भारत सरकार
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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 OF GROUND WATER RESOURCES IN KRISHNA DISTRICT, ANDHRA PRADESH

CENTRAL GROUND WATER BOARD
SOUTHERN REGION
HYDERABAD
2023

REPORT ON

AQUIFER MAPPING FOR SUSTAINABLE MANAGEMENT OFGROUND WATER RESOURCES IN

KRISHNA DISTRICT, ANDHRA PRADESH

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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 Krishna 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.

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

4. To delineate aquifer in 2-D and 3-D along with their characterization on a 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. Enhancement of coordination with concerned central/state govt. organizations and academic/research institutions for sustainable ground water management.

1.3 Study Area

Krishna District lies between the northern latitudes of 15 °45’N to 16 °45’N and eastern longitudes of 80 °45’E to 81°45’E located in the south-eastern part of Andhra Pradesh with a geographical extent of 3773 Sq. Km and coastline of 88 Km. This district is bounded on the north by NTR & Eluru districts, west by Guntur district, east and south by Bay of Bengal. The population of the District is 1735079 comprising of 486 inhabited and 16 uninhabited villages with a population density of 518 per Sq.Km. There are 3 Municipalities viz., 1. Pedana 2. Gudivada 3. Vuyyuru and one Municipal Corporation in Machilipatnam. The District is divided into 25 Mandals covering 2 Revenue Divisions viz., 1.Bandar 2. Gudivada. Fig.1.

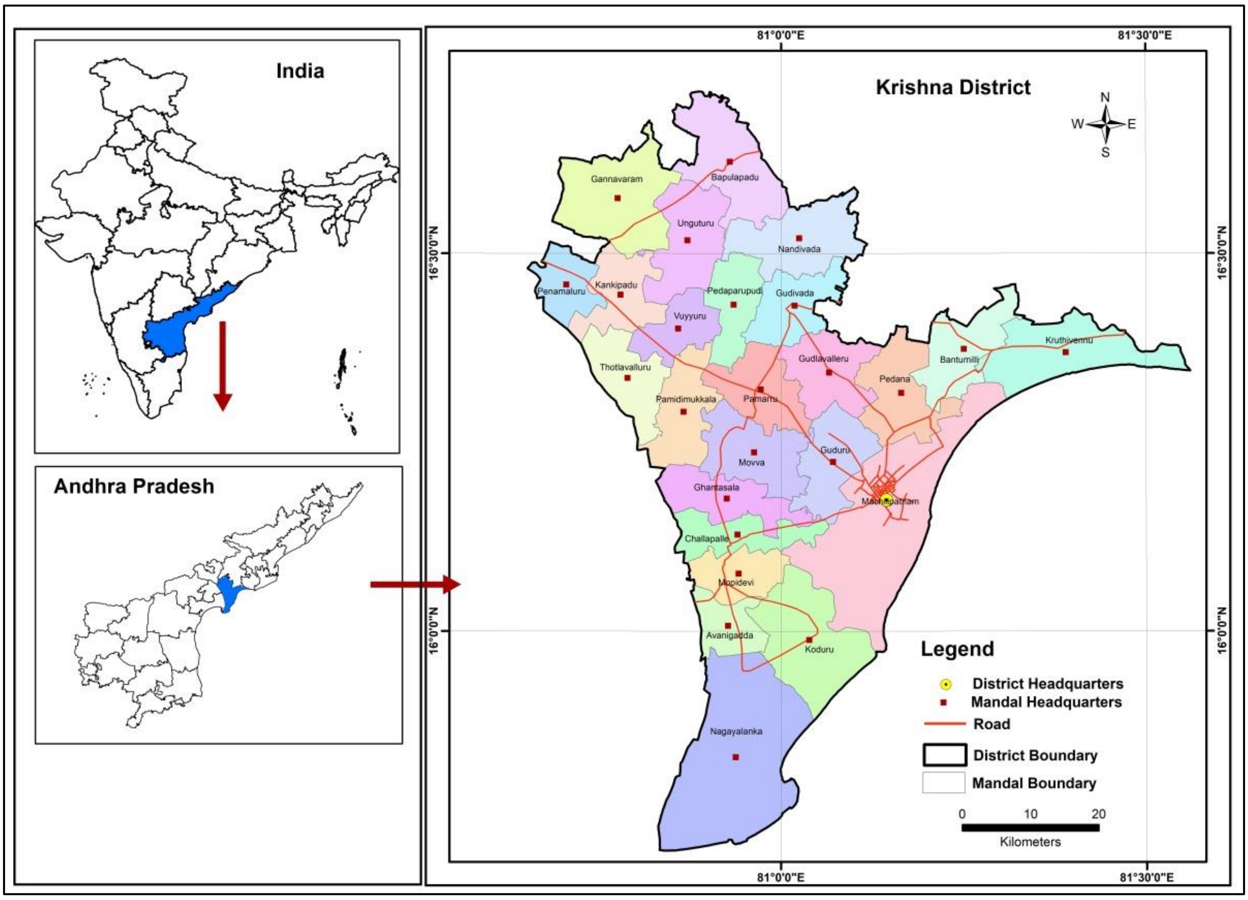

Fig.1. Location map of Krishna District

1.4 Climate and Rainfall

The climate of the district is characterised by tropical wet and dry climate, characterized by year round high temperatures. Tropical Climate conditions with extreme hot summer and cold winter prevail in this district. December is the coldest month with the mean daily maximum temperature of about 28.6°C. and the mean daily minimum temperature is 20.2°C. Temperature begins to rise after February. May is the hottest month with mean daily maximum temperature of about 37.2°C and mean daily minimum temperature is about 27.7°C. Relative humidity in this area is generally high throughout the year. The monsoon usually breaks in the middle of June and brings good rains up to middle of October. The normal rainfall of this district is 992 mm, 2/3rds of which is received through the South West monsoon. The rainfall recorded during the year 2022-23 it is 1107 mm.

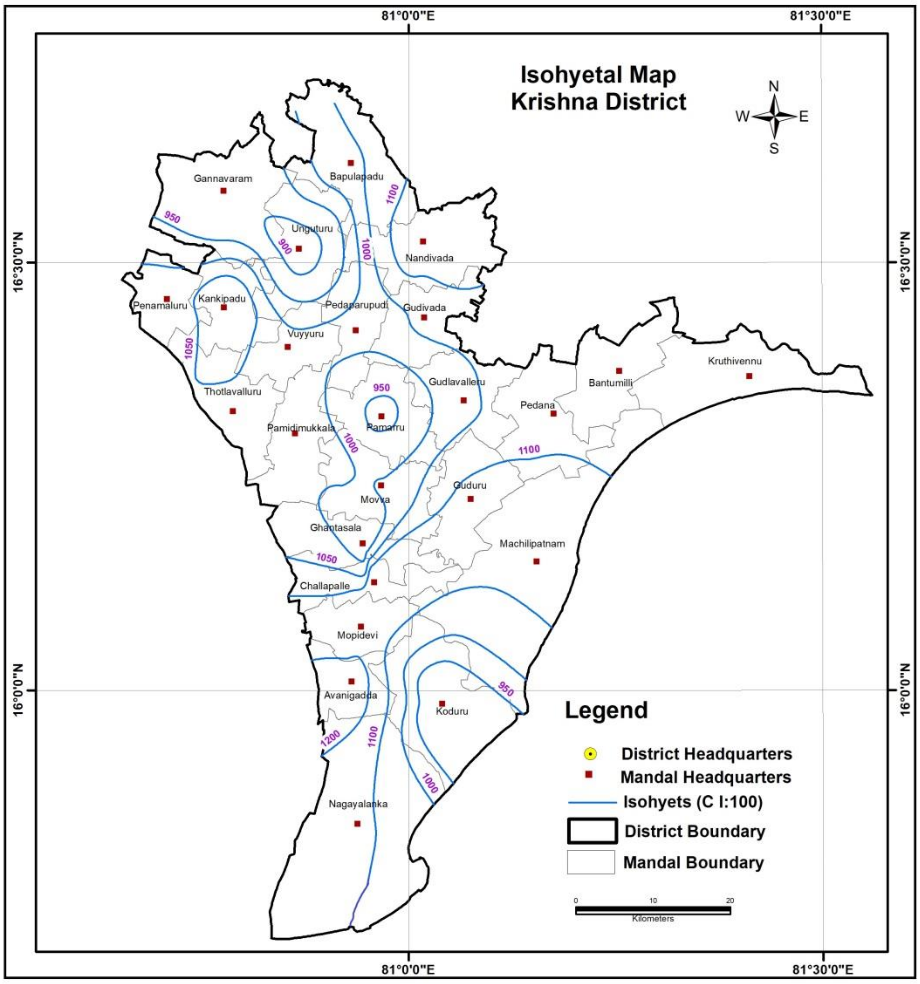

Fig.1.2 Isohyetal map of Krishna District

1.5 Geomorphological Set up

The landforms present in the area are mainly fluvial land forms and marine landforms. Geomorphologically the district can be broadly divided into 3 distinct units, viz., Pediplain, Alluvial plains, and Coastal & Deltaic plains. The pediplain area i.e., northern part of the district consists of an undulated plain with broken ridges. Major part of the district in the southern part is represented by the alluvial plains forming the Krishna delta. The river Krishna and its tributaries have contributed to the formation of this alluvial plain. There is no significant surface drainage in these alluvial plains. The delta is relatively a flat area. The alluvial plains along the major course of rivers form the flood plain deposits. The coastal and deltaic alluvial plain extends from Challapalli on the west to Kolletikota on the east and upto the coast line on the south. The main geomorphic units exist in these plains are palaeo-channels, beach ridges, lagoons, sand spits and sand barriers. Krishna river divides itself at Avanigadda and south of Nagayalanka into four branches forming an arcuate delta. The deltaic coast protrudes towards open sea at the mouths of these four branches forming a cuspate foreland. Around 54% of the area is occupied by fluvial land forms which consist of channel bars, Channel Islands, cut 39% of the area is occupied by marine landforms and are presented in Fig.1.4. The altitude varies from 1 m near coast to 191 m above mean sea level with a slope towards SE direction. and the Digital Elevation Profile is presented in Fig.5.

