केन्द्रीय भूमि जल बोर्ड

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

भारत सरकार

Central Ground Water Board
Department of Water Resources, River
Development and Ganga Rejuvenation,
Ministry of Jal Shakti
Government of India

AQUIFER MAPPING AND MANAGEMENT OF GROUND WATER RESOURCES

Krishna Deltaic area (Parts of Krishna and Guntur Districts), Andhra Pradesh

दक्षिणी क्षेत्र, हैदराबाद
Sourthern Region, Hyderabad

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

CENTRAL GROUND WATER BOARD

REPORT ON

AQUIFER MAPPING AND MANAGEMENT PLAN OF KRISHNA DELTAIC AREA (PARTS OF KRISHNA AND GUNTUR DISTRICTS), ANDHRA PRADESH

By

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AQUIFER MAPPING AND MANAGEMENT PLAN OF KRISHNA DELTAIC AREA PARTS OF KRISHNA AND GUNTUR DISTRICTS, ANDHRA PRADESH

Area at a Glance

1	Districts Area Location	:	Parts of Krishna and Guntur of Andhra Pradesh 7,278 Km^2 15° 42' to 16° 41' N 80° 07' to 81° 33' E
2	Mandals Villages	:	56 (Full = 45, Part = 11) 831
3	State	:	Andhra Pradesh
4	Normal Rainfall (mm)	:	690 – 1230 mm Monsoon : ~ 68% Non-Monsoon: ~ 32%
5	Major Drainage	:	Krishna
6	Gross area Irrigated	:	5,04,877 ha Major crop: Paddy Irrigation is mainly based on surface water
7	Ground water levels		DTW: < 1 - 10 m bgl Piezometric Head: < 5 to 40 m bgl
8	Aquifer - characteristics	:	Principal Aquifer: Alluvium underlain by sandstone. Multi-layer Aquifer System (6 aquifers up to 300 m depth) Shallow Aquifer: Yield = < 5 – 15 lps Deeper Aquifers: Yield = 1 to 44 lps
9	Ground water Resources (MCM)	:	Dynamic Resources: • Net GW availability : 2001 • Gross GW draft : 389 • Stage of GW Development : 19% • Category : Safe
9	Chemical quality of ground water	:	• Shallow Aquifer: In general, Good • Deeper Aquifers: In general Saline
10	Major Ground Water Issue	:	• Ground Water Salinity • Aquaculture • Water Logging

Executive Summary

The Krishna Delta is one of the major delta systems along the east coast of India covering an area of 7,278 km^2 in Krishna and Guntur districts of Andhra Pradesh. It has a coast line of about 246 km. The area is served by Krishna canal system and other drains. The altitude varies from 1 m near coast to 12 m above MSL in the upper reaches of the area. The area is mostly agrarian. The delta soils are most fertile. In deltaic alluvium two crops are harvested every year. Paddy and sugarcane are extensively raised on these lands. The Krishna Delta Irrigation Project is the major irrigation project 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 pisciculture in this area is practised in 58,634 hectares in Guntur (7,826 ha) and Krishna (50,808 ha) districts.

The area is mainly underlain by the recent to sub-recent alluvium comprising Sand, Gravel, Clay and Silt. The area has multi-layer aquifer system. Alluvium is the principal aquifer, which is followed by sandstone aquifer. Six aquifers exist up to a depth of 300 m in alluvium, whereas two aquifers exist in sandstone. The shallow aquifer (UC) is limited in thickness and varying between <10 m to 35 m bgl. and is being tapped by dug wells, filter points/ shallow tube wells and the depth of the wells generally ranges from 3 to 12 m and the yields are up to 15 lps. The deeper aquifers are (C1, C2, C3, C4 & C5) are in confined conditions and not being tapped as the quality of the water is saline except the areas in the northern part of the area in the near vicinity of the river Krishna. Over all, the ground water development is low in the delta area and being developed as and when need arises.

In general, ground water levels in shallow aquifer are < 6 m and < 4 m during pre-monsoon and post monsoon seasons respectively. No significant changes exist in the long-term water level trend. Piezometric head in deeper aquifers is varying from < 5 m to 40 m bgl. The variation in ground water quality in the area is observed in space and time. The quality of ground water in shallow aquifers is fresh except the area near coast, where as the deeper aquifers in general are saline. Sandstone aquifers encountered below the alluvium are also inferior in ground water quality except in the northern margin of the deltaic area. The occurrence of deeper fresh water aquifers all through or at any depth are restricted up to 1st strandline. Net

ground water availability is 1998 MCM and the stage of development is 19%. The hydraulic gradient is towards sea and the fresh water discharges into sea were computed as 102284 m^3/day and 103216 m^3/day during the pre and post monsoon seasons respectively.

An area of 500 km^2 (7 %) and 4800 km^2 (66%) under water logged condition during pre-monsoon and post monsoon periods respectively. Whereas the area prone to water logging is 3000 km^2 (41 %) and 1300 km^2 (18 %) during pre-monsoon and post monsoon periods respectively. Ground water salinity problem in shallow aquifers exist mainly in the coastal area and some inland pockets area. Sea water intrusion is observed at few places in the coastal area due to the exploitation of ground water during water scarce periods. The quality of ground water is getting deteriorated due to aquaculture activities particularly in the area near the coast.

The Management Plans include proper monitoring of the saline water - fresh water interface by establishing purpose-built piezometers with predefined monitoring parameters of ground water level and quality with reference to depth. In the area along the coast, it is very much essential to demarcate the dynamic boundary of saline and fresh water interface and proper measures should be taken up, to restrict the interface below the maximum pumping water level. Navigable coastal/tidal regulators may be installed on the creeks to check the quality deterioration where the direct recharge of saline water is taking place due to back waters. Conjunctive use of surface water and ground water should be adopted to minimize the water logging problem. Excess surface water to be utilised for recharging the deeper aquifers in the recharge area of the deeper aquifers to make them 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. Existing regulations must be adhered strictly to avoid ecological imbalances and environmental problems arise due to aquaculture.

REPORT ON

AQUIFER MAPPING AND MANAGEMENT PLAN OF KRISHNA DELTAIC AREA PARTS OF KRISHNA AND GUNTUR DISTRICTS, ANDHRA PRADESH

1. INTRODUCTION

Aquifer mapping is a process wherein a combination of geologic, geophysical, hydrologic and chemical analyses is applied to characterize the quantity, quality and sustainability of ground water in aquifers. In recent past, there has been a paradigm shift from "groundwater development" to "groundwater management". As large parts of India have become water stressed due to rapid growth in demand for water due to population growth, irrigation, urbanization and changing life style. Therefore, in order to have an accurate and comprehensive micro-level picture of groundwater in India, aquifer mapping in different hydrogeological settings at the appropriate scale is devised and implemented, to enable robust groundwater management plans. This will help in achieving drinking water security, improved irrigation facility and sustainability in water resources development in large parts of rural and many parts of urban India. The aquifer mapping program is important for planning suitable adaptation strategies to meet climate change also. Thus, the crux of National Aquifer Mapping (NAQUIM) is not merely mapping, but reaching the goal-that of ground water management through community participation.

In view of the above challenges, an integrated hydrogeological study was taken up in the Krishna deltaic area covering parts of Krishna and Guntur districts of Andhra Pradesh by AP SUO, Visakhapatnam during AAP 2019-20. The main objective of the study is to prepare aquifer maps and to suggest ground water management plans of the area.

Study Area:

The Krishna Delta is one of the major delta systems along the east coast of India. The river Krishna is dividing the area into two units viz., Eastern Delta and Western Delta. Administratively the Eastern Delta is in Krishna District and the Western Delta is in Guntur District of Andhra Pradesh. Only after construction of the anicut on river Krishna at Vijayawada i.e., Prakasam barrage (initially constructed in 1852 which was designed by Sir

Arthur Cotton and reconstructed in 1957), gradual and regulated development took place in terms of irrigation and agricultural production.

Administratively the area is with 831 habitations covering fully 45 and partially 11 mandals of Krishna and Guntur districts of Andhra Pradesh (Fig. 1). The area is located between North latitude 15° 42’ to 16° 41’ and East longitude 80° 07’ to 81° 33’ covering an area of 7,278 km^2 falling in parts of Survey of India Toposheets 65 D/04, 07, 08, 10, 11, 12, 14, 15, 16, 65 H/02, 03, 04, 06, 07, 11, 65 A/05, 09, 13, 14 and 66 E/01. The area is bounded by Bay of Bengal in the south, where as in the east and north east it is bounded by West Godavari district and in the west by Prakasam district, and north by remaining mandals of Krishna and Guntur districts. The area has a coast line of about 246 km.

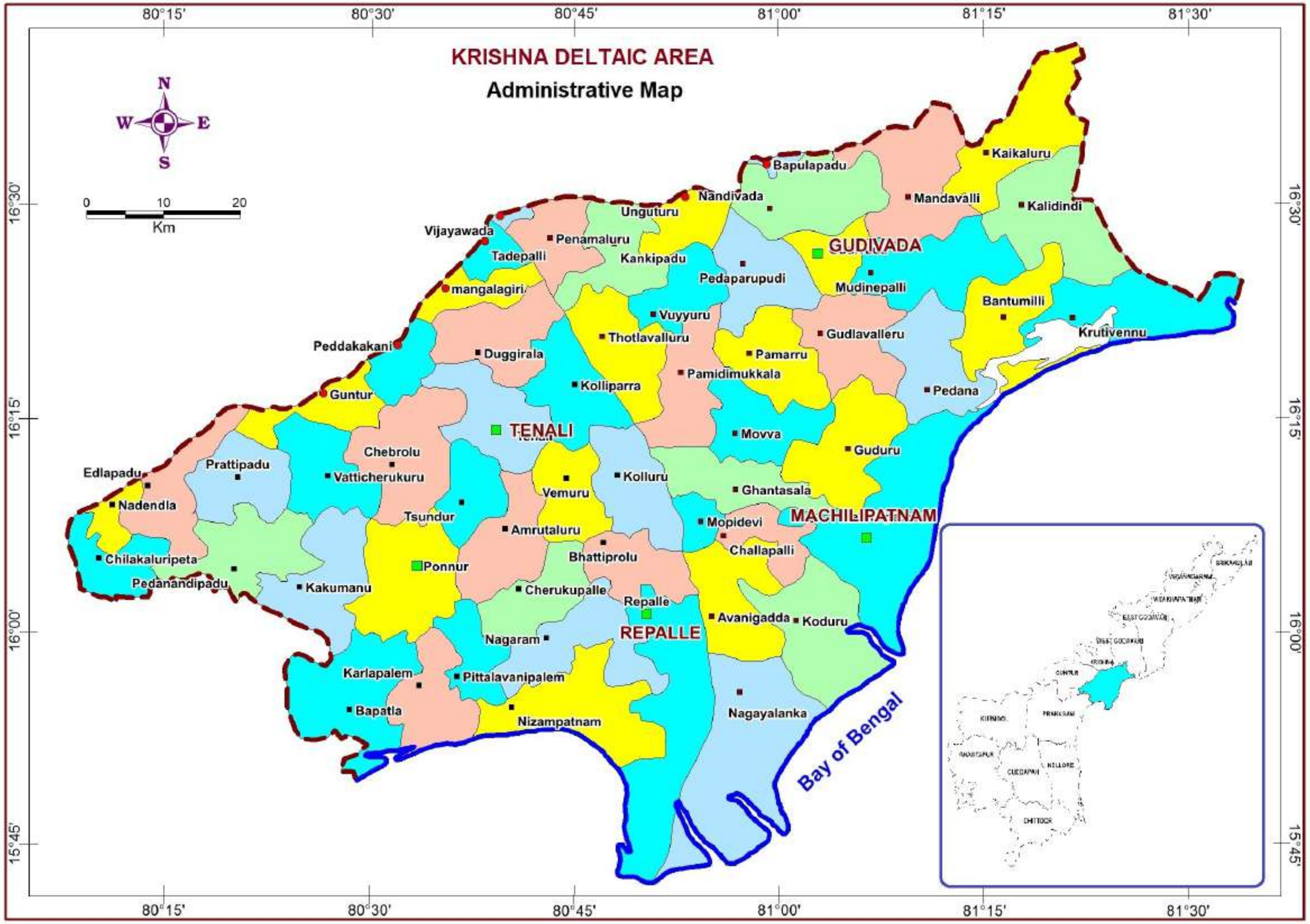


Fig-1: Location and Administrative Divisions of Krishna Delta

Climate and Rainfall:

The area experiences dry, sub-humid, mega thermal climate with oppressive summer and good seasonal rainfall. The south west monsoon sets in the second week of June and lasts till September end. October and November receives rainfall from north east monsoon. The winter starts from December and lasts till mid February followed by summer season up to early June. The study of long term rainfall pattern from the rain gauge at Machilipatnam shows that the long term normal is 1052 mm and 55% of the years in this period the area received normal rainfall and 17 % of years the area received excess rainfall where and 28% of the years received deficit rainfall. The long term trend analysis of rainfall indicates that the rainfall has an increasing trend of 1.60 mm/year (Fig. 2A). The normal annual rainfall in the area by considering the data recorded at mandal headquarters is varying from 690 to 1230 mm (Fig. 2B). Most of the rainfall (68%) occurs during the south west monsoon season.

