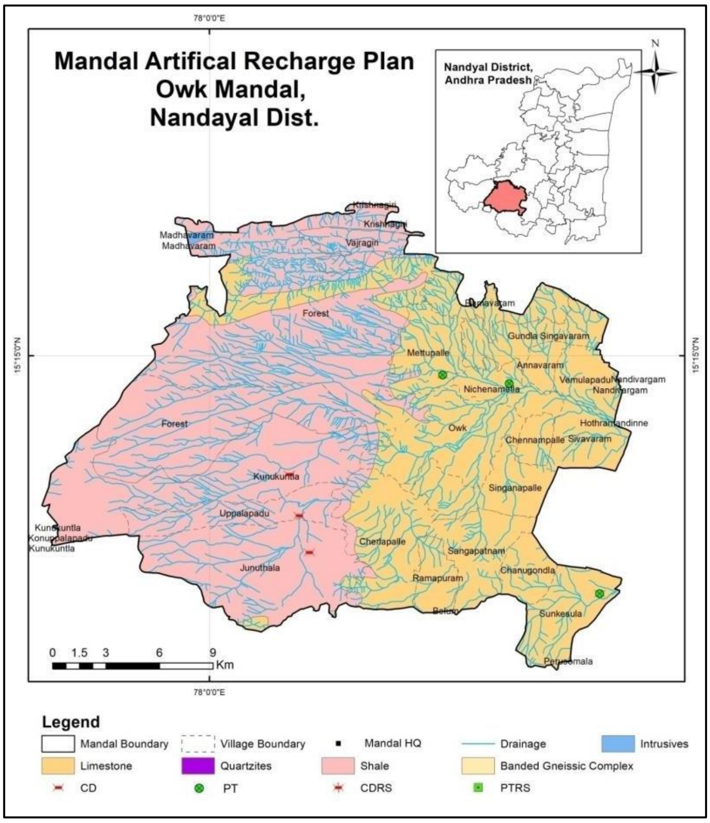


Fig. 6.4.Preferable locations proposed for ARS in Owk mandal

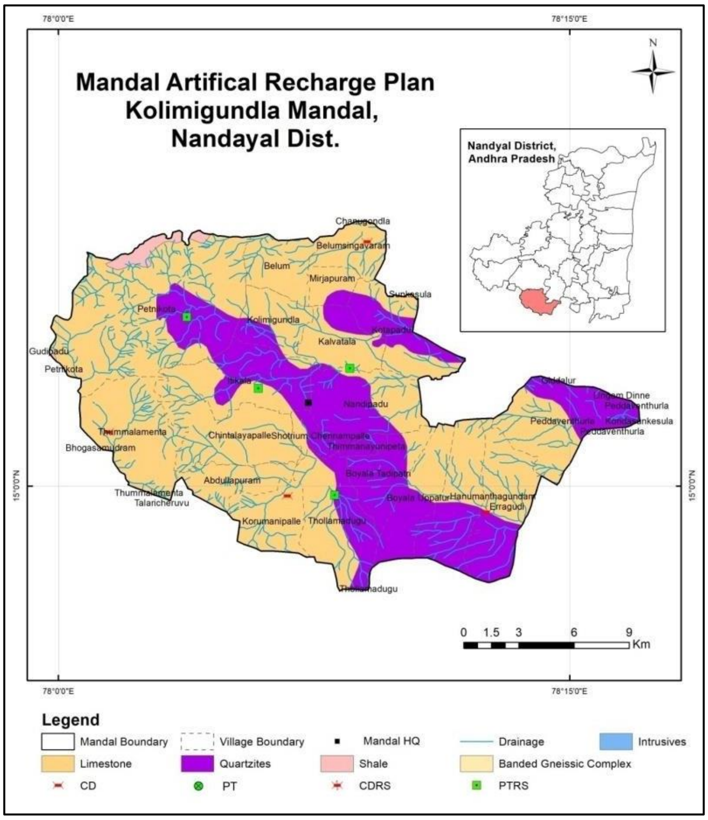


Fig. 6.5.Preferable locations proposed for ARS in Kolimigundla mandal

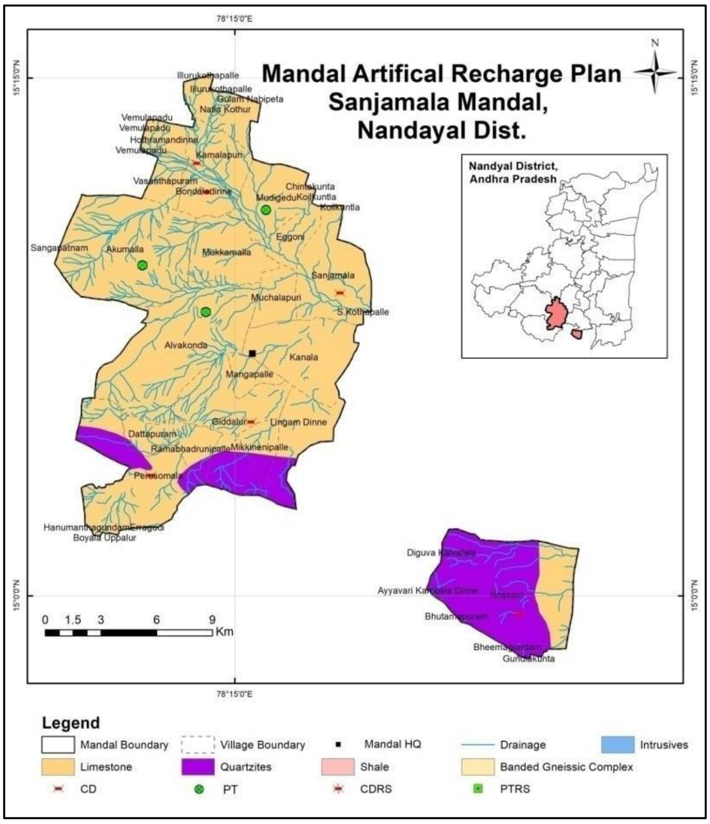


Fig. 6.6.Preferable locations proposed for ARS in Sanjamala mandal

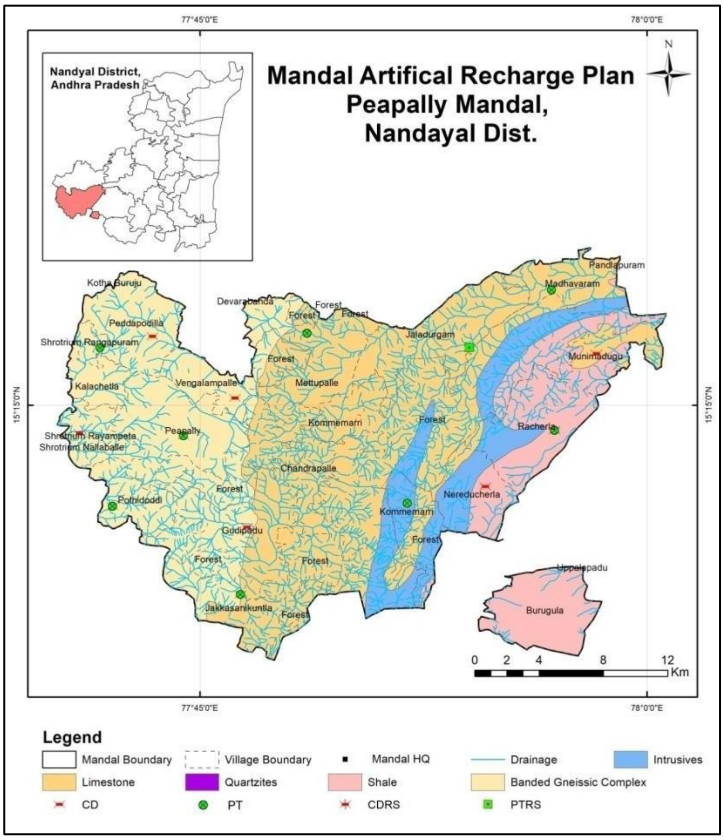


Fig. 6.7.Preferable locations proposed for ARS in Peapally mandal

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

6.1.5 Proposed Work

- Micro-irrigation: The area faces low sustainability in terms of ground water yield. The recharge potential is more than the total run off and surplus run off availability. Particularly in meta sedimentary formations in western and southern parts, the massive limestones making the ground water yield unpredictable and posing serious challenges to agriculture sustainability. Considering these, the sprinkler and drip irrigation system with suitable cropping pattern wherever feasible may be practiced as a measure for ground water conservation, protection and management. An about 22,650 ha of land can be brought under micro-irrigation (@50 ha/village in 453 villages, considering 1 unit/ha @0.6 lakh/ha). With adoption of micro irrigation practices, the total water requirement for irrigation can be reduced upto 60% to 70%. With this ~14.7 MCM of ground water can be conserved over the traditional irrigation practices, considering @ 0.006 MCM/ha for Irrigated Dry crops with traditional irrigation methods).