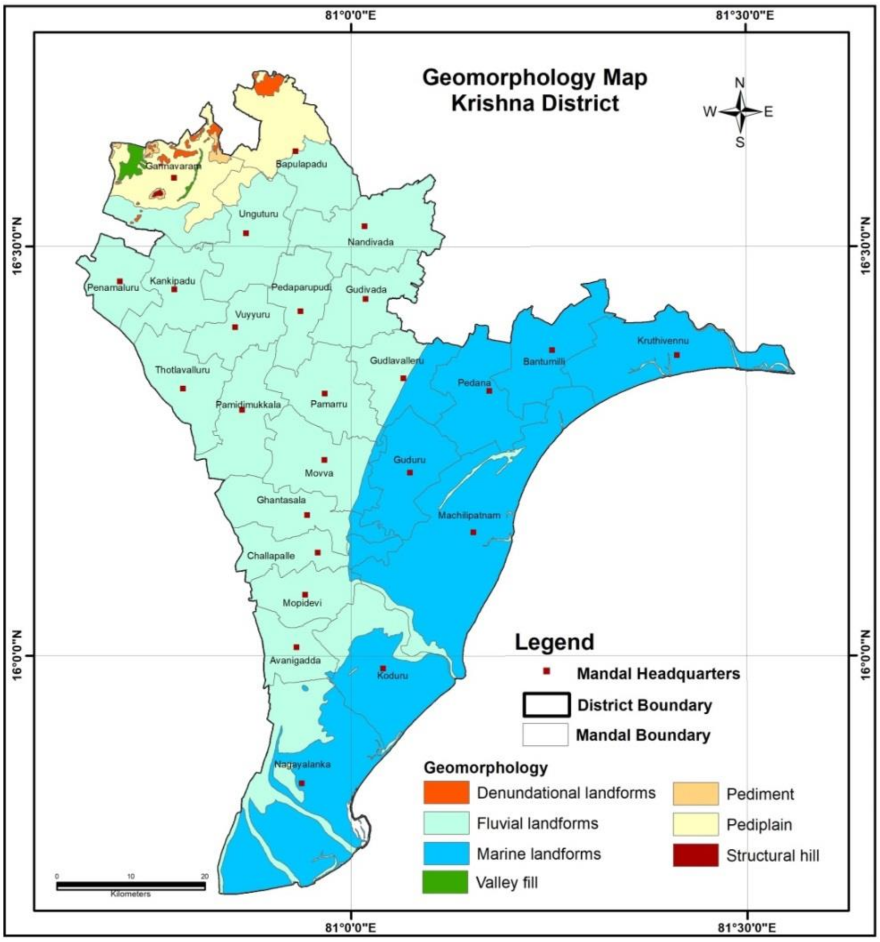

Fig.1.4 Geomorphology in Krishna District

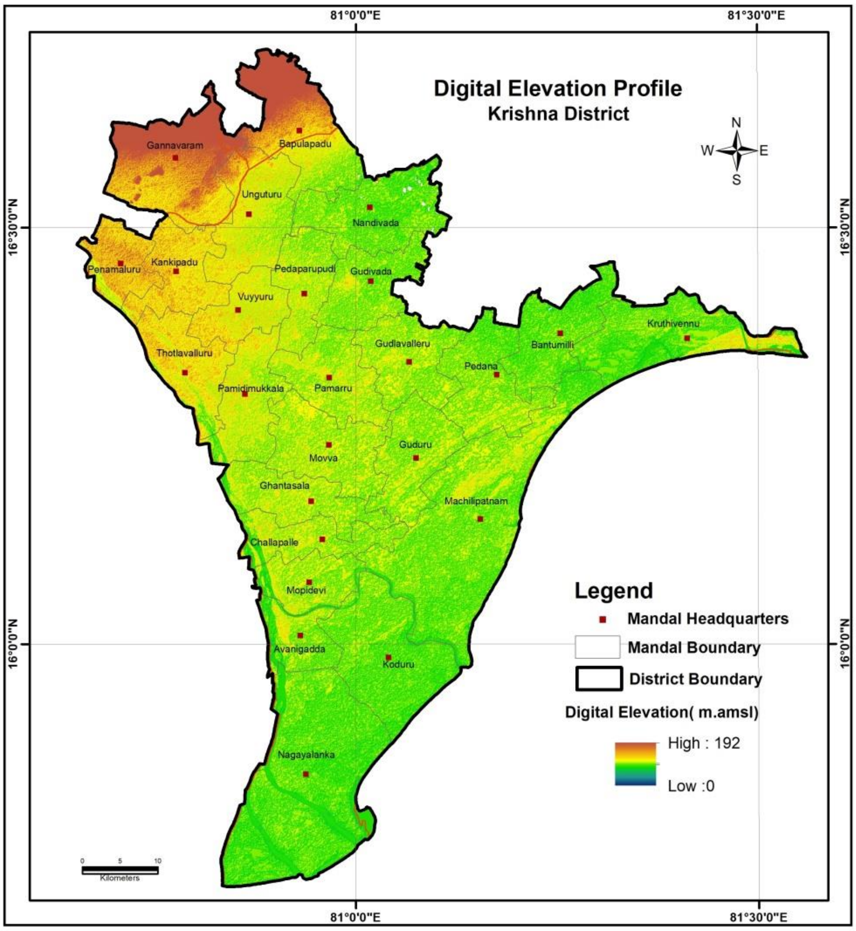

Fig.1.5 Digital Elevation Profile of Krishna District

Shoreline Development: The geomorphic features present in the coast indicate the shoreline development in the past. In Krishna delta, the presence of beach ridge complexes on land indicate the shore line development and existence of four strand lines. The strandlines (Palaeo-shorelines) are almost parallel to the present day cost. Each strandline represents a set of ancient beach ridges and tidal flats

1.6 Drainage

The area is drained by Krishna River and flows North to South direction. The river Krishna originates in the Western Ghats near Mahabaleshwar and debouches into the Bay of Bengal at Hamsaladivi and Nachugunta in Krishna district. It is perennial in nature and flows along the western boundary of the District. Among the other streams and tributaries Muniyeru, Budameru and Tammileru are significant. The drainage density is high in consolidated formations, low in semi-consolidated formations, whereas in alluvial areas the density is meagre (CGWB, 2013). The first distributary of the river Krishna branches off north of Avanigadda. The main channel bifurcates into three distributaries further south near Edurmodi. The eastern branch channel is termed Gulumuttapaya, the central branch is called the Medimurru and the westernmost is the Krishna. The area is served by Krishna canal system and other drains. The majority of the ponds particularly near to coast in eastern delta (Krishna district) are being converted to pisciculture.

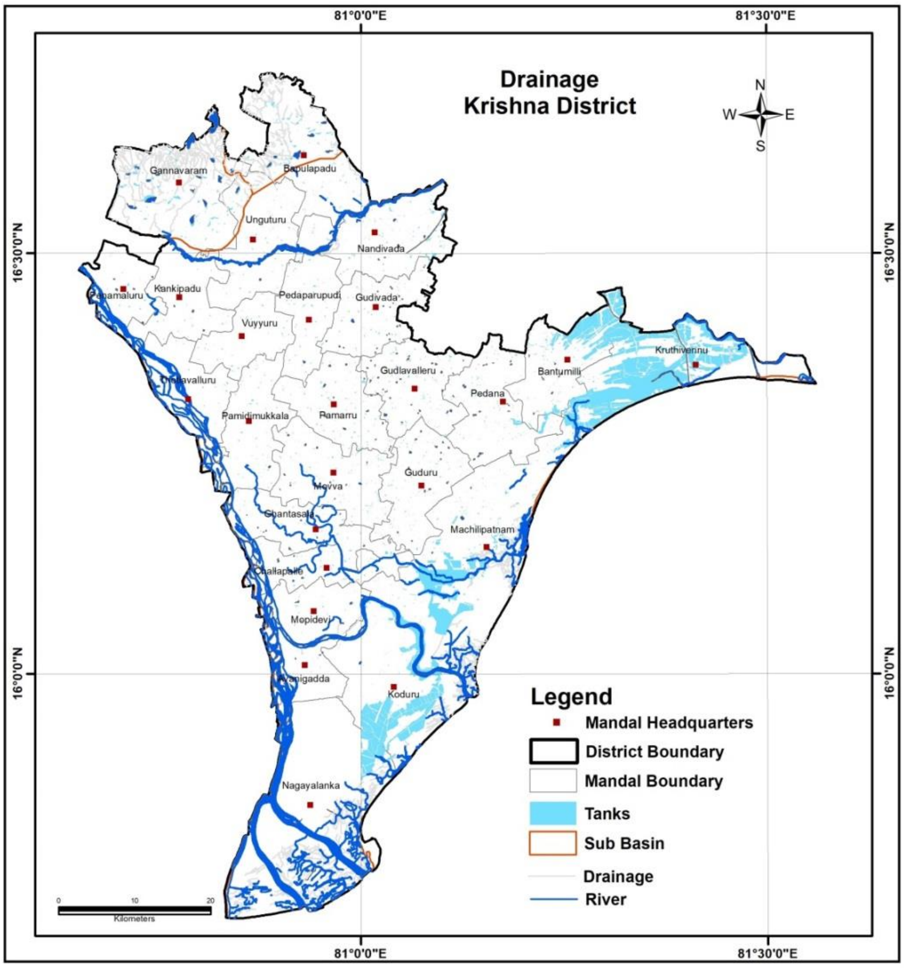

Fig.1.6. Drainage in Krishna district

1.7 Land use and cropping pattern

The land use pattern in the study area indicates that the area is mostly agrarian. About 90 % of the study area is occupied by agricultural land and the remaining area by tree crops, mangroves, aquaculture practices and small water bodies. The village tanks, ponds and percolation tanks present in the area are very limited. The majority of the ponds are being converted to pisciculture particularly in eastern deltaic area. The pisciculture in this area is practised in 50,808 ha area. The principal crops are paddy and sugarcane. The other crops are Maize, Pulses, turmeric, fruits and vegetables. The land use pattern in the area are presented as Fig. 8 & Table 1.1

Table 1.1. Land utilization of Krishna District (2020-2021)

Land Utilization	Area (Ha)	% of Geographical Area
Forest Area	17448	5%
Barren & Uncultivable Land	14382	4%
Land Put To Non Agri Uses	79549	21%
Culturable Waste	10691	3%
Permanent Pastures & Grazing Land	2100	1%
Land Under Misc. Tree Crops & Groves	4660	1%
Other Fallow Lands	10797	3%
Current Fallow Lands	9881	3%
Fish& Prawn Culture	25278	7%
Net Area Sown	202613	54%
Area Sown More than Once	173837	
Total Cropped Area	376450	

Source : Handbook of statistics of Krishna District

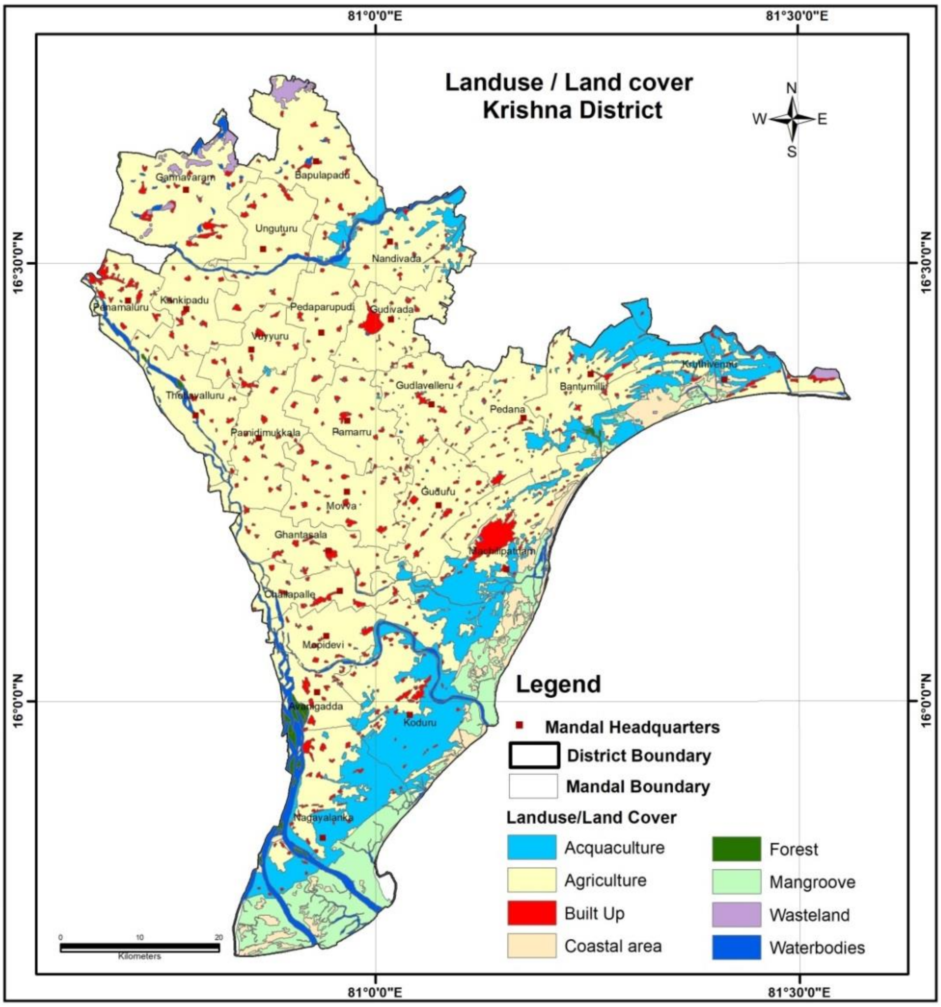

Fig.1.7. Landuse map of Krishna district

1.8 Soils

The predominant soils in the district are black cotton soils/deltaic soils, red loamy soils and sandy soils. Red clayey soils with sandy loam to clayey loam in texture and occur in the northern part of the district. The deltaic alluvium is grey brown to black in colour with fine to medium texture and poorly permeable. The deltaic soils have high clay content and are less permeable and poorly drained and are highly fertile in nature and have high cation exchange capacity. The coastal sandy soils occur all along the coast, highly porous and lack of binding material.