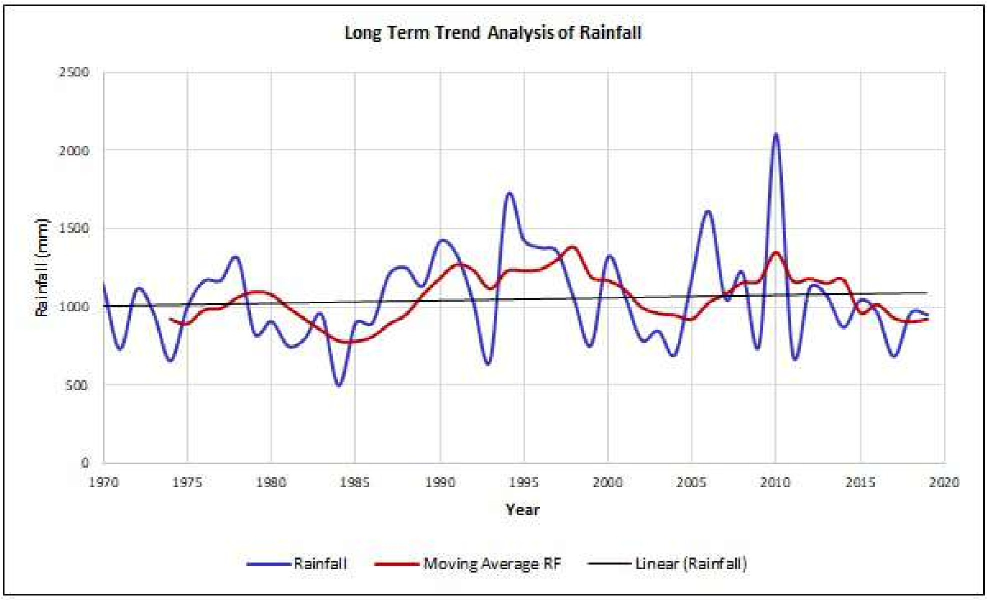


Fig. 2a Long Term Trend Analysis of Rainfall – IMD Station, Machilipatnam

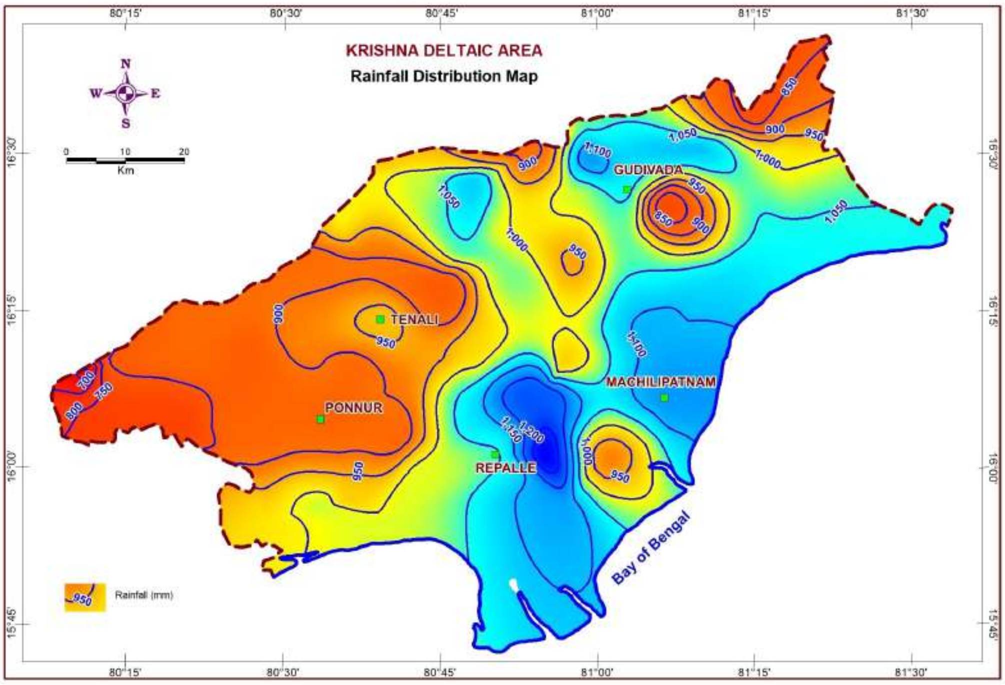


Fig. 2B Normal Rainfall Map of the Area

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. During south west monsoon, the relative humidity is of the order of 80% in the morning and 75% in the evening. During summer particularly in May, relative humidity is about 72% at 8.30 hrs and 65% at 17.30hrs. The winds are generally light to moderate throughout the year. During the post monsoon season winter winds are generally from North East to South East with speed in the order of 6 to 7 kmph. During summer, winds are mainly from South East and South West with speeds increasing from 7 to 12 kmph and during the South West monsoon season winds are mainly from South West and North West with speeds from 7 to 12 kmph.

Drainage:

The area is drained by Krishna River and flows North to South direction (Fig. 3) and separates Krishna and Guntur Districts. The river Krishna originates in the Western Ghats near Mahabaleshwar and debouches into the Bay of Bengal at Hamsaladivi and Nachugunta in Krishna district. 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.

A small river Budameru which is a hill stream flows through Kaikaluru and finally falls into the Kolleru Lake which is in the north eastern part of the area. The area is served by Krishna canal system and other drains. The drainage density in the area is sparse due to high permeability of alluvial soils. The majority of the ponds particularly near to coast in eastern delta (Krishna district) are being converted to pisciculture when compared to western delta (Guntur district).

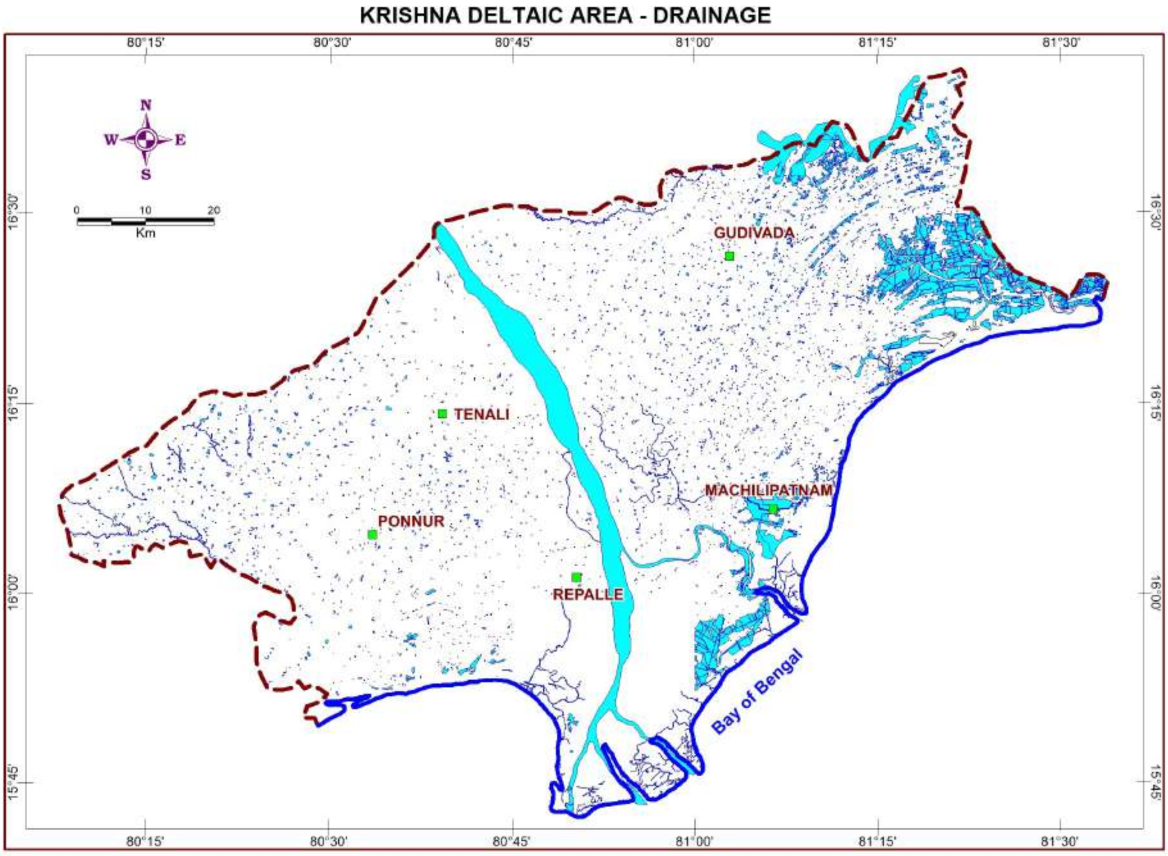


Fig. 3 Drainage Map of the Area

Geomorphology:

The area is basically occupied by deltaic and coastal plains. The landforms present in the area are mainly fluvial land forms and other forms are of marine and aeolian. Various landforms occurring in the area are presented in Fig. 4. Land forms derived from the streams are known as fluvial land forms. These land forms can be due to erosional or depositional processes. The study area has some of the important depositional land forms viz. channel bars, Channel Islands, cut off meanders, deltaic plains, meander scars, natural levees, oxbow lakes and palaeo channels. The altitude varies from 1 m near coast to 12 m above MSL in the upper reaches of the area (Fig. 5).