- Change in cropping pattern from water intensive paddy to irrigated dry crops like pulses and oil seeds are recommended, particularly in water stress areas. If necessary some regulatory rules may be framed and implemented.
- To avoid the interference of cone of depression between the productive wells, intermittent pumping of bore wells is recommended through regulatory mechanism.
- Power supply should be regulated by giving power in 4 hour spells two times a day in the morning and evening by the concerned department so that pumping of the bore well is carried out in phased manner to allow recuperations of the aquifer and increase sustainability of the bore wells.
- As a mandatory measure, every ground water user should recharge rainwater through artificial recharge structures in proportionate to the extraction.

6.1.6 Other measures

- A participatory ground water management (PGWM) approach in sharing of ground water 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 ground water may be given to the concerned farmers.

- The open stone quarries / abandoned quarries can be filled with soil and covered with vegetation; it will prevent further erosion and weathering of salts, minerals and also escalation of the salinity levels in aquifers.
- Recommending to use of red mud pot to store potable household water in Fluoride contaminated areas to reduce the impact of fluorosis
- In urban and rural areas proper sewerage system should be constructed to arrest leaching of Nitrate.
- Uranium causes radiotoxicity as well as chemical toxicity. Therefore in U contaminated areas (Gulamaliabad, Yalluru, Muthaloor, Ayyalur ,Reddivari Jambuladinne, Kotha Buruju, Venkatapuran, Gudipadu) it is advised to use ground water only for non potable purposes or installation of permeable reactive barrier (Ferric iron, phosphate) in Govt sponsored RO plants is recommended.
- Restrict use of extensive chemical fertilizers as it will eventually degrade soil and leach to join ground water which already has high salinity.
- Recommend to cultivate high EC tolerant crops like cotton, safflower, sesame etc.

6.1.7 Ongoing Projects

Repair, Renovation and Restoration of existing tanks(Completed):

Neeru-Chettu Mission

Important activities to be undertaken by the Neeru-Chettu Mission

a) Inventory of existing water harvesting structures and repairs needed.

b) Construct new water harvesting structures using remote sensing technology.

c) Construction of targeted recharge structures (roof water harvesting, artificial recharge of aquifers and defunct wells).

d) Restoration of major, medium and minor irrigation systems (repair of breach to structures and supply channels, desilting of tanks).

e) Participatory Hydrological Monitoring (surface and ground water) for community water audit and crop water budgeting.

6.2 Expected Results and Outcome:

With the above interventions, the likely benefit would be the net saving of 17.73 MCM of ground water either through water conservation measures like adoption of drip and sprinkle irrigation and artificial recharge to ground water. Further stage development would be controlled to avoid all the mandals of district to fall into semi-critical/critical category.