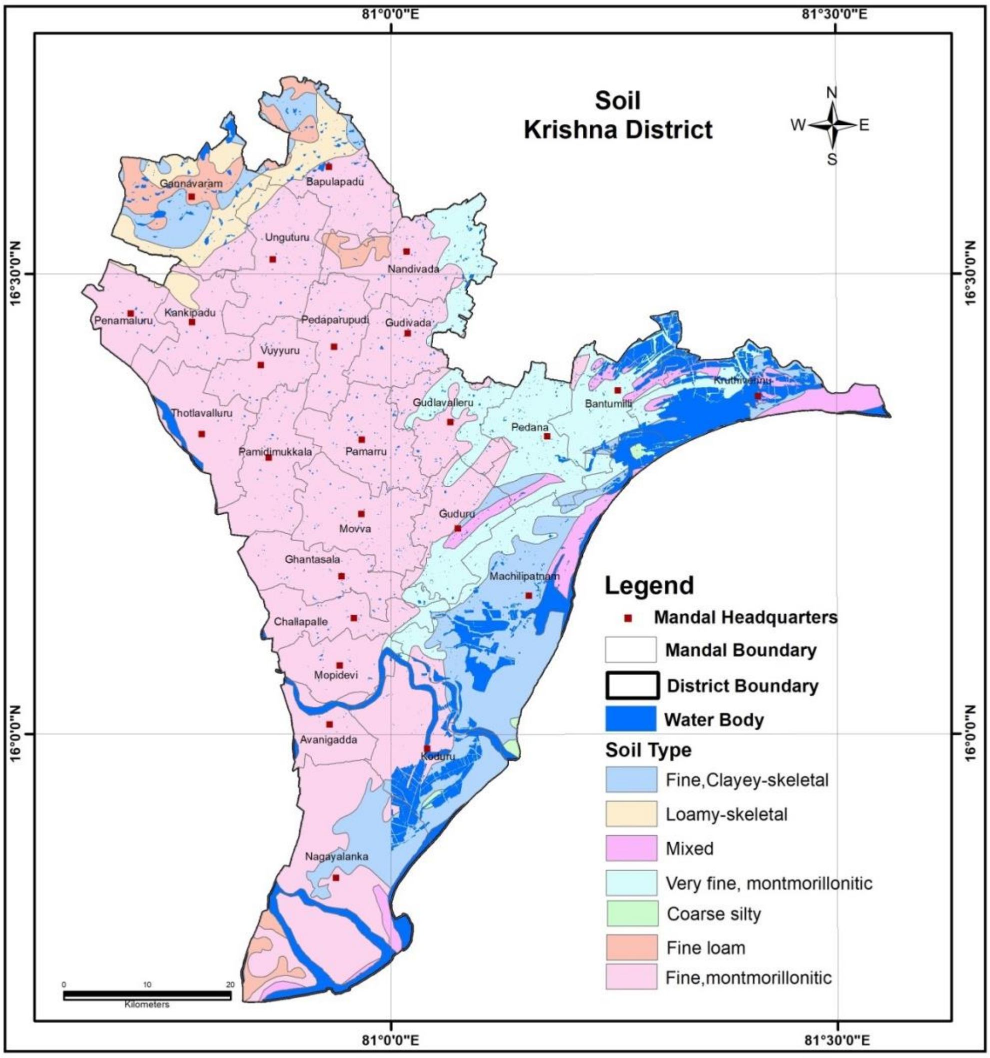

Fig.1.8. Soil map of Krishna district

1.9 Irrigation:

The area has the distributary network of the river Krishna. The area is crisscrossed by the canal network of Krishna Delta Irrigation System. The major irrigation projects covering Krishna district are Krishna Eastern Delta (Prakasam Barriage) and Pollavaram. In Krishna eastern delta an extant of

2,74,600 hectares.. The Krishna Delta Irrigation Project is catering the irrigation needs of the area in Kharif and in Rabi seasons. Gross area irrigated during Kharif and Rabi seasons is 375391 ha and 129486 ha respectively. The village tanks, ponds and percolation tanks present in the area are very limited. The majority of the ponds are being converted to pisciculture particularly in eastern deltaic area. The pisciculture is practised in Krishna nearly 25278 ha. The areas irrigated by different sources are presented in Table 1.2.

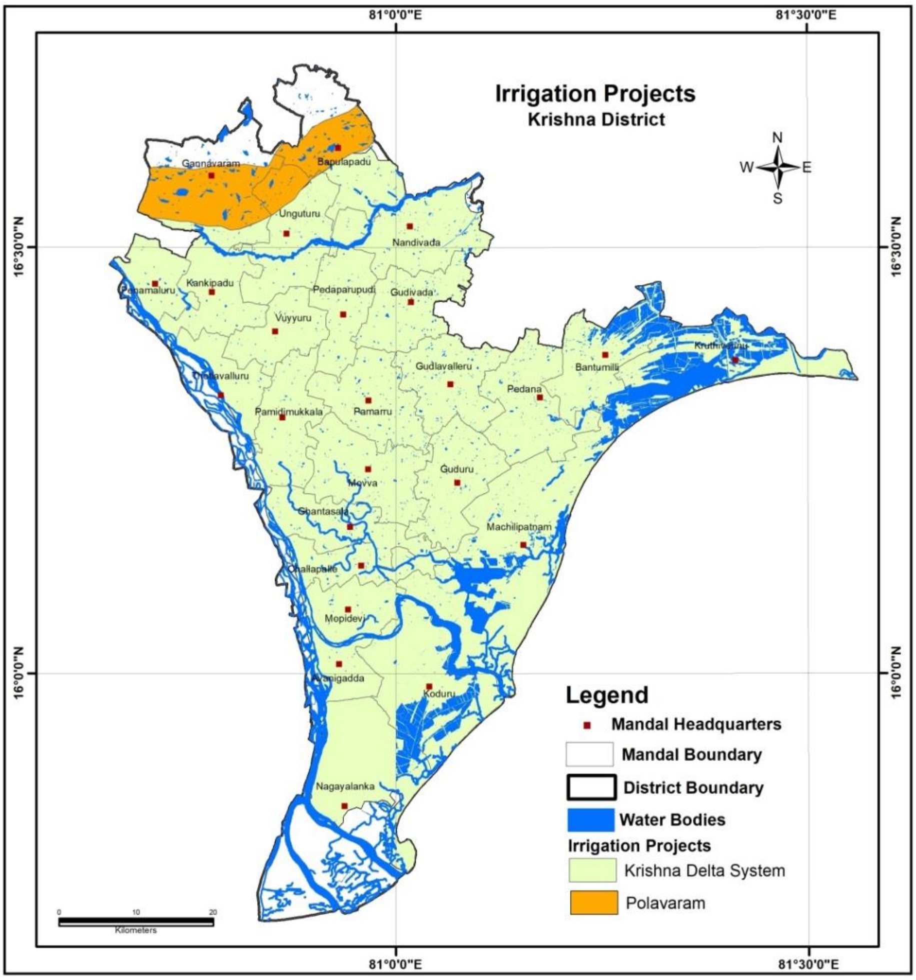

Fig.1.9. Irrigation map of Krishna district

Table 1.2Area irrigated under different sources, 2019-20

Area Irrigated Under different Sources	
Sources	Area(Hectre)
Canal	186188
Tanks	3010
Tubewells	50272
Dug wells	796
Lift Irrigation	1455

1.10 Geology

The district is underlain by deltaic and coastal alluvium consisting of fine to medium sand, silt and gravel with intercalations of clay of recent age followed by sandstones of Mio Pliocene age followed by crystalline and at places alluvium directly underlain by crystalline/ basement from the oldest Archaeans to Recent (Fig 1.10). Hydrogeologically, these formations are classified as consolidated (Hard), semi-consolidated (Soft) and unconsolidated (Soft) formations. The consolidated formations include crystallines (Khondalites, Charnockites and granitic gneisses). The semi consolidated formations are represented by Tertiary formations (Rajahmundry & Gollapalli sandstones) and unconsolidated formations comprise deltaic alluvial deposits of Quaternary period (CGWB, 2013) comprising Sand, Gravel, Clay and Silt. . Consolidated formations occur in the northern part of the District.

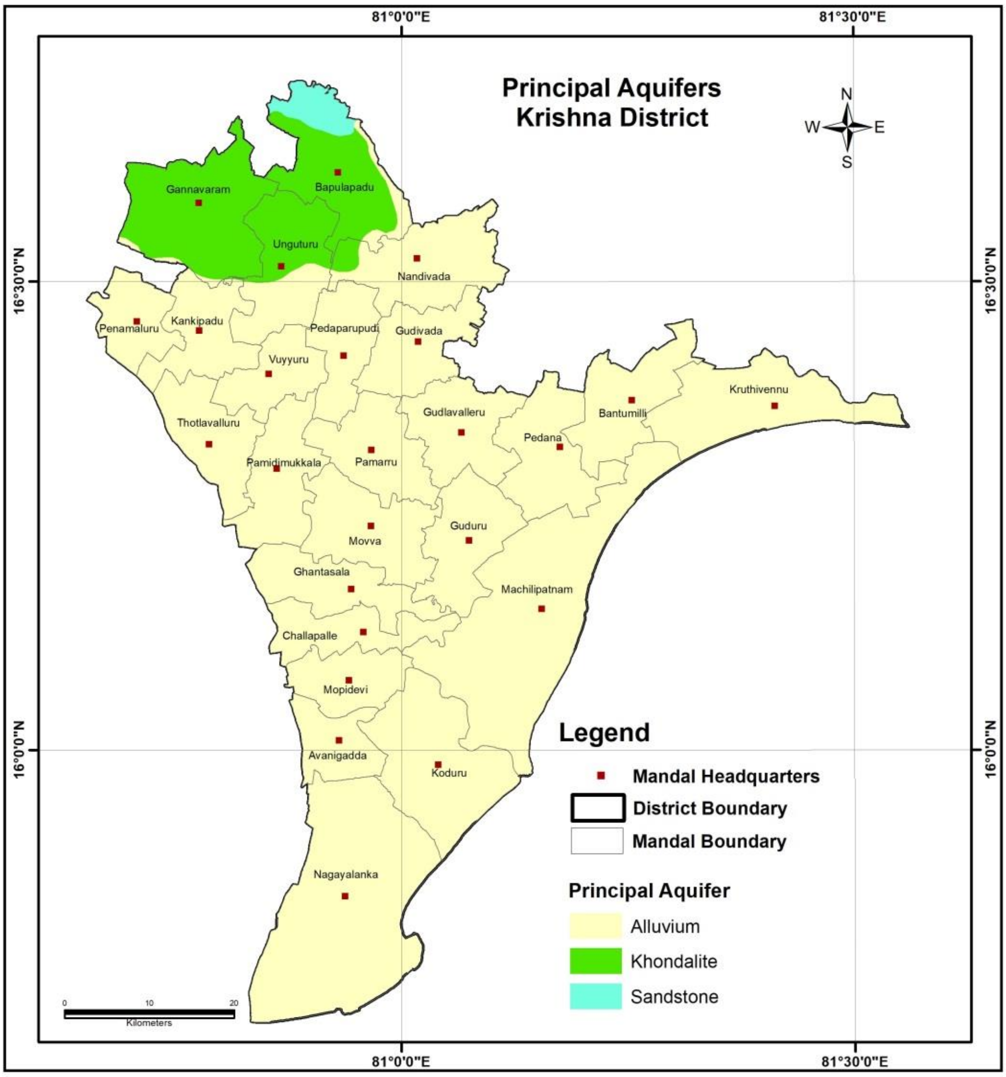

Fig:1.10 Geology of Krishna District

Table 1.3 Geological Succession of Krishna District

Age	System	Formation	Lithology
Recent to Sub -Recent		Alluvium	Gravel, sand, silt, and clay
Mio-Pliocene		Rajahmundry	Sandstone and shale/ clay
Upper Cretaceous to Lower Eocene		Deccan Traps	Basalt
Lower Cretaceous to Lower Triassic	Upper Gondwana	Tirupathi	Sandstone and shale/ clay
		Raghavapuram	Sandstone and shale/ clay
		Gollap alli	Sandstone and shale/ clay
	Lower Gondwana	Chintalapudi	Sandstone and shale / clay
Unconformity			
Archaean			Charnockite, Khondalite and Gneisses

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	Analysis of ground water for general parameters including fluoride.

		quality parameters	
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 Exploratory drilling

Information on aquifer geometry, Groundwater potential of various formations, fracture systems, their characterization is primarily inferred from the exploratory drilling data. CGWB has a total of 80 wells in the district. Out of these, 57 wells were drilled during the year 2012-22 based on the data gap analysis carried out in the study area as part of NAQUIM studies. A total of 80 exploratory borewell data of CGWB were used for the hydrogeological studies.