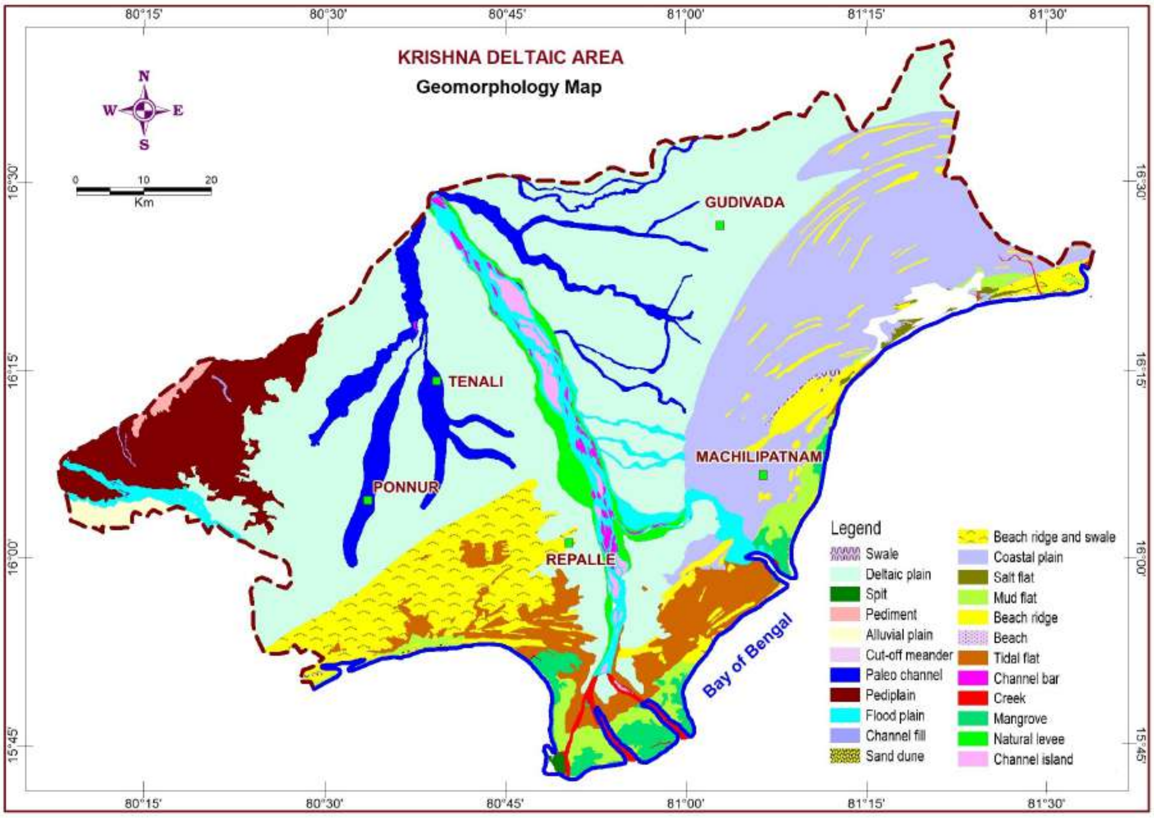


Fig. 4 Geomorphological Map of the Area

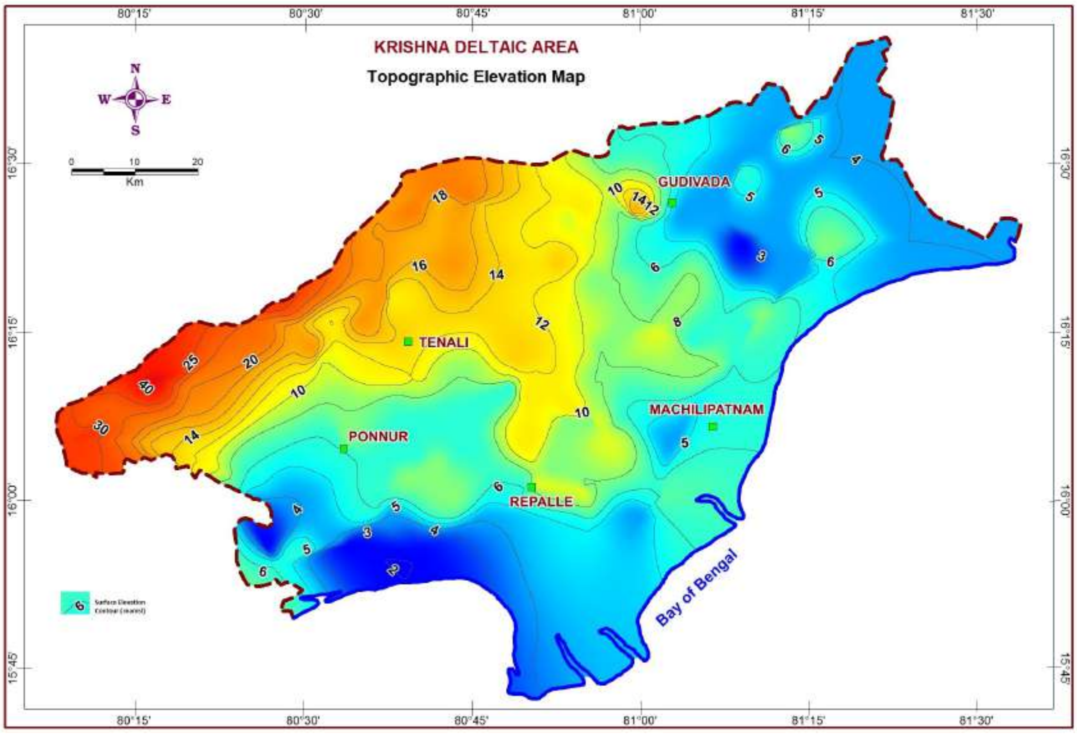


Fig. 5 Topographic Elevation of the Area

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. The strand lines and the present-day coast are depicted in Fig. 6 and the details are as follows

1. Kaikaluru (Krishna district) – Bapatla strandline (Guntur district) 6500 yrs BP
2. Guduru strandline: Bantumilli – Guduru (Krishna Dist.) – Bapatla (Guntur Dist.) 4500 yrs BP
3. Machilipatnam strandline: Peddapatnam – Machilipatnam – Avanigadda (Krishna Dist.) – Idupalli (Guntur Dist.) 3250 yrs BP.
4. Koduru strandline: Machilipatnam – Koduru (Krishna Dist.) – Nizampatnam (Guntur Dist.) 2450 to 2150 yrs BP.
5. Present Shore/ Beach Ridge 1500 yrs BP.

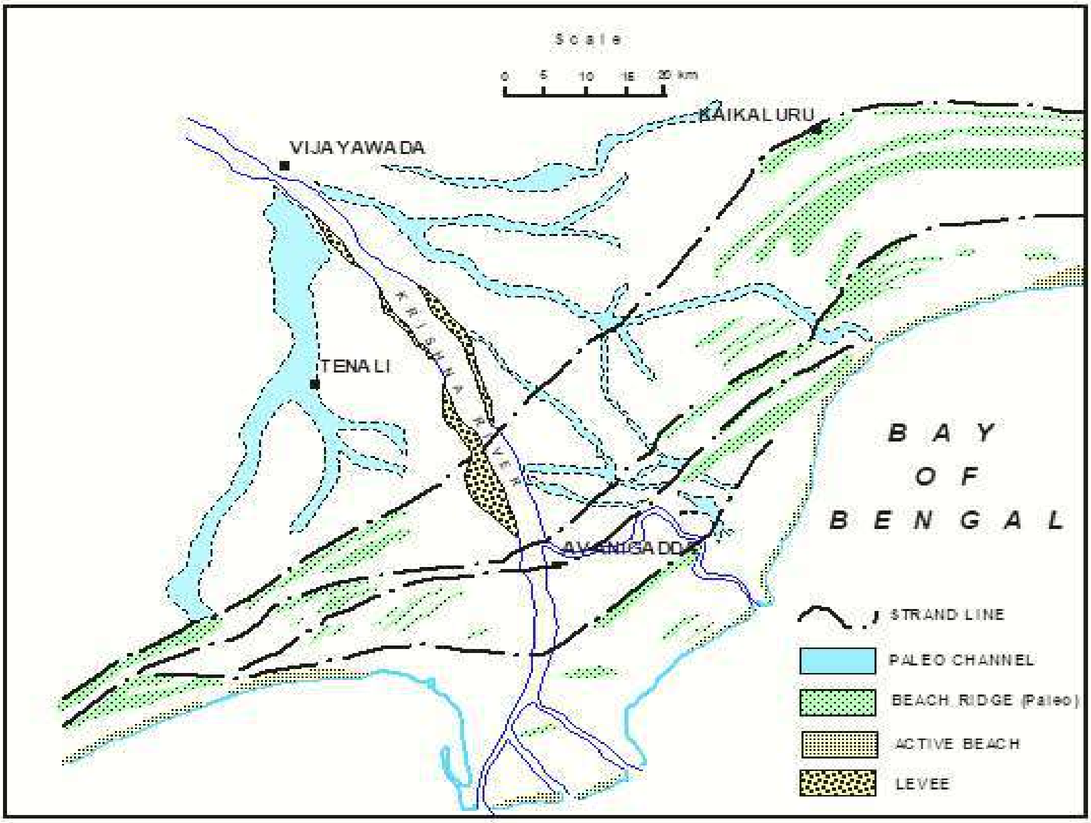


Fig. 6 Shoreline Development in Krishna Delta

Soils :

The delta soils are considered to be the most fertile. The important soil groups in the area are deltaic alluvial soils and coastal sands. 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. In deltaic alluvium two crops are harvested every year. Paddy and sugarcane are extensively raised on these lands. The Coastal sands on the other hand are highly porous and lack of binding material. The taxonomic classification is depicted in Fig. 7.

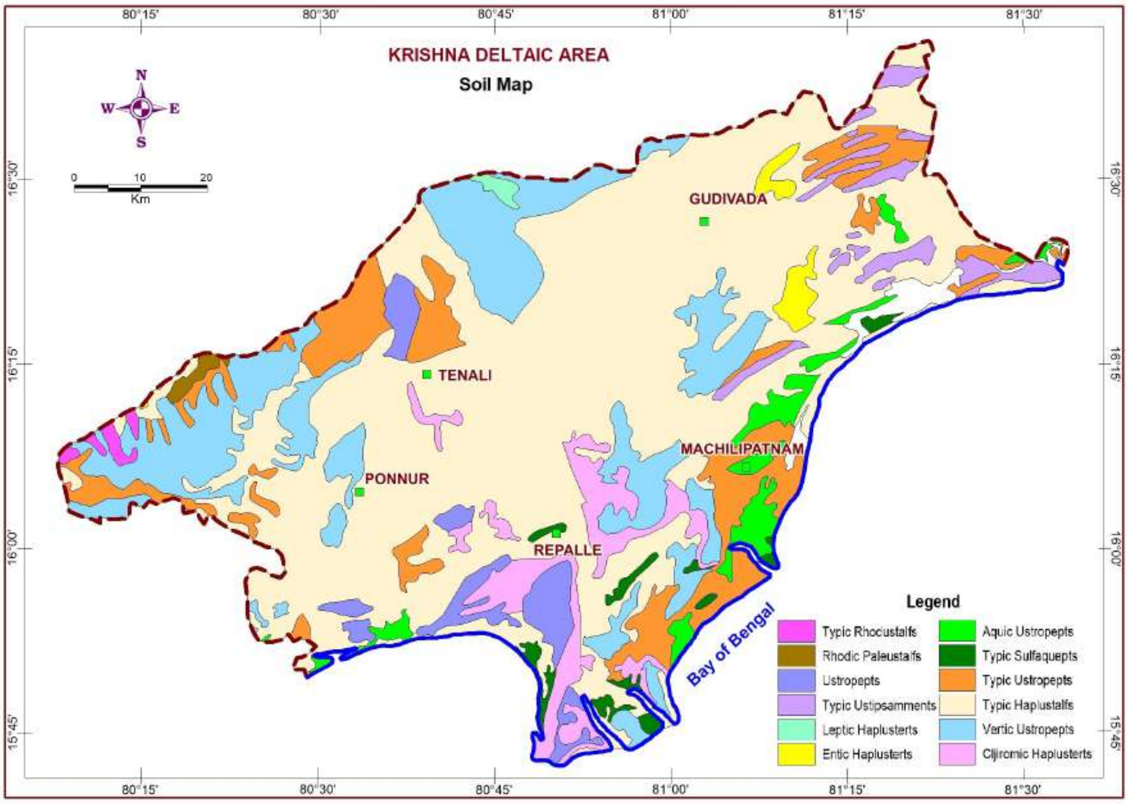


Fig. 7 Paedology of the Area

Land Use, Irrigation & Cropping Pattern:

The Krishna Delta Irrigation Project is the major irrigation project catering the irrigation needs of the major portion of the area. Registered Ayacut of this project in the Eastern and Western delta is 2,74,600 hectares and 1,98,100 hectares respectively. There are no medium irrigation projects in the area. Only small area is irrigated under minor irrigation schemes in the area as most of the area is under the command of Krishna Delta major irrigation project. No area is registered under the ayacut of tanks in the area.