Acknowledgment

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Annexure 1

Proposed supply side interventions for Artifical recgarge structures

Proposed villages for constructing check dams		
Mandal	**Village**	**No. Of structures**
Banaganapalle	Nandivargam	1
Banaganapalle	Salamabad	1
Banaganapalle	Nandavaram	1
Banaganapalle	Vittalapuram	1
Banaganapalle	Appalapuram	1
Banaganapalle	Pathapadu	1
Banaganapalle	Niluvugondla	1
Bethamcherla	Emboy	1
Bethamcherla	Muddavaram	1
Bethamcherla	Bethamcherla forest	1
Bethamcherla	Kolumulapalle	1
Bethamcherla	Gutupalle	1
Bethamcherla	Bethamcherla	1
Bethamcherla	Rangapuram forest	1
Dhone	Venkatapuram	2
Dhone	Jagadurthi	1
Dhone	Dhone	3
Dhone	Udumulapadu	2
Dhone	Kamaganikuntla	1
Dhone	Ungaranigundla	2
Dhone	Yapadinne	3
Dhone	Kotha buruju	2
Dhone	Chanugondla	1
Dhone	Shotrium valasa	1
Dhone	Eddupenta forest	1
Dhone	Malkapuram	1
Dhone	Shotrium gundala	1
Kolimigundla	Belumsingavaram	1
Kolimigundla	Thummalapenta	1
Kolimigundla	Korumanipalle	1
Owk	Mettupalle	1
Owk	Kunukuntla	1
Owk	Uppalapadu	1
Owk	Junuthala	1
Owk	Sunkesula	1
Peapally	Peddapodilla	1
Peapally	Racherla	2
Peapally	Munimadugu	1
Peapally	Vengalampalle	1

Peapally	Peapally	1
Peapally	Shrotrium nallaballe	1
Peapally	Pothidoddi	1
Peapally	Nereducherla	2
Peapally	Gudipadu	3
Peapally	Jakkasanikuntla	2
Sanjamala	Hothramandinne	1
Sanjamala	Bondaladinne	1
Sanjamala	Akumalla	1
Sanjamala	Sanjamala	1
Sanjamala	Alvakonda	1
Sanjamala	Giddalur	1
Sanjamala	Perusomala	1
Sanjamala	Nossam	1

Proposed villages for constructing check dams with recharge shafts		
Mandal	**Village**	**No. Of structures**
Banaganapalle	Yerragudi	1
Dhone	Kocheruvu	2
Kolimigundla	Erragudi	1
Peapally	Jaladurgam	2

Proposed villages for constructing percolation tanks		
Mandal	**Village**	**No. Of structures**
Dhone	Venkatapuram	2
Dhone	Dhone	1
Dhone	Ungaranigundla	1
Dhone	Yapadinne	1
Dhone	Eddupenta	2
Dhone	Chanugondla	1
Dhone	Malkapuram	2
Dhone	Kothakota	1
Owk	Mettupalle	1
Owk	Nichenametla	1
Owk	Sunkesula	1
Peapally	Madhavaram	1
Peapally	Mettupalle	2
Peapally	Racherla	1
Peapally	Sho.rangapuram	1
Peapally	Peapally	1
Peapally	Pothidoddi	2
Peapally	Kommemarri	1
Peapally	Jakkasanikuntla	1
Sanjamala	Mudigedu	1
Sanjamala	Akumalla	1
Sanjamala	Alvakonda	1

Proposed villages for constructing percolation tanks with recharge shafts		
Mandal	**Village**	**No. Of structures**
Banaganapalle	Salamabad	1
Dhone	Kocheruvu	2
Peapally	Jaladurgam	1
Kolimigundla	Thollamadugu	1
Kolimigundla	Petnikota	1
Kolimigundla	Kalvatala	1
Kolimigundla	Itikala	1