2.2 Water Level

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 groundwater monitoring wells were used in order to understand the spatio-temporal behaviour of the groundwater regime. 10 year water level data of 62 wells of CGWB & SGWD is utilized for the Aquifer Mapping studies.

2.3 Hydro chemical Studies

Water quality data of CGWB and SGWD is utilized for understanding the spatial variation of quality in the district. A total of 62 Ground water monitoring well data of Central Ground Water Board, Andhra Pradesh Ground water and Water audit department (mostly tapping combined aquifers Aq-1 and aq-2) is utilized to understand the chemical characteristics of groundwater. 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.

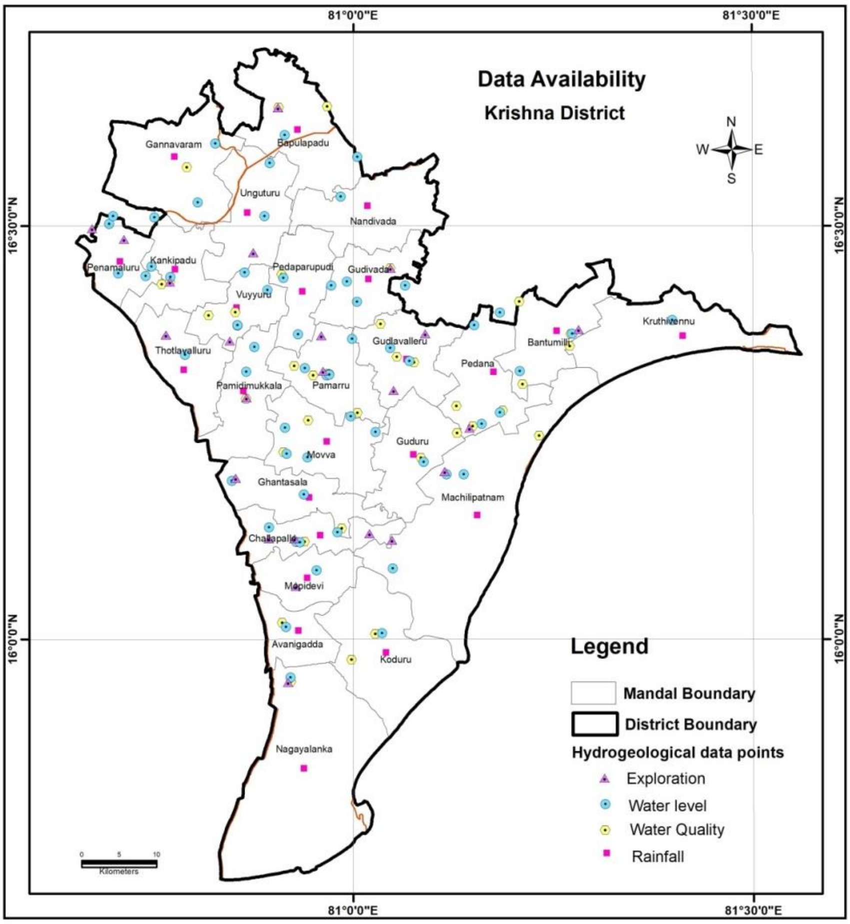

Fig:2.1 Data Availability in Krishna District

3. DATA INTERPRETATION, INTEGRATION AND AQUIFER MAPPING

3.1 Ground water Level Scenario

The water levels behaviour was studied based on the pre-monsoon and postmonsoon water level data of observation wells maintained by CGWB and State Ground Water & Water Audit department and the fluctuation of depth to water level for the premonsoon and post- monsoon is determined. The data set was used for preparing maps of pre-monsoon depth to water level, post monsoon depth to water level and fluctuation.

3.1.1 Depth to ground water level

The water levels behaviour was studied in the ground water regime of the area based on the pre-monsoon and post-monsoon water level data of monitoring stations. The depth to water level in the shallow aquifer during pre-monsoon is ranges from < 1 m bgl to a maximum of 21 m bgl. Pre-monsoon depth to water level map reveals that mostly the water levels in the area ranges in between 2 and 5 m bgl (Fig.3.1). The depth to water level during post-monsoon in the majority of the area is < 10m bgl. (Fig. 3.2).

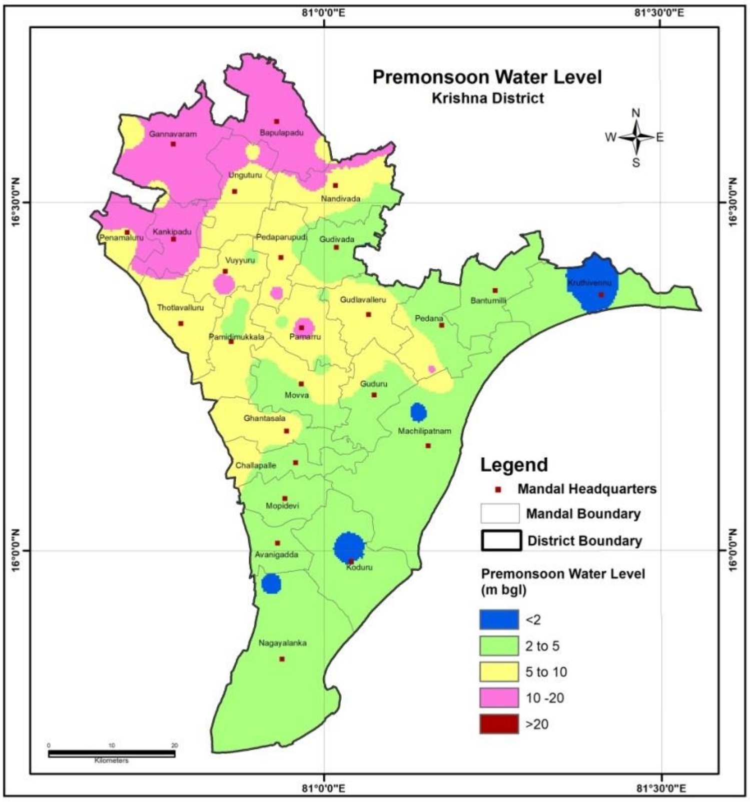

Fig: 3.1 Pre monsoon Water level in Krishna District

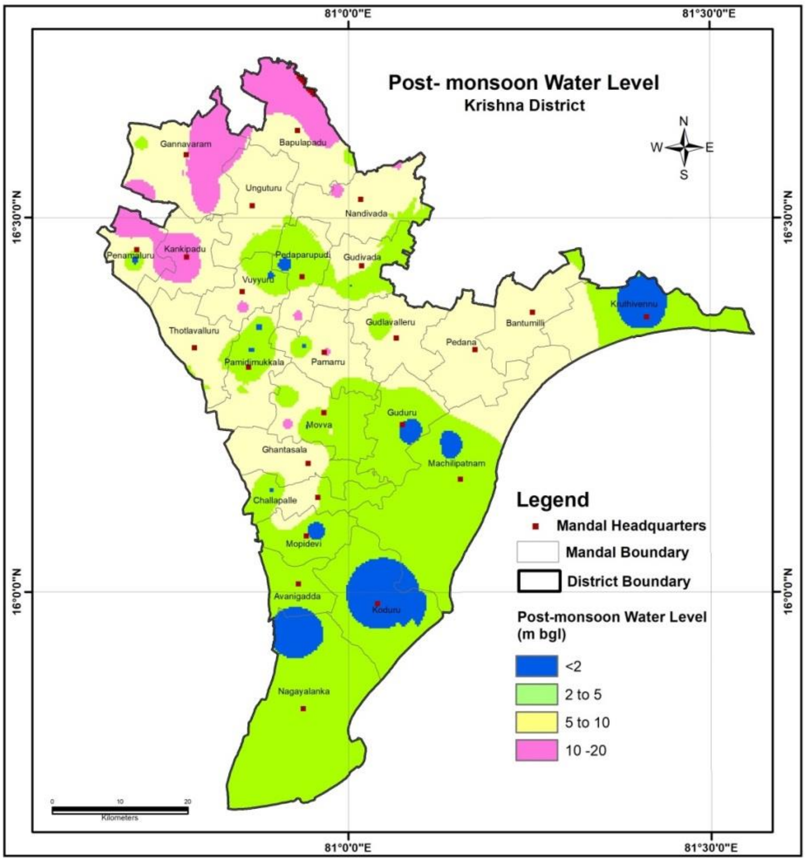

Fig: 3.2 Post monsoon Water level in Krishna District

3.1.2 Water Table Elevation

The water table elevation map was prepared to understand the ground water flow directions. The water table elevation ranges between <2 m amsl in the coastal area and > 12 m amsl in the north eastern part of the area. The general ground water flow direction is towards sea (Fig. 20). The water table contours also indicate that there are conspicuous water discharges into the sea.

3.1.3 Water Level Fluctuation:

The water level fluctuation in shallow aquifers between pre-monsoon and postmonsoon water levels i.e., May and November ranges in between -2 and >4 m. The fluctuation map reveals that the majority of the area shows rise of about 2 m in water level, whereas fall recorded at few isolated patches

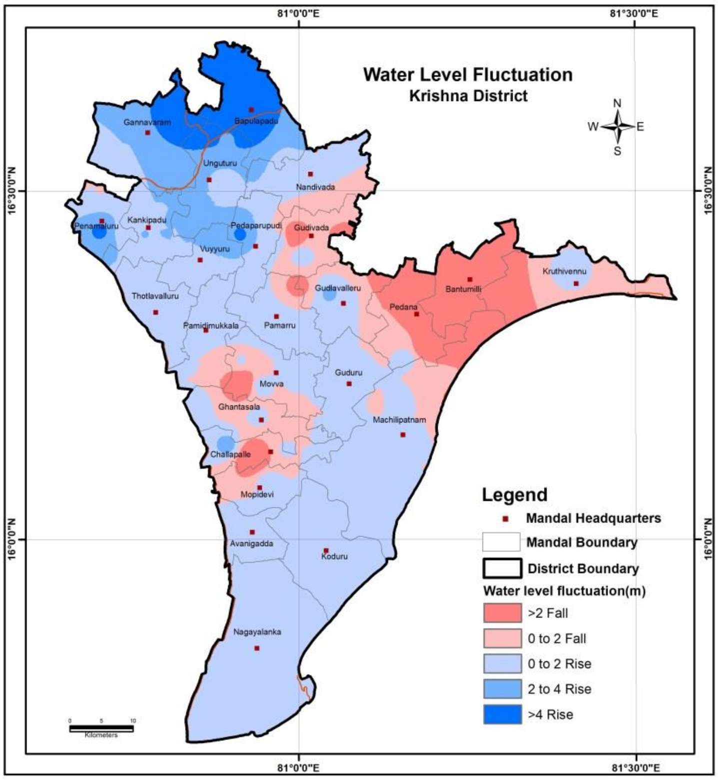

Fig: 3.3 Pre monsoon Water level in Krishna District

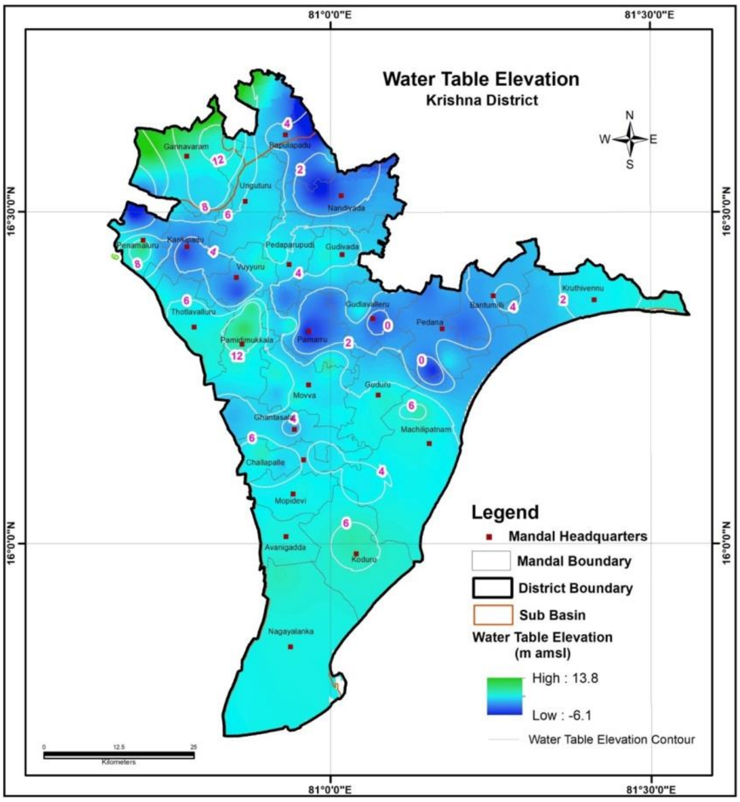

Fig: 3.4 Water table elevation in Krishna District

3.1.4 Long term water level trends :

Long term water level data of shallow aquifer indicates that, the water levels in general is stable. The details of the trend analysis and few hydrographs are presented in the Table-2 and Fig. 25 respectively. The trend of ground water levels by considering the pre and post monsoon seasons' data it is observed that decline in the range of 0.003 to 0.091 m/year and 0.001 to 0.090 m/year respectively, whereas rise observed in the range of 0.002 to 0.132 m/year and 0.0004 to 0.129 m/year respectively. The magnitude of trend values indicates that significant change is not occurred in the ground water scenario except at few places.