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 area has the distributary network of the river Krishna. The area is crisscrossed by the canal network of Krishna Delta Irrigation System. 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 in this area is practised in 58,634 hectares (Guntur = 7,826 ha & Krishna=50,808 ha), which is about 7 % of total area.

The principal crops are paddy and sugarcane. The other crops are Maize, Pulses, turmeric, fruits and vegetables. Surface water is the main source of irrigation (>80 %). The land use pattern and the area irrigated by different sources in the area are presented as Fig. 8 & 9.

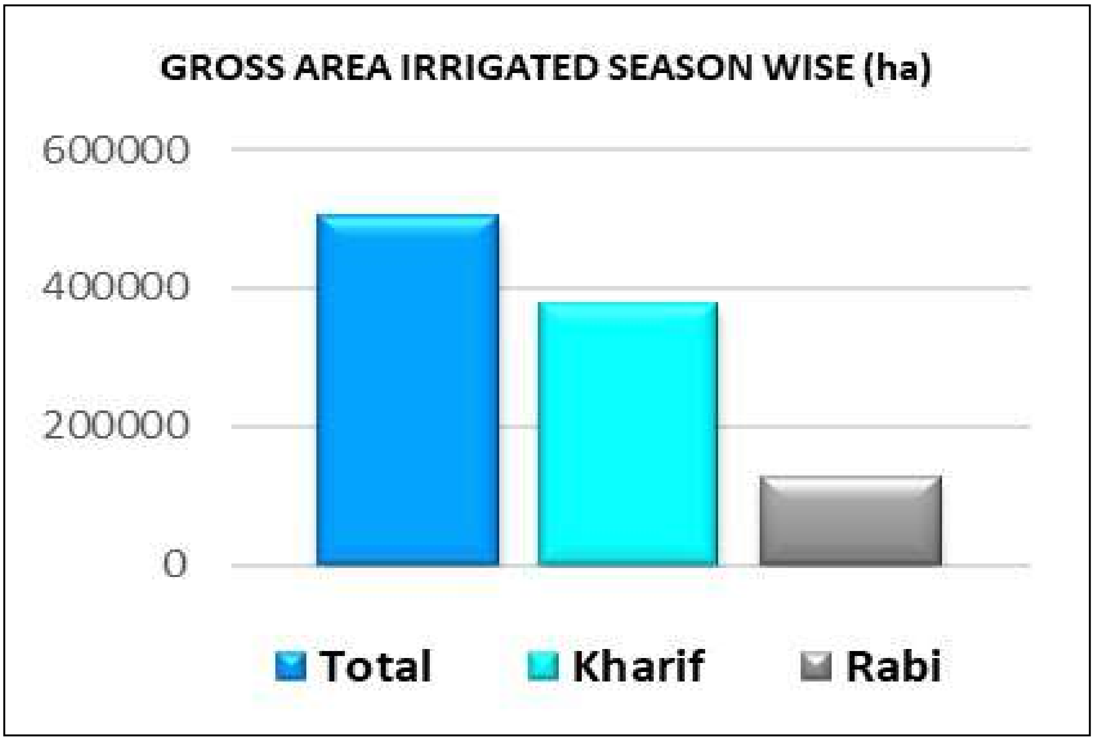


Fig. 8: Land Use Pattern and Principal Crops

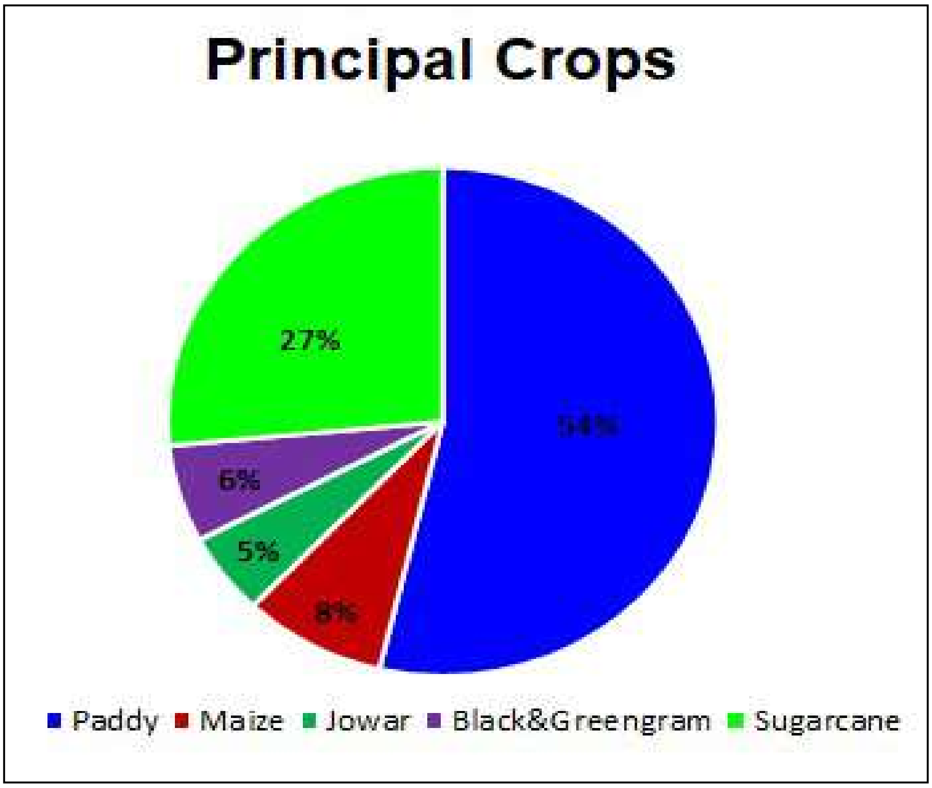
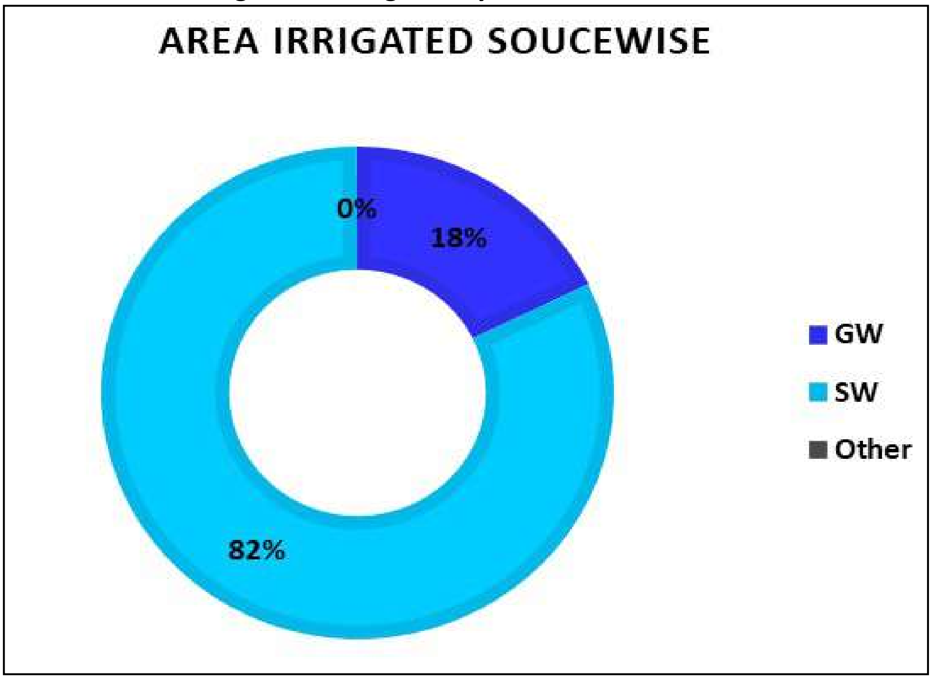


Fig. 9 Area Irrigated by Different Sources



Previous Work:

Several Organizations like Geological Survey of India, Central Ground Water Board and ONGC at the national level and Andhra Pradesh State Ground Water Department, State Irrigation Development Corporation and Rural Water Supply and Sanitation Department at State level have carried out geological and hydrogeological surveys in this area.

2. DATA COLLECTION AND GENERATION

Collection, Compilation and processing of data for aquifer mapping studies is carried out in conformity with EFC document of XII plan of CGWB encompassing various activities.

Geology:

Geologically the area is mainly underlain by the recent to sub-recent alluvium comprising Sand, Gravel, Clay and Silt. The Upper Gondwana formations (Gollapalli sand stones) are occur as isolated linear out crops trending NE – SW direction in the north western parts of the area around Chebrolu. The alluvium is underlined mainly by the Rajahmunry sandstones in eastern deltaic area and by the Gollapalle sandstones in western deltaic area and at places directly by crystallines. The sandstones formations and crystallines are encountered at different depth in the boreholes drilled by CGWB in the western and northern parts of the area at shallow depths, and towards coast and south eastern parts at greater depths.

The geological succession of the area is shown in Table-1. The geological map of the area is shown as Fig. 10.

Table–1 : Geological Succession of the Area

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
		Gollapalli	Sandstone and shale/ clay
	Lower Gondwana	Chintalapudi	Sandstone and shale/ clay
------------------------------- Unconformity -------------------------------			
Archaean			Charnockite, Khondalite and Gneisses

Fig-10: Geology map of Krishna Delta

Sub-Surface Geology

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. 11. 3D stratigraphic model for the area has been synthesized and shown in Fig. 12.

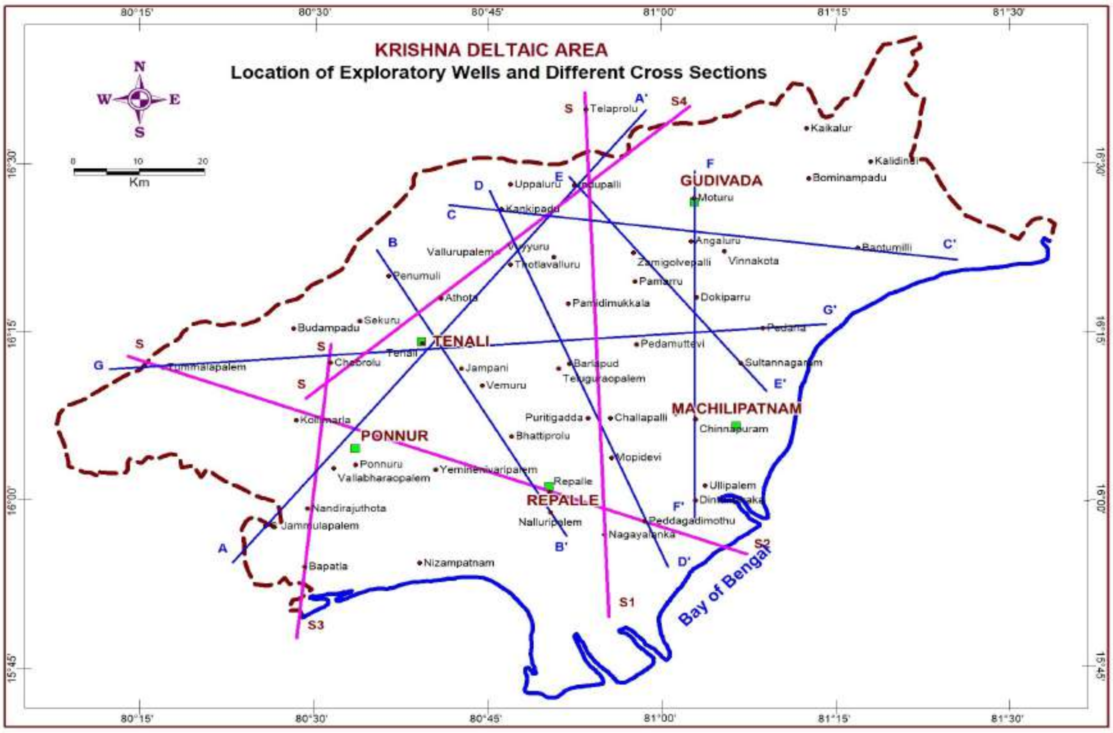


Fig. 11 Location of Exploratory Wells and Different Cross Sections

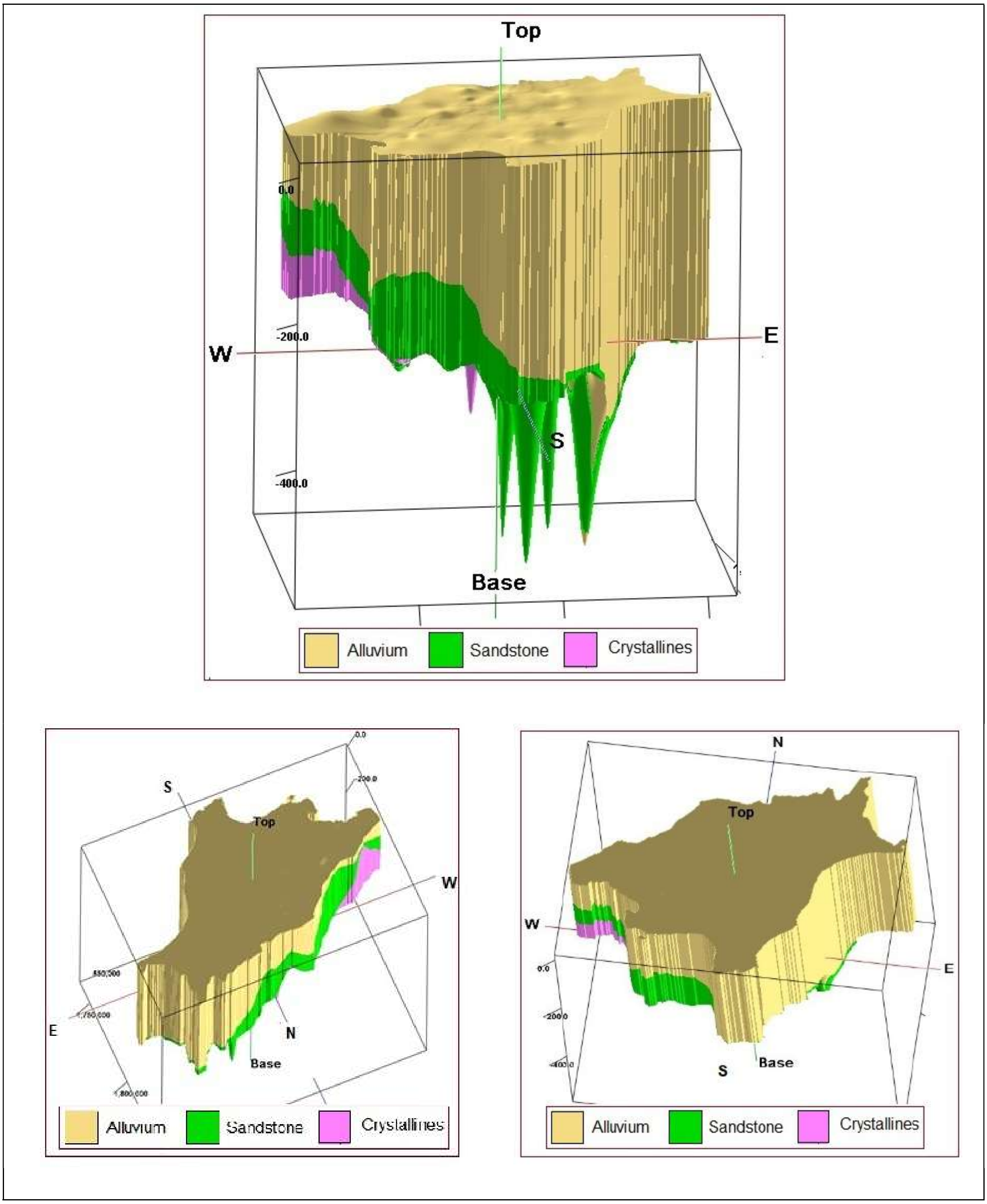


Fig. 12 3D Geological Models of the Area

Generalised schematic geological cross sections of the area are prepared along the sections *S-S1, S-S2, S-S3* and *S-S4* and presented as Fig. 13 a to d. These sections clearly shows that the alluvium is underlained by sandstones and at places directly by crystallines.

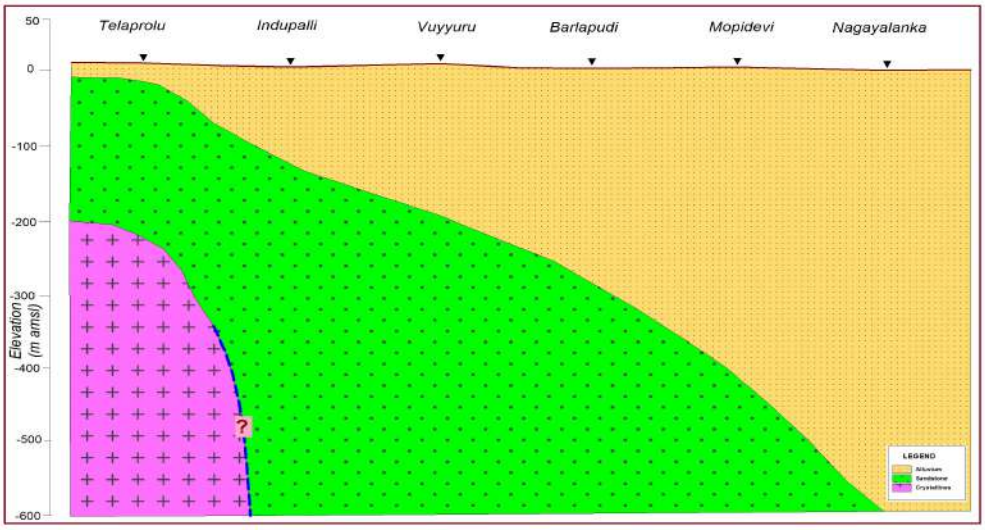


Fig. 13a Schematic Cross Section Along Telaprolu – Nagayalanka (S – S1)

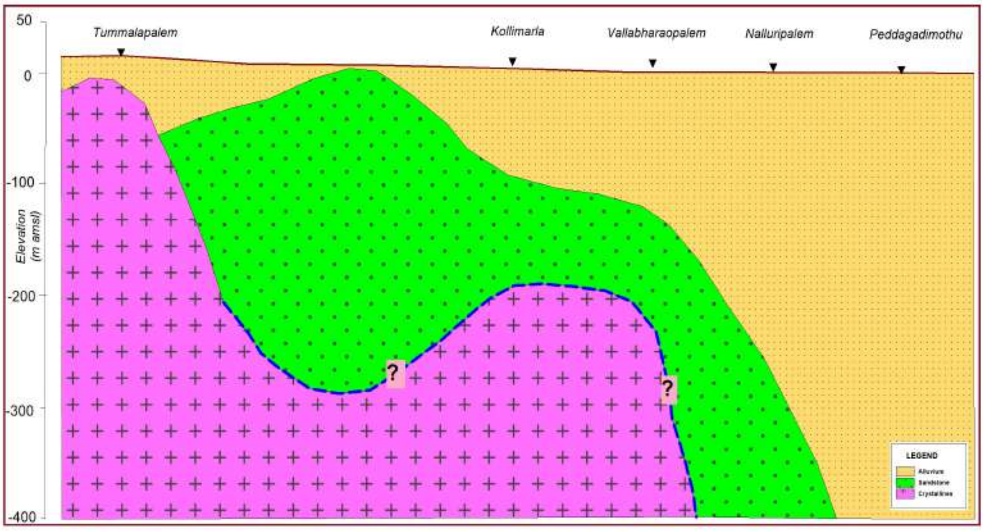


Fig. 13b Schematic Cross Section Along Tummalapalem – Peddagadimothu (S – S2)

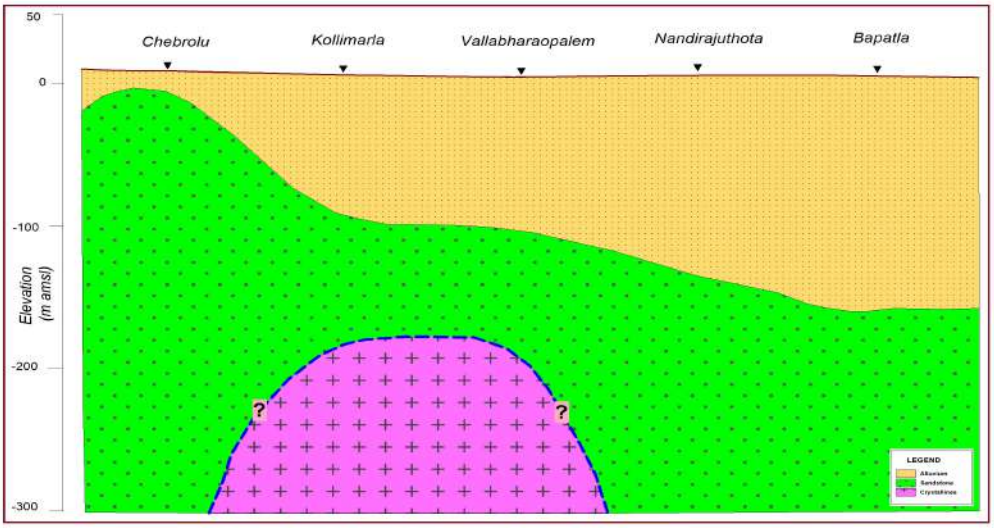


Fig. 13c Schematic Cross Section Along Chebrolu – Bapatla (S – S3)

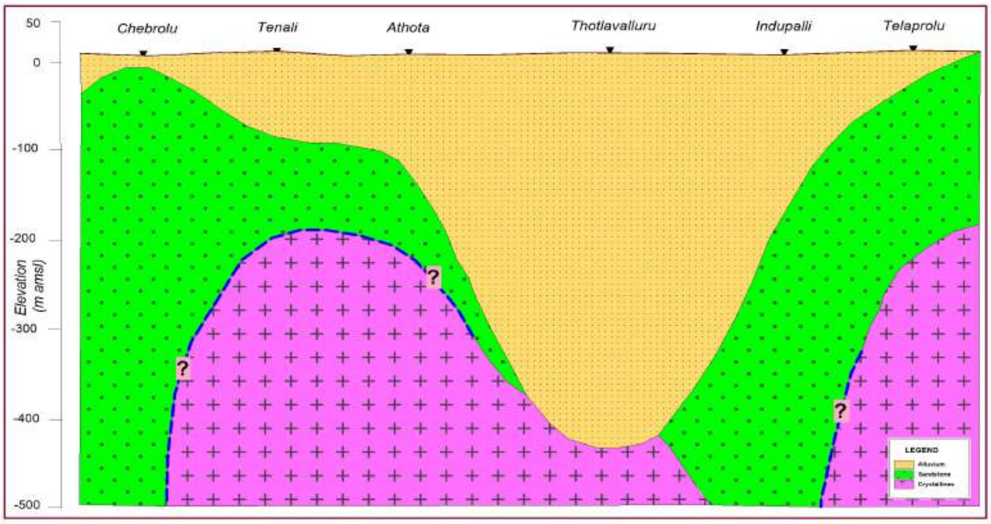


Fig. 13d Schematic Cross Section Along Chebrolu – Telaprolu (S – S4)