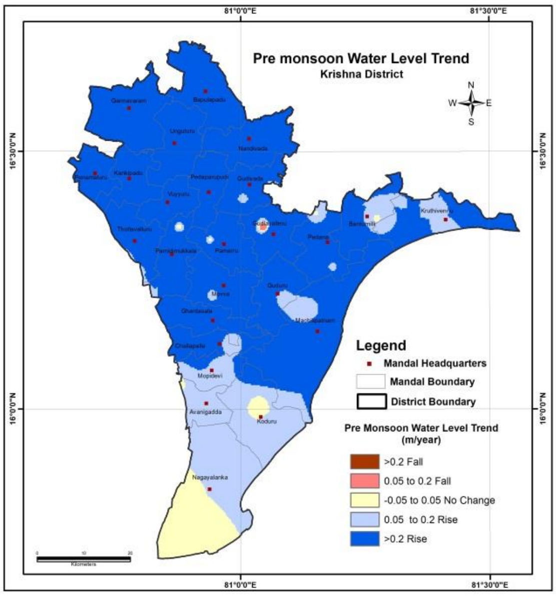

Fig: 3.5 a Premonsoon Waterlevel trend

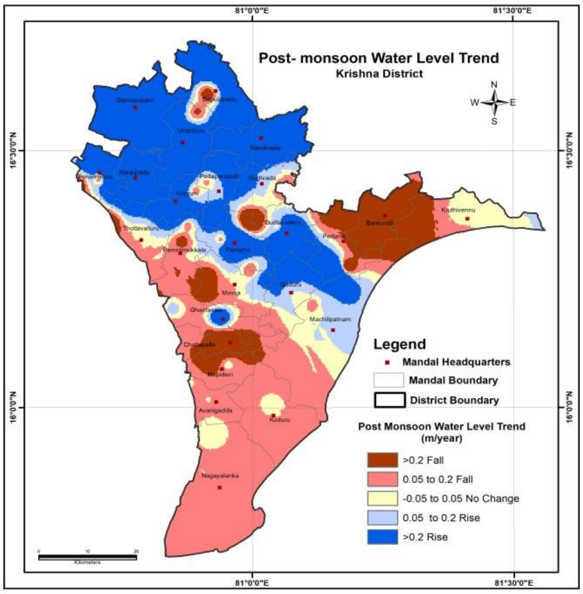

Fig: 3.5 b Postmonsoon Waterlevel trend

3.2 Ground Water Quality

In order to understand the quality of ground water in the area, the chemical quality data of the ground water samples from the aquifers during pre monsoon period (2022) is utilized for the study.

Classification of Ground Water: The analytical data of water samples were plotted on Piper's Trilinear diagram for Geochemical classification of waters. From the figures it is evident that the ground water at major part of the area is Mixed and NaCl type.

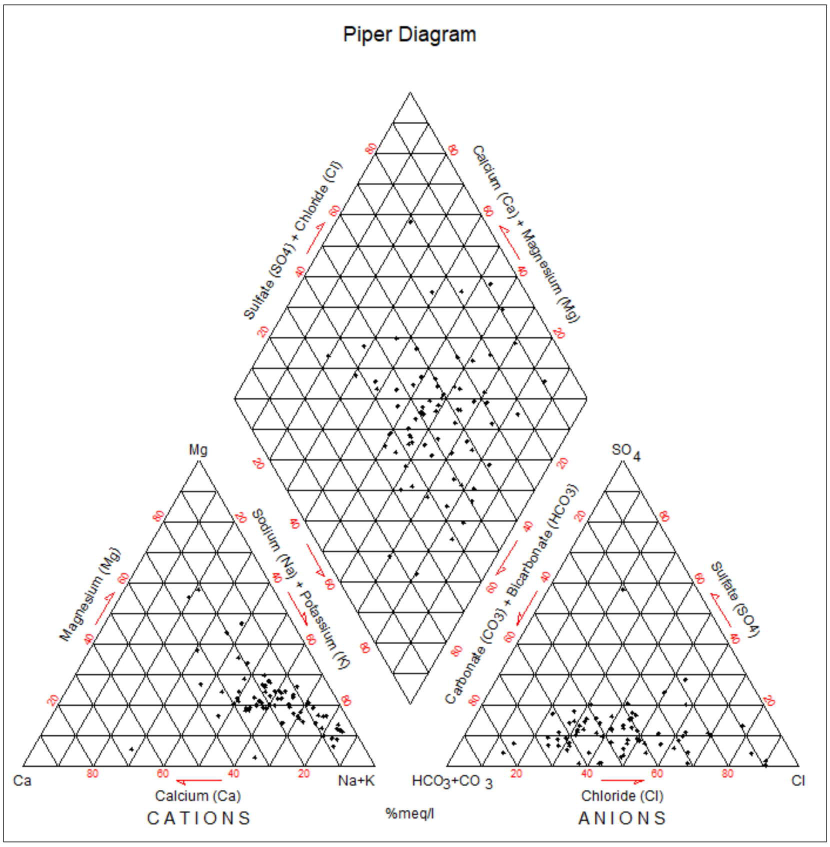

Fig:3.6 Piper plot

Suitability of Ground Water:

Finding the suitability of water for various uses is important as its quantity. The criteria for judging the water quality vary with the purpose. There are different criteria for the same purpose depending upon the country, climatic conditions, soil conditions and other local parameters. Therefore, it should be clearly understood that the suitability of water is relative concept, not an absolute reference. The temperature of shallow ground water is controlled a large extent by the atmospheric temperature. The range of temperature in the study area is from 28° C to 31° C. The ground water temperature is lower than atmospheric temperature. The pH values of ground water in the study area are ranging in general between 7.5 and 8.0 indicating that water is alkaline. Electrical Conductivity is the ability of a substance to conduct the electric current. In water, it is the property caused by the presence of various ionic species and in general indicator of water quality in relation to inorganic constituents. EC distribution map for pre-monsoon period was prepared for the study area and presented as Fig. 29. The EC distribution map reveals that in major portion of the study area EC values >3000 micro siemens/cm at 25°C except in the northern and southern part. The fluoride content in the ground water of the study area is ranges between <1.5 in all the places except one location. In general nitrate content in the ground water of the area is < 45 except at 3 places where it is recorded up to 150 mg/l.

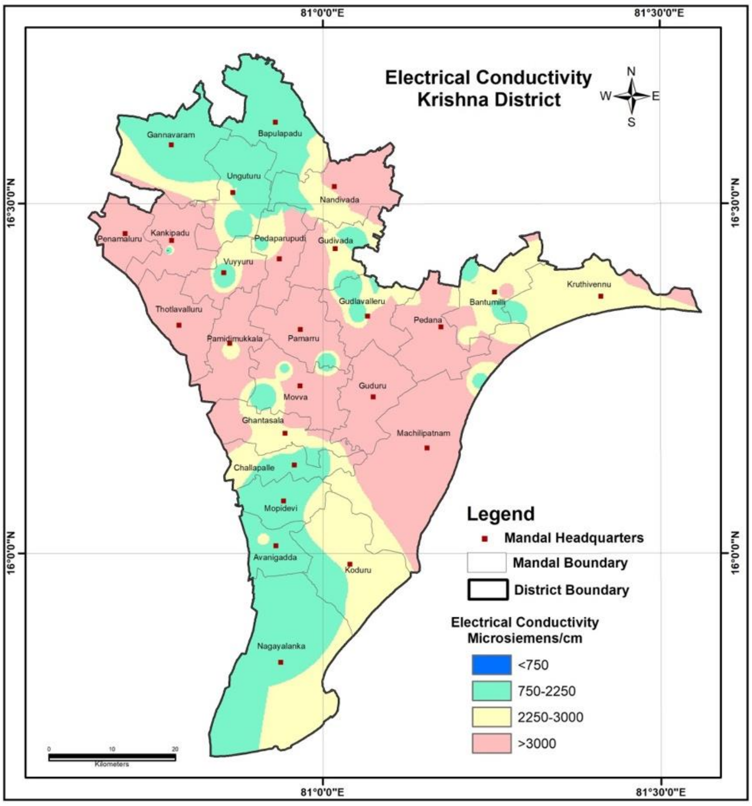

Fig:3.7 Electrical Conductivity

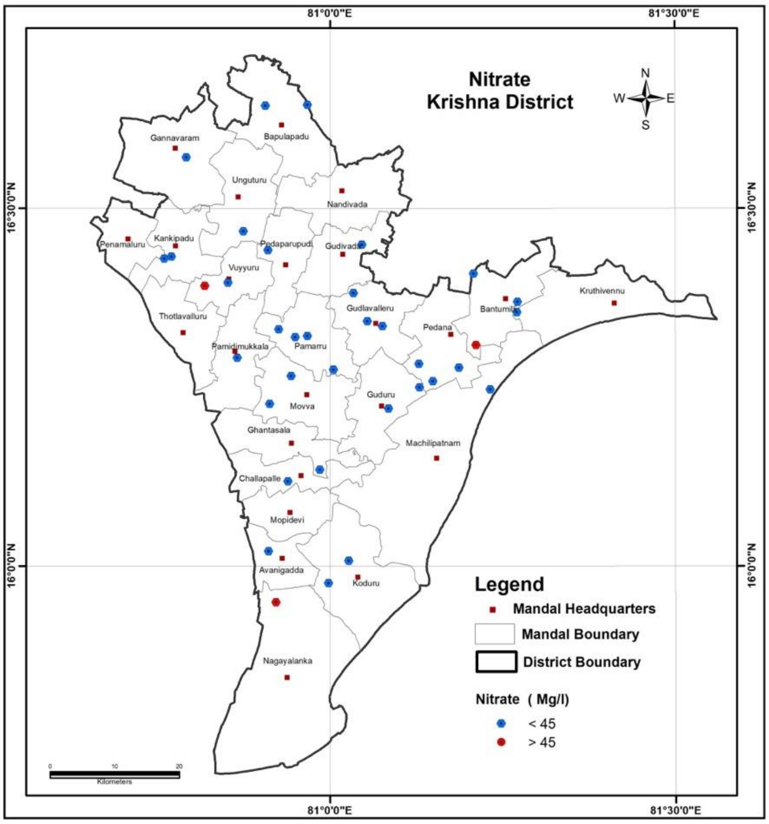

Fig:3.8 Nitrate distribution

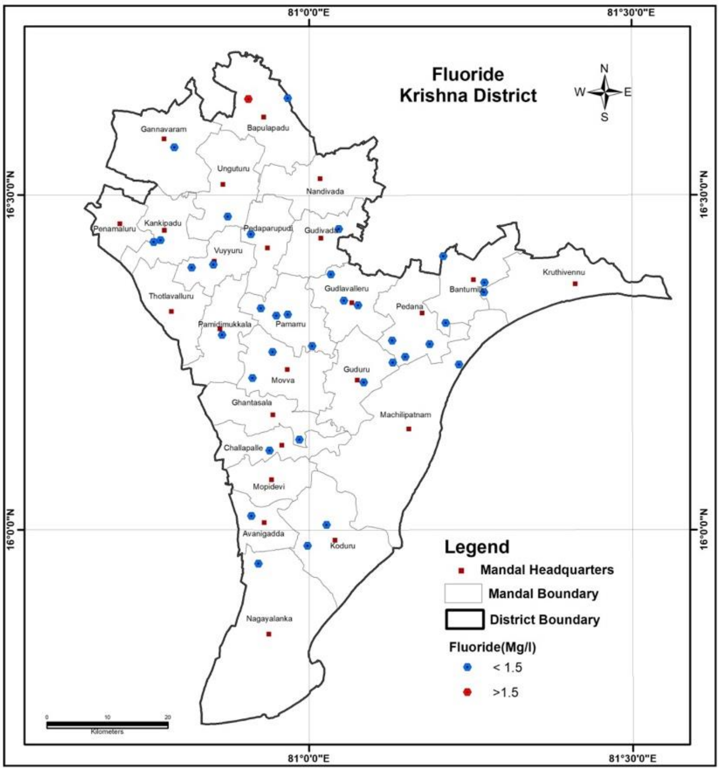

Fig:3.8 Flouride distribution

Suitability for Domestic Purpose :