Above schematic geological cross sections reveals that the thickness of alluvium varies from a few meters to more than 400 m and in general it overlies sandstones, where as in the western fringes and north central portions of the deltaic area alluvium is underlined directly by charnockites and gneisses respectively. The thickness of alluvium increases from north to south and west to east south east. The thickness of alluvium recorded in a well drilled by CGWB at Mopidevi is 420 m. In western deltaic area alluvium is mainly underlain by Gollapalli sandstones, whereas in eastern deltaic area mainly may be by Rajahmundry sandstones. Based on the exploration data of CGWB, a schematic map is prepared and presented as Fig. 14, which shows depth to sandstone in the Deltaic area. The figure reveals that sandstones occur at shallow depths (< 100 m) in the north western parts of the area and at moderate depths (< 200 m) in the north eastern fringes of the deltaic area, where as in the south eastern parts, the thickness of the alluvium is more than 400 m (Mopidevi – 420 m). The thicknesses of alluvium and sandstone recorded about 80 m and 120 m at Tenali and Athota respectively. The alluvium is underlain directly by crystallines at places (Thummalapalem and Thotlavalluru). The depth to basement increases from north west to south east (15 m at Thummalapalem; 435 m at Thotlavalluru; > 600 m at Mopidevi – CGWB wells). The data from deep wells drilled by Vedanta Ltd. for oil exploration at Kaza (near Machilipatnam) depicts that the basement is at 2075 m. Based on the available data a schematic map is prepared and presented as Fig. 15, which shows pseudo depth to basement in the Deltaic area.

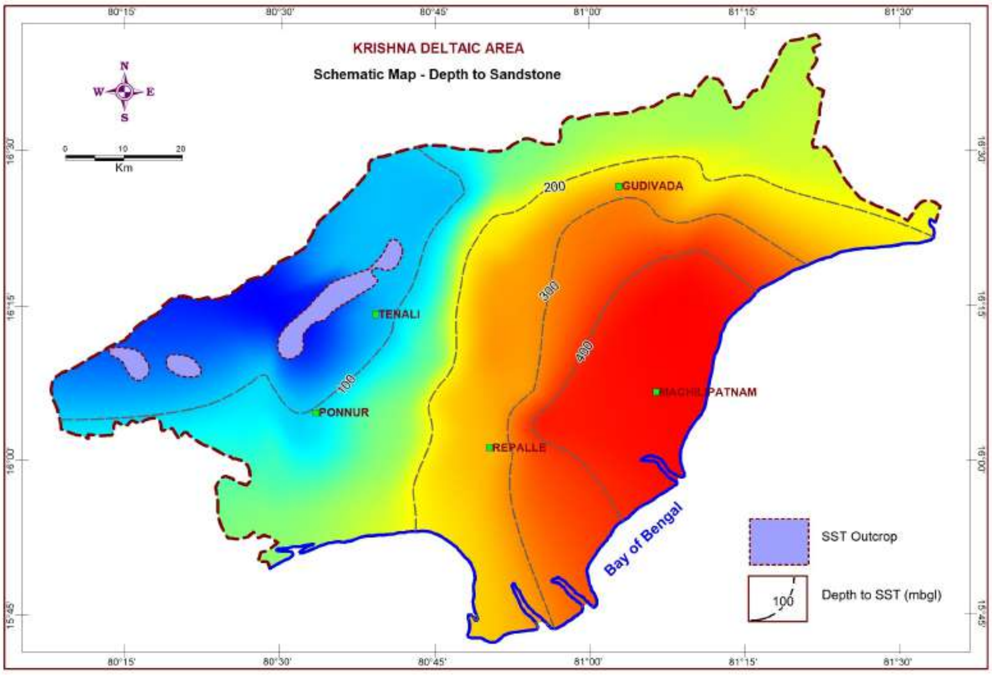


Fig . 14 Schematic Map of Depth to Sand Stone

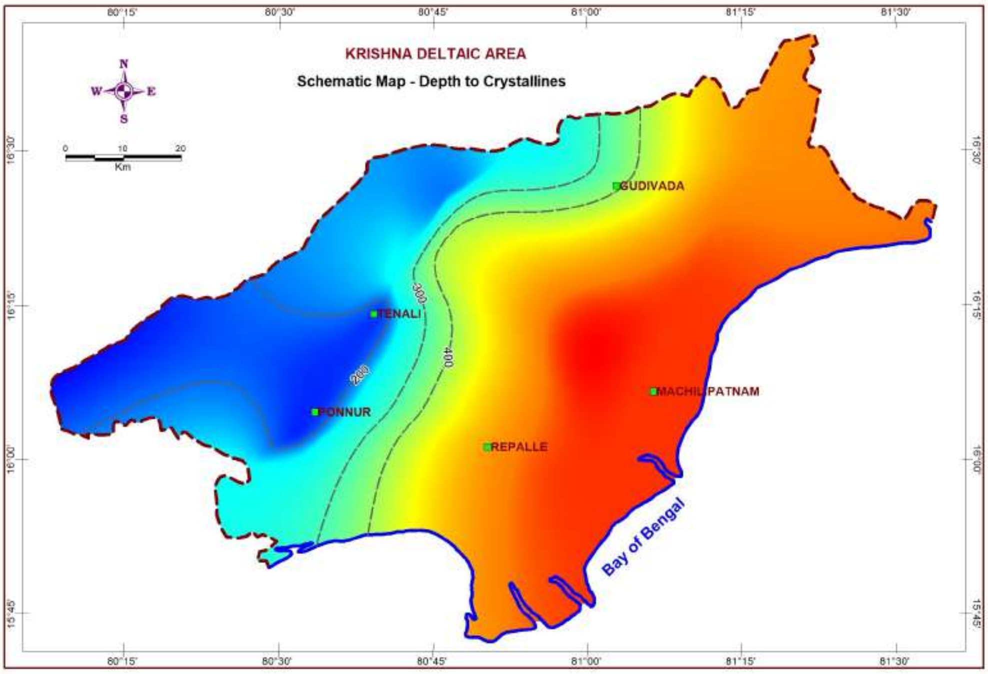


Fig. 15 Schematic Map of Depth to Crystallines

In order to have a clear picture and better understanding of the sub-surface geology and disposition of different formations mainly the principal aquifers, different geological cross sections were drawn based on the available exploration data of CGWB, and presented as Fig. 16.

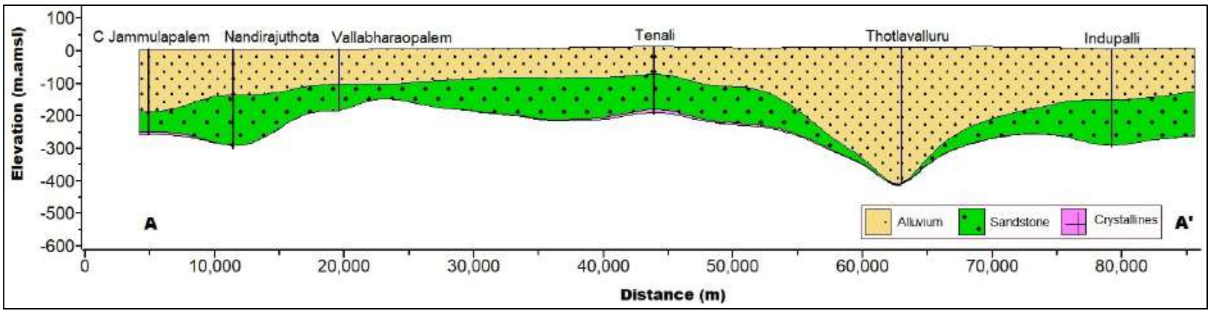


Fig. 16a 2D Geological Cross Section along A-A’

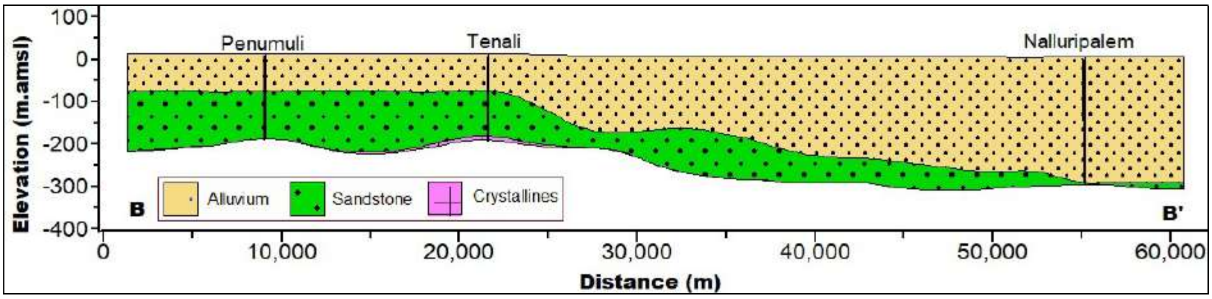


Fig. 16b 2D Geological Cross Section along B-B’

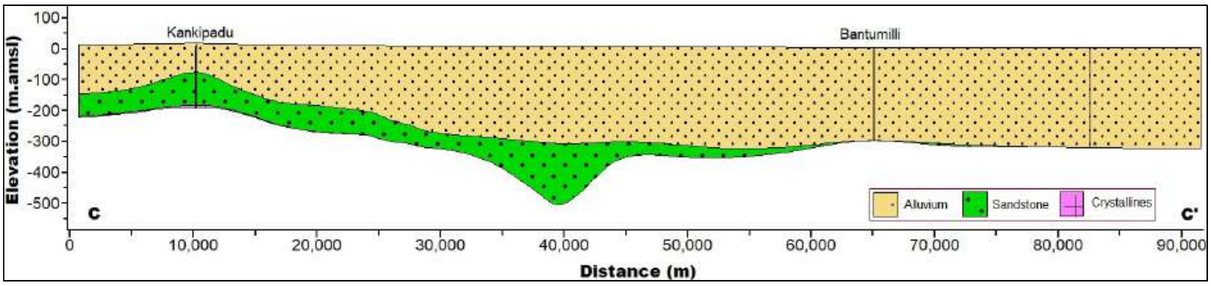


Fig. 16c 2D Geological Cross Section along C-C’

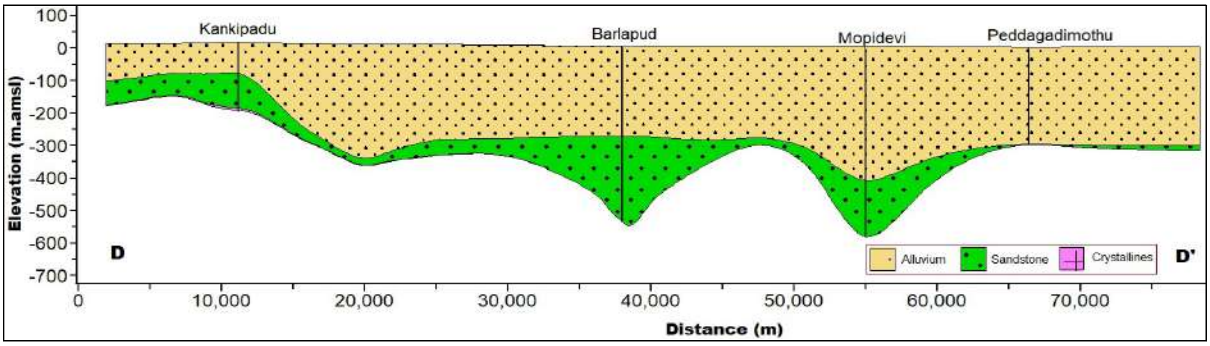


Fig. 16d 2D Geological Cross Section along D-D’