Suitability of ground water from shallow aquifers of the study area for domestic purpose is examined on the basis of norms of Indian Standards for drinking water recommended by WHO/ BSI. The average concentration and variation of different chemical constituents present in ground water of study area along with the specifications of drinking water are presented in Table-3. In general, the quality of ground water from shallow aquifers in the area is potable except the area near coast and eastern part of the area where EC and Chloride values are more than permissible limits

Suitability for Irrigation Purpose

Suitability of ground water from the aquifers in the area for irrigation purpose has been insinuated by USSL diagram (Fig. 3.8). Majority of the water samples are varying from high Salinity - low Sodium hazard (C3S1) to very high Salinity – medium Sodium hazard (C4S2). High Salinity and low to medium sodium hazard water may be used for irrigating salt tolerant crops with adequate drainage system and with special amendments like applying gypsum and organic matter.

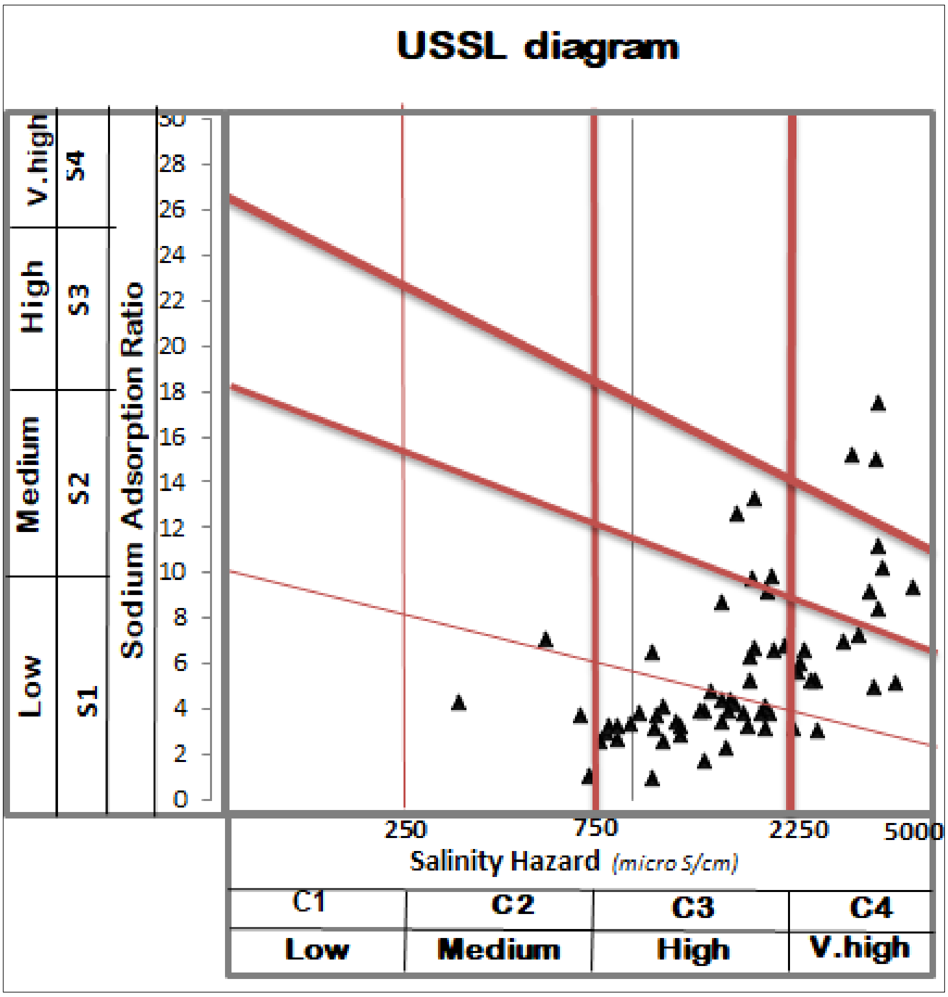

Fig:3.8 USSL Diagram

3.3 AQUIFER MAPPING

Hydrogeological Studies

Hydrogeologically, the formations in the district are classified as consolidated (Hard), semi-consolidated (Soft) and unconsolidated (Soft) formations. The consolidated formations include crystallines (Khondalites, Charnockites and granitic gneisses). The semi consolidated formations are represented by Tertiary formations (Rajahmundry & Gollapalli sandstones) and unconsolidated formations comprise deltaic alluvial deposits of Quaternary period. Hydrogeological map of the area is presented as Fig. 3.9

Ground Water in alluvium occurs under unconfined conditions in shallow aquifers, whereas confined conditions in the deeper aquifers. Buried/Paleo channels existing in the area are promising potential zones. Overall, the ground water development is insignificant in the area. Shallow aquifer is being tapped by dug wells and by filter points/ shallow tube wells in the area. Ground water is being used as and when required particularly during canal closure times for raising seedbeds and where canal water cannot reach to some extent in the high level patches.

The depth of open wells generally ranges from 3 to 12 m bgl and the depth of tube wells/ filter point wells ranges from 10 to 25 m. In the areas near coast, wells are restricted 3 to 4 m. The yield of the wells varies in between 5 and 15 lps. Transmissivity values are varying from 250 to 6200 m2/day. The ground water extraction from sandstone formations is limited to the area around Chebrolu i.e., in north western part of the delta. Ground water occurs under water table and semi confined conditions. The ground water is being tapped by dug wells and tube wells. The depth of dug wells varies from 5 to 18 m bgl whereas the tube wells are in the range of 30 to 60 m bgl. The yield of tube wells ranges from 28 to 1300 lpm.

Rainfall, canal system and the river Krishna are the main source of recharge. The fresh ground water is limited to shallow aquifer. The depth of these fresh water shallow aquifers varies considerably from place to place. The exploratory data reveals that the thickness of this aquifer is restricted to a maximum depth of 35 m. The deeper aquifers are not being tapped as the quality of the water is saline except in the northern part of the area in the near vicinity of the river Krishna. In the deltaic area in general, the deeper alluviual aquifers contains saline water, even sandstone aquifers encountered below alluvium also yielded saline water except at few places. Ground water occurs in unconfined, semi-confined and confined conditions in the study area depending on the availability of impervious beds. In general, the first aquifer which is present up to a maximum of 35 m below MSL is unconfined whereas the deeper aquifers are confined in nature.

The hydrogeological studies reveal that the shallow aquifer is in unconfined condition and the deeper aquifers are confined in nature and the quality of the ground water in general deteriorates from shallow to deeper aquifers. These aquifers have been broadly grouped into three principal aquifers viz., Alluvium aquifers , Sandstone aquifers, Khondalite aquifers. The area has multi-layer aquifer system. Sub surface geology and hydrogeology have been synthesized based on the hydrogeological cross sections, and aquifer disposition is summarized in Table4. The Hydraulic parameters of Various Aquifers were statistically analysed and presented in the Table-5. The aquifer wise details are presented below.

Aquifers and their Characteristics in the area

Formation	Aquifer Type	Depth Range (m bgl)		PZ Head Range (m bgl)		Discharge Range (lps)		T (m^2/day) Range		Storativity Range		EC Range		Temp. Range	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Alluvium	C1	15	104	5.41	19.46	2.08	18	264	3051	2.93x10-4	5.3x10-2	550	26850	30.10	34.90
	C2	48	185	4.83	32.12	1.83	44	288	3520	2.3x10-4	3.74x10-3	800	19000	30.20	34.50
	C3	95	162	5.66	40.1	0.85	38	144	6000	2.21x10-5	5.5x10-2	454	29300	28.20	38.60
	C4	131	295	5.62	16.1	1.08	25.8	43	1969	3.56x10-5	2.14x10-2	893	27460	31.00	36.70
	C5	164	300	11.93	13.99	3	25	97	106			8560	31200	34.40	40.60
SST	C1	13	359	6.58	17.28	1.08	9.5	144	885	3.08x10-3		800	21100	31.10	34.90
	C2	81	400	4.41	13.99	25	35.4	106	429	2.22x10-4	2.3x10-4	2330	31200	31.00	42.20

Alluvium Aquifers

Aquifer I (Unconfined Aquifer - UC): Unconfined aquifer occurs in the entire area. This aquifer generally occurs down to a maximum depth of 35 m bgl. Based on the exploration data, depth to bottom of first aquifer/ unconfined aquifer is prepared and shown as Fig. 35. Depth to water level is < 1 m bgl to a maximum of 10 m bgl. The yield of the wells and Transmissivity (T) values varies from < 5 to 15 lps and 250 to 5500 m2/day respectively. Hydraulic Conductivity of the unconfined aquifer varies from 9 to 31m/day with a median of 15m/day whereas the Specific yield of this aquifer varies from 0.04 to 0.20 with a median of 0.13. The quality of the ground water is in general good(CGWB,2021).

Aquifer II (Alluvium: Confined Aquifer – C1): The top of the aquifer is found in depths of 15 to 60 m below surface. Maximum depth to bottom of second aquifer is 104 m bgl. Depth to piezometric surface ranges between 5.41 and 19.46 m The yield ranges from 2 to 18 lps. Transmissivity values are in the range of 264 to 3051 m2/day. The Hydraulic Conductivity of the Confined aquifer C1 varies from 9 to 122m/day with a median of 21m/day whereas the Specific Storage of this aquifer varies from 5.33X10-6 to 2.12X10-3 with a median of 2.19X10-5. EC values ranges from µS/cm at 25°C (CGWB,2021).

Aquifer III (Alluvium: Confined Aquifer – C2): This aquifer is found at depths between 48 and 185 m below surface, and its thickness ranges from 13 m to 90 m. Depth to piezometric surface ranges between 4.83 and 32.12 m (Fig. 38). Discharges of the wells tapping this aquifer ranges from < 2 to 44 lps. Transmissivity of the aquifer is ranges from 288 to 3520 m2/day. The Hydraulic Conductivity of the Confined aquifer C2 varies from 9 to 61 m/day with a median of 13 m/day whereas the Specific Storage of this aquifer varies from 5.00X10- 6 to 5.10X10-5 with a median of 7.95X10-6. EC values are in the range of 800 to 19000 µS/cm at 25°C(CGWB,2021)).

Aquifer IV (Alluvium: Confined Aquifer – C3): The thickness of the Alluvial confined aquifer – C2 varies from 18 to 93 m. The piezometric head is in the range of 5.66 to 40 m bgl (Fig. 40). The yield of the wells constructed in this aquifer varies from < 1 to 38 lps, whereas T is in the range of 144 to 6000 m2/day. The Hydraulic Conductivity of the Confined aquifer C3 varies from 3 to 66m/day with a median of 17m/day whereas the Specific Storage of this aquifer varies from 3.95X10-7 to 4.89X10-5 with a median of 7.59X10-6. EC is in the range of 450 to 29300 µS/cm at 25°C at 25°C (CGWB,2021).

Aquifer V (Alluvium: Confined Aquifer – C4): This aquifer occurs at depths from 131 to 267 m below the ground level. The thickness varies from 20 to 74 m. Depth to piezometric surface varies from 5.62 to 16 m bgl (Fig. 42). Discharges of the wells constructed in this aquifer varies from 1 lps to 25 lps and T ranges from 43 to 1969 m2/day. The Hydraulic Conductivity of the Confined aquifer C4 varies from 1 to 60m/day with a median of 7m/day whereas the Specific Storage of this aquifer varies from 1.11X10-6 to 6.48X10-4 with a median of 8.33X10-6. The EC values are in the range of 893 to 27460 µS/cm at 25°C (CGWB,2021)

Aquifer VI (Alluvium: Confined Aquifer – C5): Bottom most confined alluvium aquifers to explored depth of 300 m occurs at a depth from 164 to 300 m with a thickness of 14 to 81 m. The piezometric head is in the range of 11.93 to 13.99 m bgl and discharge varies from 3 to 25 lps. Transmissivity values are in the range of 97 to 106 m2/day. Temperature of ground water from this aquifer varies from 34.40 to 40.600C. The Hydraulic Conductivity of the Confined aquifer C5 is 2m/day and the Specific Storage of this aquifer is 4.35X10-6. The quality of ground water is saline in the entire aquifer, EC varies from 8560 to 31200 µS/cm at 25°C.

Sandstone Aquifers

Sandstone Aquifer (Confined - SC1): This sandstone aquifer occurs at different places at different depths varying from 13 to 283 m below the ground level and at places top of the sand stone aquifer recorded at deeper depths (Angaluru – 322 m and Mopidevi – 420 m). The thickness of this aquifer varies from 15 to 93 m. Depth to piezometric surface varies from 6.58 to 17.28 m bgl. The yield of the wells is in the range of 1 to 9.5 lps and T varies from 144 to 885 m2/day. The EC values of ground water vary from 800 to 21100 µS/cm at 25°C(CGWB,2021).

Sandstone Aquifer (Confined – SC2): The top of this aquifer occurs at depths from 81 to 289 m below ground level and at Angaluru it occurs at 363 m bgl. The piezometric head is in the range of 4.41 to 13.99 m bgl. Yield of the wells constructed in this aquifer is in the range of 25 to 35 lps. Transmissivity is varying from 106 to 429 m2/day and the EC of ground water is 32 in the range of 2330 to 31200 µS/cm at 25°C. The temperature of ground water is varying from 31 to 42.200C(CGWB,2021).

The aquifer wise information reveals that the most promising area for tapping ground water from deeper aquifers in general is north central parts of the deltaic area close to Krishna River sides. In the rest of the area ground water quality in general is saline in the deeper aquifers and the type of water as per the Piper's Trilinear diagram is Mixed and Na K – Cl type. Sandstone aquifers encountered below the alluvium are also yielding inferior quality of ground water except in the northern margin of the deltaic area (CGWB,2021).

Khondalitic Aquifers

Weathered Khondalites (Unconfined Aquifer-1): It consists of weathered residuum where ground water occurs under water table condition and is mainly developed by construction of dug wells or shallow bore wells. The shallow aquifer is considered up to the maximum depth of weathering and first fracture encountered (below weathered depth) generally down to ~30 m depth. They are unconfined aquifers. Ground water yield varies from 0.4 to 6.9 lps (avg: 3.6 lps) in weathered Khondalites.

Khondalites (Confined Aquifer-I1):

The aquifer-II is the deeper aquifer which tapped the fractured zone. Ground water in the second aquifer occurs under semi-confined to confined condition in the fractures upto the maximum depth of 180 m bgl (Deepest fracture encountered). The deth of fracturing varies from 25 m to 180 m with yield of <1 to more than 10 lps. The transmissivity of consolidated formation varies from <1 to more than 100 sq.m/day. The storativity varies from 4.84 *10-6 to 1.06*10-4.

3.3.2 Aquifer Disposition 3D and 2D

Conceptualization of hydrogeological model was carried out by interpreting and integrating available data for preparation of 3-dimentional maps, fence diagrams, panel diagrams and hydrogeological sections. Based on the available subsurface data geological model, hydrogeological cross sections and fence diagrams are prepared. The exploratory drilling within the explored depth of 600 m in Krishna deltaic area by CGWB revealed that the alluvium is underlained by sandstones at varying depths and at places directly by crystallines/ bedrock. In the area below alluvium, sandstone formations are encountered at shallow depth in the western and northern parts of the area, and towards south eastern parts and towards coast at greater depths. Subsurface configuration of the formations was studied through different geological cross sections. The location of exploratory wells and different geological cross section lines are shown as Fig. 3.10. 3D stratigraphic model for the area has been synthesized and shown in Fig. 3.11

3.1 Conceptualization of aquifer system in 3D

The detailed analysis of the data reveals that the alluvium is the principal aquifer system, which is underlain by sandstone aquifer, at places alluvium aquifer is directly underlain by crystallines in the area. Sandstone formations are exposed in the NE parts of the area limited to small area.

3–dimentional lithological model of the area is presented as Fig. 3.11. It clearly shows that the thickness of the alluvium increasing from north to south and west to south easterly direction. Based on the available hydrogeological data.. The perusal of the data indicates that there are multiple thick sand beds in the area with intervening thick clay beds. These sand beds which act as aquifers in the area and there are six distinct beds in alluvium which behave as regional aquifers. Whereas in sandstones two aquifers exist. Thin beds and pinched beds are neglected in making out the regional aquifer system as they are integral part of regional aquifer system in regional ground water flow. Hydro geologic sections are synthesized based on the lithological logs and electrical logs. Hydrogeological cross sections drawn along different directions of the area are presented as Fig. 3.12a to d. The study of the different sections indicate that the alluvium thickness is increasing from north to south and there are six aquifers exist up to a depth of 300 m in the Krishna deltaic area. At places aquifers of alluvium are underlain by sandstone aquifers. The shallow aquifer thickness is varying from place to place.

4. GROUND WATER RESOURCES (2022)

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 Krishna district is 1557 MCM. 9 mandals are saline mandals

Out of 25 mandals 16 mandals are safe and 9 mandals including Nagayalanka, Machilipatnam, Gudur (Krishna), Bantumilli, Kruthivennu, Nandivada, Gudlavalleru, Pedana, Koduru are saline(Fig 4.1)

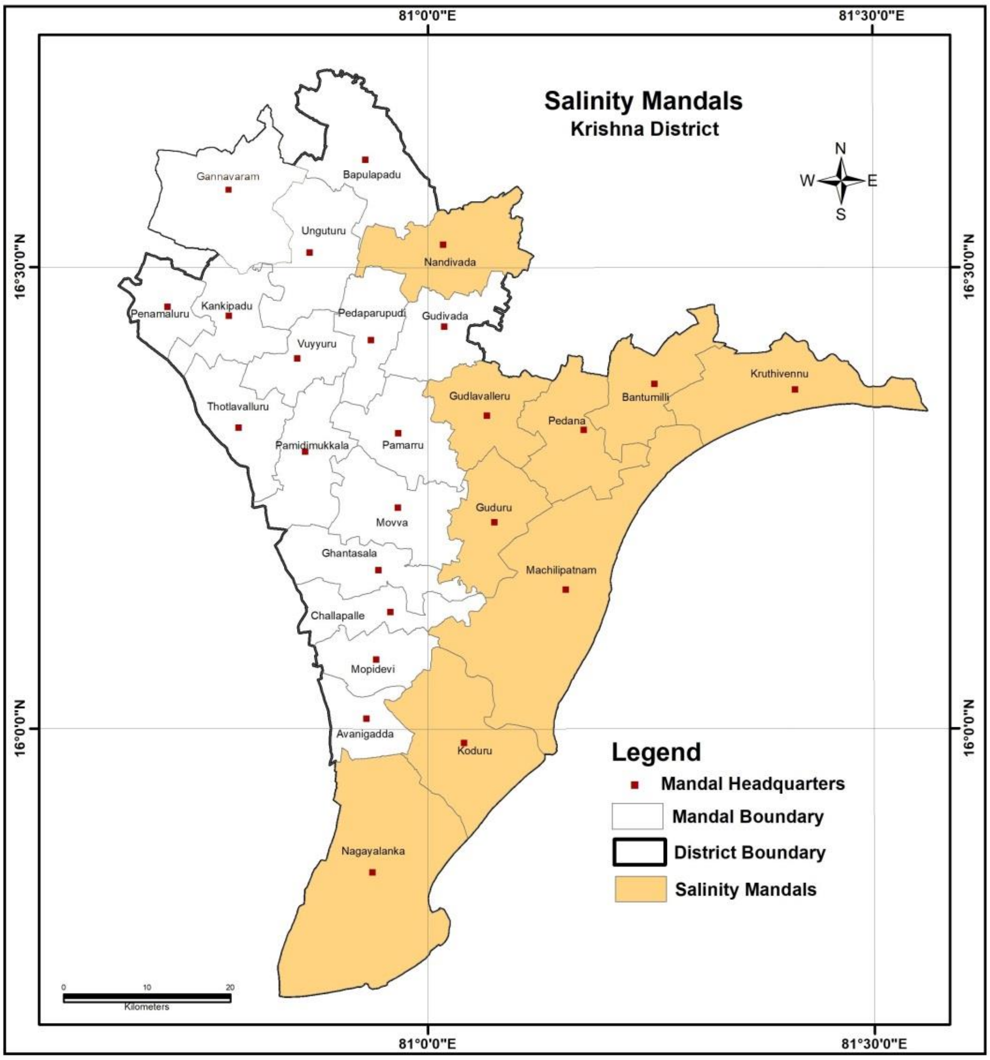

Fig 4.1 Saline Mandals

Table 4.1Ground water resources of Krishna District

Resources As per GEC 2022	MCM
Dynamic (Net GWR Availability)	**1557**
• Monsoon recharge from rainfall	271
• Monsoon recharge from other sources	974
• Non-Monsoon recharge from rainfall	7
• Non-monsoon recharge from other sources	387
Gross GW Draft	**431**
• Irrigation	398
• Industrial	13
• Domestic	21
Provision for Drinking and Industrial use for the year 2025	27
Net GW availability for future use	1120
Stage of GW development (%)	**28%**

5. GROUND WATER RELATED ISSUES

The Delta system has emerged due to the depositional cycles of the River Krishna, debouching the inland sediments into the Bay of Bengal. On the southern side the delta is bounded by the Bay of Bengal and on the other two sides the delta is bounded by land. Therefore, along the coastal area the action of the saline water is predominant. Since the area is just few meters above mean sea level with very low gradient and large quantum of water from the river Krishna and canal system are applied from landward side on one hand and on the other hand it is bounded by the large saline water body in the form of Bay of Bengal, naturally problems like water logging, in situ ground water salinity and saline water intrusion etc., are of great concern. During the last two decades with the advent of prawn culture some of the paddy fields have been converted into tanks for growing the prawns and salt water fish. This took place mostly in the areas along the coast where water is available with the required degree of salinity from the drains/creeks or groundwater by means of filter point/shallow tube wells.

The major considerable ground water issues in the Krishna delta are:

- Water Logging
- Ground Water Salinity
- Impact of Aqua Culture on Ground water Reservoir in respect of salinity and contamination due to Aqua feed and Medicinal chemicals

Water Logging:

Water logging is a common feature in irrigation commands of surface water projects. Krishna deltaic area is not an exceptional one. The DTW maps reveal that an area of about 50km^2(7%) is under water logged condition during pre-monsoon period, whereas during post-monsoon period it is extended to 4,80km^2 (6%). The area prone to water logging during pre-monsoon and post-monsoon periods is 3,0km^2 (41%) and 1,30 km^2 (18%) respectively. Irrigation by surface water, minimal withdrawal of groundwater, flat topography, high rainfall, poor drainage and nature of soils are responsible for the water logging conditions in the area

Ground Water Salinity:

In Krishna Delta, ground water in shallow aquifers is fresh except in the area near the coast and as isolated patches in inland, whereas in the deeper aquifers ground water is invariably saline. The origin of the salinity in any coastal area can be due to the following three reasons viz., palaeo salinity, due to leakage from the bottom aquifer, direct recharge of saline water from back waters and due to sea water intrusion caused by human activity. Based on the studies carried out by CGWB, the origin of salinity in the unconfined aquifer is discussed in the following paragraphs.