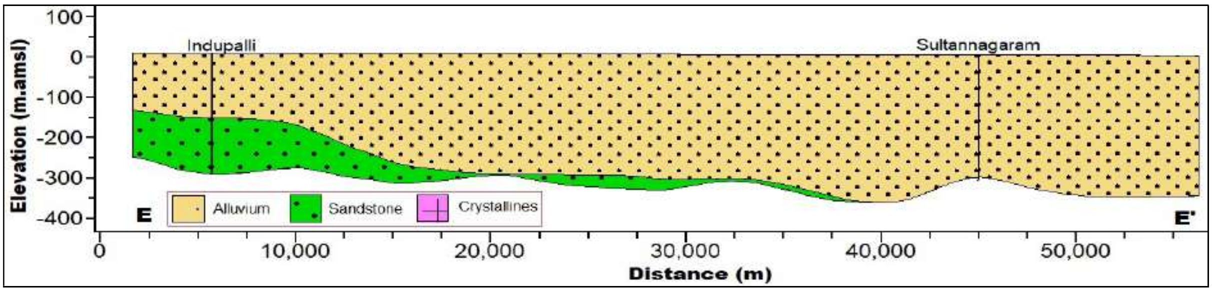


Fig. 16e 2D Geological Cross Section along E-E’

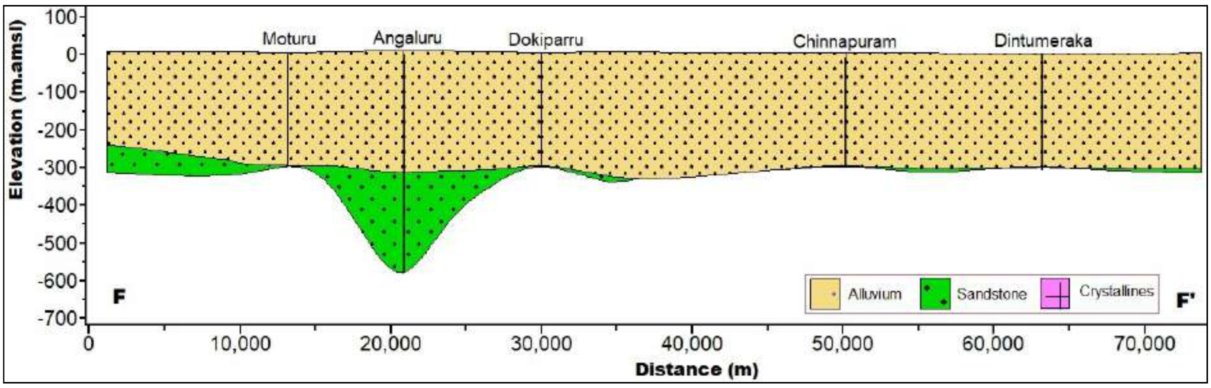


Fig. 16f 2D Geological Cross Section along F-F'

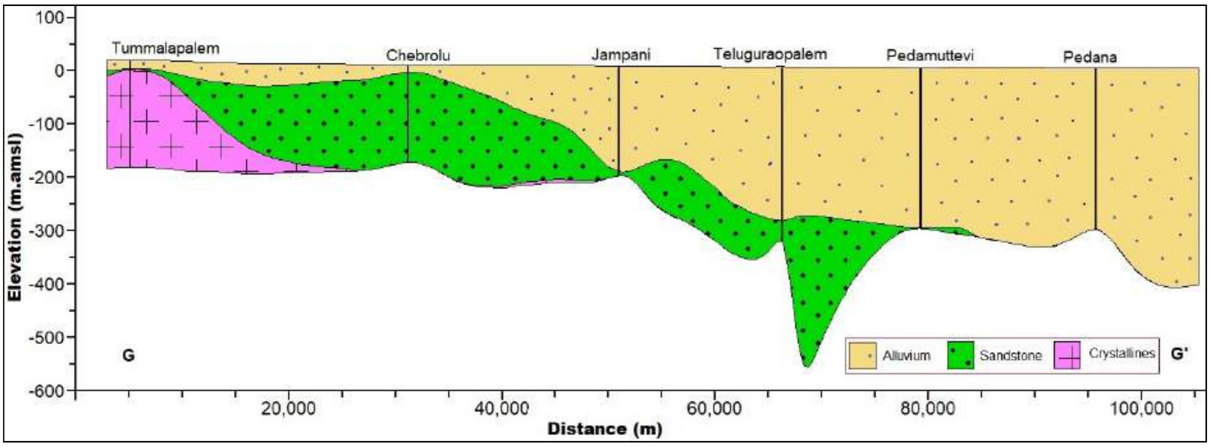


Fig. 16g 2D Geological Cross Section along G-G'

It is seen from the sections that the crystallines, which are encountered at a depth of 15 m at Tummalapalem, around 200 m at different places, 230 m at Cheruvu Jammulapalem, 435 m at Thotlavalluru and are not encountered in the south eastern area even at a depth of 600 at Mopidevi and Pedana. Sandstone formations exposed as small outcrops in the north western area occur at a depth of 85 m at Tenali, 90 m at Kankipadu, 150 to 250 m at different places, 322 m at Angaluru and 420 m at Mopidevi. Information pertains to depth to sandstones and crystallines/ basement inferred from the lithological and geophysical logs is given as *Annexure-I*.

Hydrogeology:

The area 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 crystalliness and at places alluvium directly underlain by crystallines/ basement. The sand stone formations occur as isolated linear out crops in the north western parts of the area around Chebrolu and also encountered at shallow to greater depths in other parts. Hydrogeological map of the area is presented as Fig. 17.

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 m^2/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. <1 to 18 lps.

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.

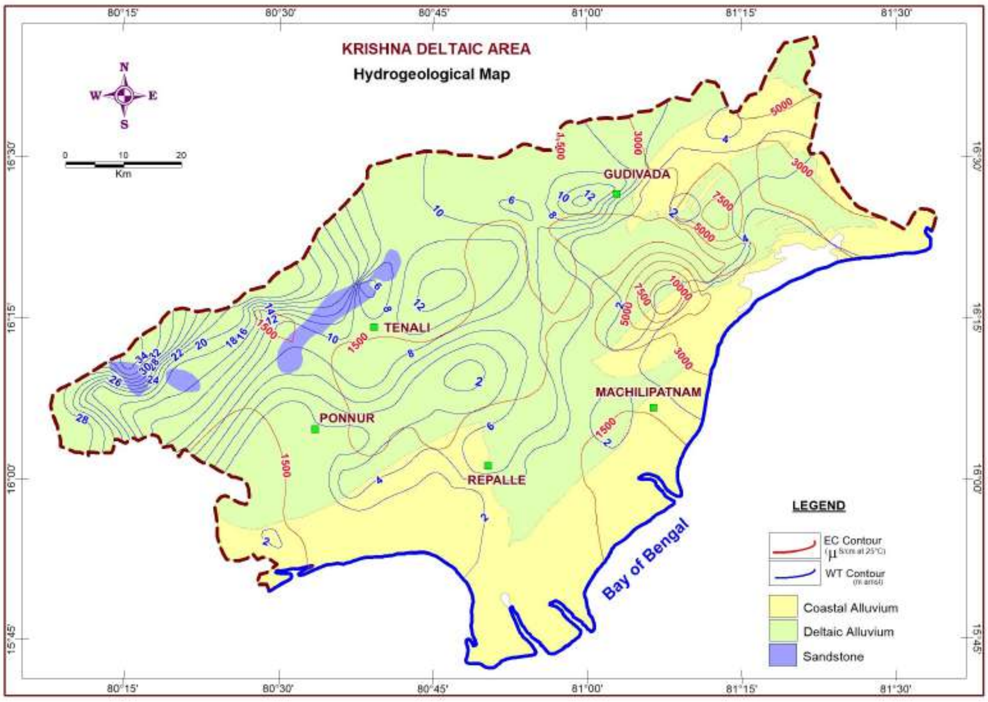


Fig. 17 Hydrogeological Map of the Area

Ground Water Levels

The water levels behaviour was studied based on the pre-monsoon and post-monsoon 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 pre-monsoon 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.

Depth to 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 (2019) is ranges from < 1 m bgl to a maximum of 10 m bgl. Pre-monsoon depth to water level map reveals that mostly the water levels in the area ranges in between 2 and 4 m bgl (Fig. 18). The depth to water level during post-monsoon (2019) in the majority of the area is < 2 m bgl, whereas in the norther part of the area is in the range of 2 to 4 m bgl (Fig. 19).

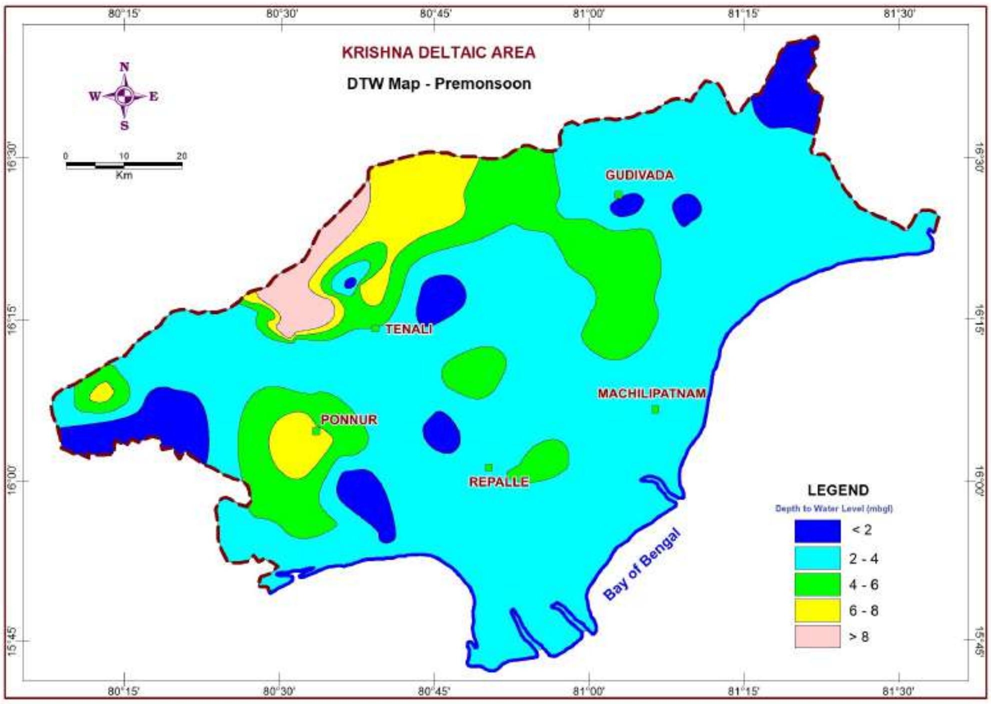


Fig. 18 Depth to Water Level - Pre-Monsoon (2019)