Paleo Salinity: By paleo salinity, it is indicated that the ground water being extracted from the aquifer today is the entrapped water in the geologic formation at the time of deposition. By studying the strand lines in the Krishna delta, it can be understood that most of the delta is under sea in the geological past. If the ground water in Krishna delta is paleo water, the salinity of the ground water in the past, due to marine regression and land upliftment, should be highest and year by year as it is being recharged by the rainfall and canal water, the salinity should follow a declining trend. In the first instance most of the saline water would have drained because of the rejuvenated hydraulic gradient. But the study reveals that the salinity in the area is not uniformly decreasing day by day. Instead, it is varying depending on the ground water being abstracted in the area. This may be leading to change in hydraulic gradient and inducing flow either from the bottom aquifer or from the sea. The salinity was also observed to have a relationship with the proximity to sea. Hence it can be safely concluded that the salinity in the unconfined aquifer in Krishna Delta is not of palaeo salinity.

Leakage from Bottom Aquifer: The Krishna Delta has five aquifers up to a depth of 30m bgl and the top one is up to maximum of 35m bgl and is unconfined in nature and has fresh water. The other four aquifers are saline in nature. The second aquifer which exists in between 15m and 140m bgl is in confined condition and is saline. Normally, in multi aquifer systems, it is possible that the second aquifer may not be fully confined and there exists a flow or leakage between the top unconfined and the bottom (semi) confined aquifer. But long duration pumping tests conducted on well fields by CWBG in the delta indicate that the second aquifer in this area is fully confined and the intervening clay bed is an aquiclude. Pumping one aquifer does not show any reflection in the other aquifer. In this situation, it can be safely concluded that the salinity in the unconfined aquifer cannot be due to the vertical flow of the saline water from the bottom aquifer.

Sea Water Intrusion: The first and foremost indicator of sea water intrusion is reversal of hydraulic gradient and hence there should not be any fresh ground water discharges into the sea. In normal course, the ground water from the aquifer will have a positive hydraulic gradient which is towards the sea and discharges directly onto sea bed. Hence as long as there are fresh water discharges into sea, it can be stated that there is a fresh water lense floating over the bottom saline water in the area and full encroachment by sea water is not present in the area. In Krishna Delta, the fresh water discharges into sea were computed as 1,02,842 m^3/day and 1,03,162 m^3/day during the pre and post monsoon seasons respectively. Because of the human activity, e.g. ground water withdrawal, when the fresh water head falls below mean sea level and reversal of gradient takes place, then the saline sea water flows into the coastal aquifer by contaminating the aquifer permanently and there will not be any fresh water discharges into the sea. The toe of the interface also starts moving towards the land. This type of situation is not present in Krishna Delta as there are huge ground water discharges into the sea at present. But even though there are fresh ground water discharges in to the sea, there is a possibility that the diffusion zone of the saline-fresh water interface interferes with the pumping water level in turn deteriorating the quality of ground water.

Apart from the indicators already studied such as electrical conductivity, Chloride concentration, etc., there are certain ratios which indicate the presence of sea water in ground water viz. Calcium - Bicarbonate, Sulphate ratio, Calcium- Magnesium ratio, Chloride-Carbonate ratio, Sodium-Chloride ratio and Boron-Chloride ratio. These ratios also indicate there is small area near the coast which is influenced by saline water.

Direct Recharge of Sea Water from Back Waters:

When the river flows are reduced to bare minimum, there is a possibility of either direct recharge from the river bed or there may be a river recharge as the ground water heads are already below the river stage/bed. Because of which the base flow component is also considerably reduced. The ground water in this aquifer is fresh except in the central portion near the creek, also indicates that the back waters in the Krishna delta has an important role in contaminating the ground water apart from the contamination due to sea water ingress.

Status of Sea Water Ingress in the Unconfined Aquifer:

Groundwater in the coastal aquifers exists in hydraulic connectivity with the sea water. Hence the situation is very delicate and requires a precise management strategy to obstruct the sea water intrusion or upcoming which will either permanently or temporarily deteriorate the ground water quality in the aquifer or in the well. All these possibilities of this type of pollution are inadvertently from the activities of human beings. Normally the natural flow of ground water is towards the sea with the decreasing head towards the sea. As long as there is no ground water abstraction in any coastal aquifer the hydraulic gradient is maintained at the maximum and the ground water discharges into the sea are at the maximum. Once the human activity of ground water withdrawal starts, the hydraulic head starts decreasing resulting in the decrease of the ground water discharges into sea. The situation induces the fresh water - saline water interface starts its journey towards the water table and depending on the quantum of abstraction, fresh water head above mean sea level and the upcoming effect starts interfering with the quality of the water being pumped. When the withdrawal increases abundantly, the hydraulic head diminishes to a situation when reversal of hydraulic gradient occurs making the aquifer fully saline.

The quality of ground water in the unconfined aquifer in the Krishna Delta was studied to find out the status of sea water ingress in the area. The unconfined aquifer in this area is up to ~ 35m below msl and the ground water in this aquifer is fresh except in the areas near to the cost particularly near to creeks. This indicates that the back waters in the Krishna delta have an important role in contaminating the ground water apart from the contamination due to sea water ingress. This also was confirmed by other indicators as well. Hence there is a need for proper monitoring of the Saline water - Fresh water interface in the area by establishing purpose-built piezometers with a predefined monitoring parameters of level and quality with reference to depth

Even though the problem today is limited to a few kilometres from the coast, there is a problem lurking behind that the situation may be worsened in future for the other areas as well. Hence there is a need for proper planning for utilizing the ground water resources in the full extent of coastal aquifers during the water stress periods without allowing the fresh water – saline water interface intersecting the pumping water levels. There is also an urgent need to establish the minimum surface water flow in Krishna River such that the saline water recharge is minimum. To attain this, a provision may be made from the interbasin transfer of Godavari river water from the Polavaram/ Pattiseema Lift Irrigation Project for protecting the bare minimum environmental flow of the river Krishna as well as other creaks in the system.

The detailed studies reveal that the area covered by poor quality ground water in the Krishna delta is exist during pre-monsoon period in the area along coast and some patches in inland, whereas during post-monsoon period it is reduced. It is evident from this that as soon as water released into canals for irrigation and after rainfall the increase in the ground water head is temporarily pushing the fresh water – saline water interface towards sea making a large fresh water lens, hence the area is getting reclaimed naturally to some extent.

In this scenario the problem of salinity in the areas near to coast, it is not a serious issue as the present cropping pattern being of semi-tolerant type i.e., Paddy, Coconut, Banana etc. Inland salinity in certain patches in eastern part of the delta mainly due to the direct recharge of saline water through creeks (Upputeru) and some contribution may be from the aquaculture activities.

It is reported that there is no reduction in crop yields and other problems due to water logging and salinity in the area. As the command area is in operation for long period, if there is any problem of significant increase of salinity/water logging in the area, by now the quality of the shallow aquifer should have been deteriorated.

Impact of Aqua Culture:

In coastal tracts and in the vicinity of the Kolleru Lake and other parts of the area, there has been enormous growth of aqua culture farming during the last two decades. This includes prawn culture and pisciculture. Brackish water from ponds, creeks is generally used in prawn cultivation. The availability of brackish water through tidal creeks as well from the ground water sources in this area facilitates aquaculture growth. Realizing this, palaeo mudflat zones, which are traditionally under paddy crop, are also being converted in to aquaculture in the recent years. Lot of brackish water is pumped from tidal creeks and after use it is released on land surface. In aquaculture, lot of organic feed as well as chemicals are being applied, due to this the drains carry high level saline water, organic content and nutrients, this causing the pollution of shallow aquifers and disturbs the eco system. Further, storing of water in the tanks at higher than specified levels is leading to water logging in the neighboring areas.

MANAGEMENT PLAN

The Problems in the Krishna district can be summarized as below:

- Limited utilization of fresh ground water resources
- Quality deterioration due to sea water intrusion
- Quality deterioration due to aqua culture
- Quality deterioration due to direct recharge of saline water
- Uncontrolled pumping through filter points during periods of less surface water availability.
- Water Logging

Management Plan for the areas where limited utilization of fresh ground water resources:

When surface water is available plenty, normally people will not extract ground water for any purpose. But it should be encouraged so that the available surface water can be utilized in the tail end areas. Unless and until people understand the aquifer disposition and availability of fresh ground water in the aquifers, they may fail in tapping the available fresh ground water. Hence for encouraging farmers for utilizing the fresh ground water resources, awareness campaigns are to be organized to educate the farmers about the aquifer disposition and the bottom of first aquifer in the area which is containing fresh water so that the depth of the filter points should be limited to the bottom of fresh unconfined aquifer in the area and availability of fresh ground water resources.

The available fresh ground water may be encouraged to be extracted along with usage of surface water through planned conjunctive use in space and time. One option can be limiting surface water for the tail end areas and encouraging ground water Usage in upper and middle reaches. It can also be attempted that the Government can extract ground water through a network of filter points preferably in the shallow water table areas and supply the water through the canal system for irrigating the lower command. The surplus surface water will lead to enhanced command/ gross irrigated area. This can lead to less extraction of ground water near the sea because of availability of surface water in tail end areas i.e., near the sea.

This in turn reduces the possibility of sea water intrusion in the tail end areas because of the reduction of pumping

Every year excess surface water and ground water available for future irrigation and Industrial needs can be utilized for recharging the deeper aquifers in the recharge area of these aquifers. This will in turn make the deeper aquifers fresh in due course and these can be used as sanctuaries and these resources can be used for domestic needs in severe drought conditions in the delta.

Management Plan for the areas, where quality deterioration due to sea water intrusion.

In the area where already sea water intrusion is taking place and is observed by quality deterioration, top priority should be given for supplying surface water for the gross irrigated area in the tail end areas of the command so that the ground water extraction is reduced and in turn sea water intrusion and quality deterioration is controlled. There should be strict Implementation of Ban on Pumping in the areas which are near vicinity of the sea and also pumping from the first two aquifers for the purpose of Aquaculture Artificial Recharge Measures should be practised in upper reaches such that the ground water head is always 2m above mean sea level which in turn maintain the natural hydraulic gradient towards sea.

Management Plan for the areas where quality deterioration due to aqua culture is taking place:

For controlling quality deterioration due to Aquaculture, Aqua Culture activities should not be encouraged beyond 2kms from the coast and also strict ban on pumping from the first two aquifers for the purpose of aquaculture.

Management Plan for the areas where quality deterioration due to direct recharge of saline water is taking place:

Direct recharge from sea water is possible where the back waters are reaching areas beyond 2kms from the coast and the same water is used for spreading in the ponds for aqua culture and pisciculture. The back waters available in the creeks should be arrested beyond 2kms from the coast by maintaining the flows in the creek either from direct river water or drain water from the irrigation canals. This can also be achieved by making a provision from the inter basin transfer of Godavari river water from the Ploavaram/ Pattiseema Lift Irrigation Project for protecting the bare minimum environmental flow of the river Krishna as well as other creaks in the system.

Aqua Culture encouraged beyond 2kms from the coast.

This problem can also be solved to some extent by installing coastal/tidal regulators on the creeks to arrest the back waters. As the creeks in most of the area are used for navigation by the fishing industry, it is required to install navigable coastal regulators i.e., regulators with gates, which can stop the flow of back waters and at the same time it will not disturb the navigation through the channel when required.

Management Plan for the areas where uncontrolled pumping through filter points during periods of less surface water availability:

As this problem exists only in case where surface water is not available in the area, top priority should be given for providing surface water for the gross irrigated area in the tail end areas of the command. Based on the availability of surface water, ground water in the upper reaches should be pumped into the canal network such that there should not be a need for pumping in the tail end areas. Strict ban on Pumping in the areas which are less than 2kms from the sea. Artificial Recharge measures should be encouraged to be practiced in upper reaches such that the ground water head is always 2m above MLS.

Management Plan for the areas which are waterlogged or prone to water logging:

For the water-logged areas, Ground water extraction should be encouraged through conjunctive use in space and time. Pumping the ground water through a network of filter points and pump the water in the canals for catering the irrigation needs of the lower reaches of the command. There should be strict Implementation of Ban on Surface Water Supply for Irrigation and Industrial purpose in these areas.

Acknowledgment

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