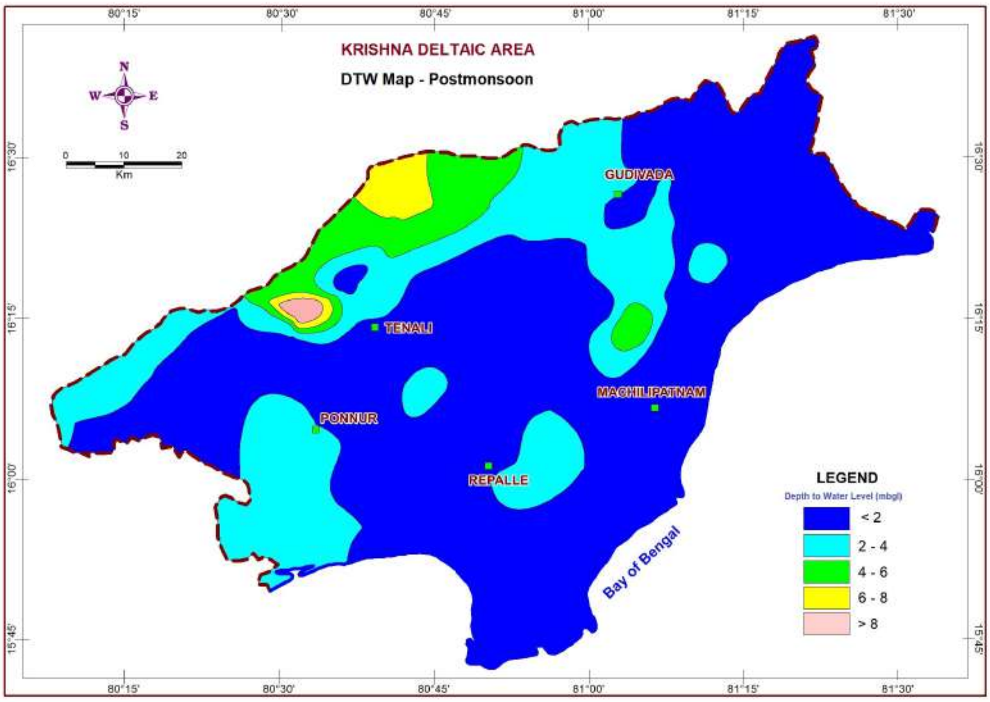


Fig. 19 Depth to Water Level - Post-Monsoon (2019)

The water table elevation ranges between 2 m amsl in the coastal area and > 12 m amsl in the north western 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.

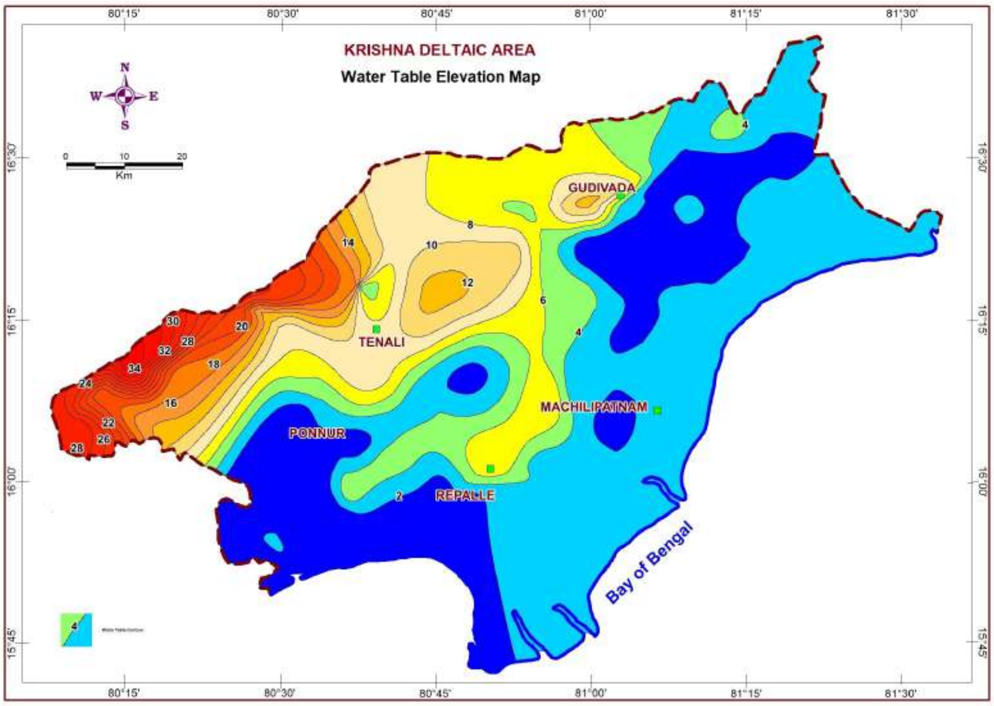


Fig. 20 Water Table Elevation Map

The piezometric head in the deeper aquifers (the data may be pertains to mainly 2nd aquifer) during pre-monsoon (2019) is ranges from < 5 m bgl to a maximum of 15 m bgl (Fig. 21). The piezometric head during post-monsoon period is ranges from < 2 m bgl to a maximum of 15 m bgl (Fig. 22).

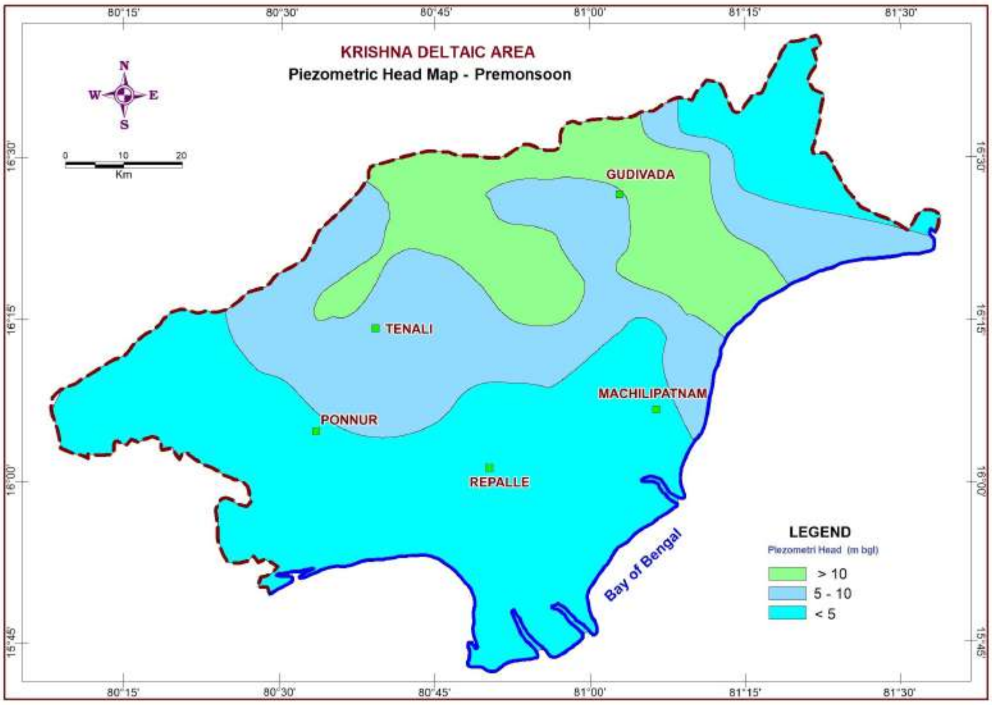


Fig. 21 Pre Monsoon – Piezometric Head (2019)

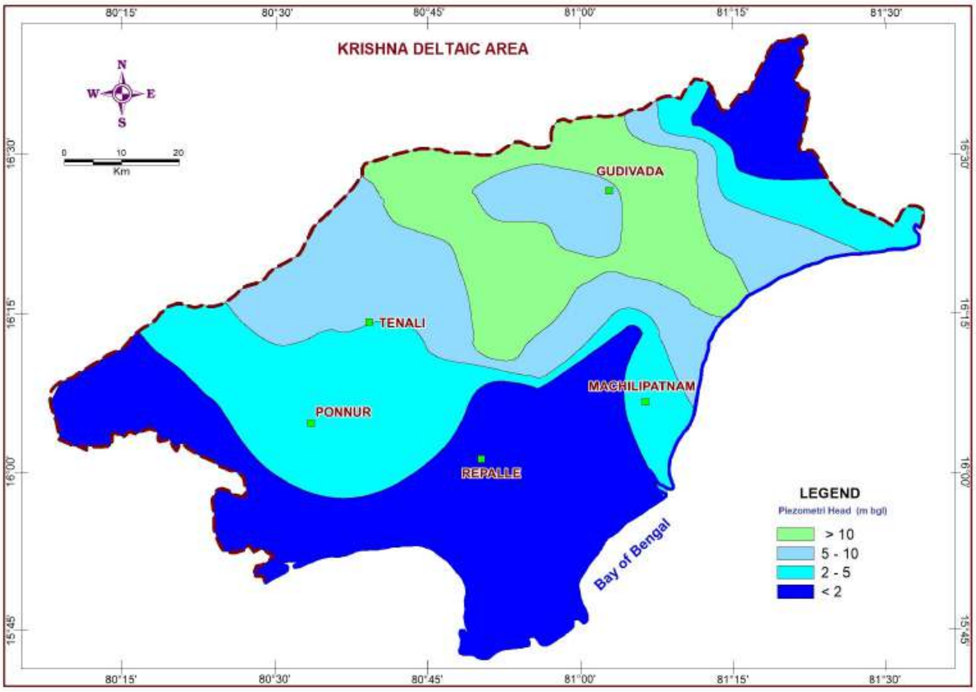


Fig. 22 Post Monsoon – Piezometric Head (2019)

Water Level Fluctuation

The water level fluctuation in shallow aquifers between pre-monsoon and post-monsoon water levels i.e., May and November, 2019 ranges in between -2 and 3 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. 23).

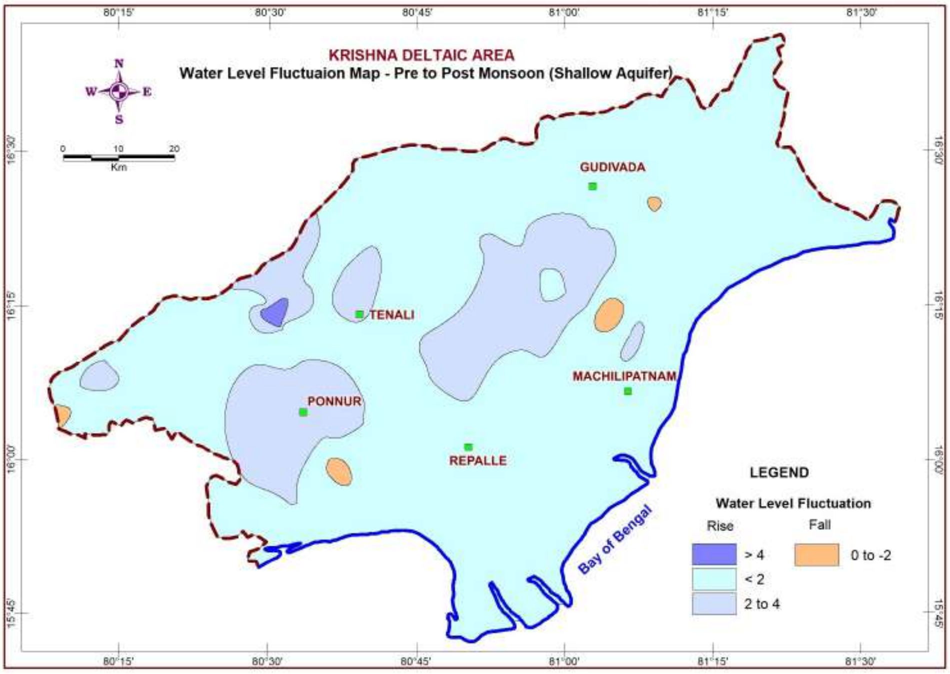


Fig. 23 Shallow Aquifer - Water Level Fluctuation (Pre to Post monsoon, 2019)

The piezometric head fluctuation in deeper aquifers (mainly 2nd aquifer) between pre-monsoon and post-monsoon ranges in general in between -2 and 3 m. The fluctuation map reveals that the major portion of the area shows rise up to 2 m, except in the central and NE portion of the area where decline of < 2 m exist as isolated patches (Fig. 24).

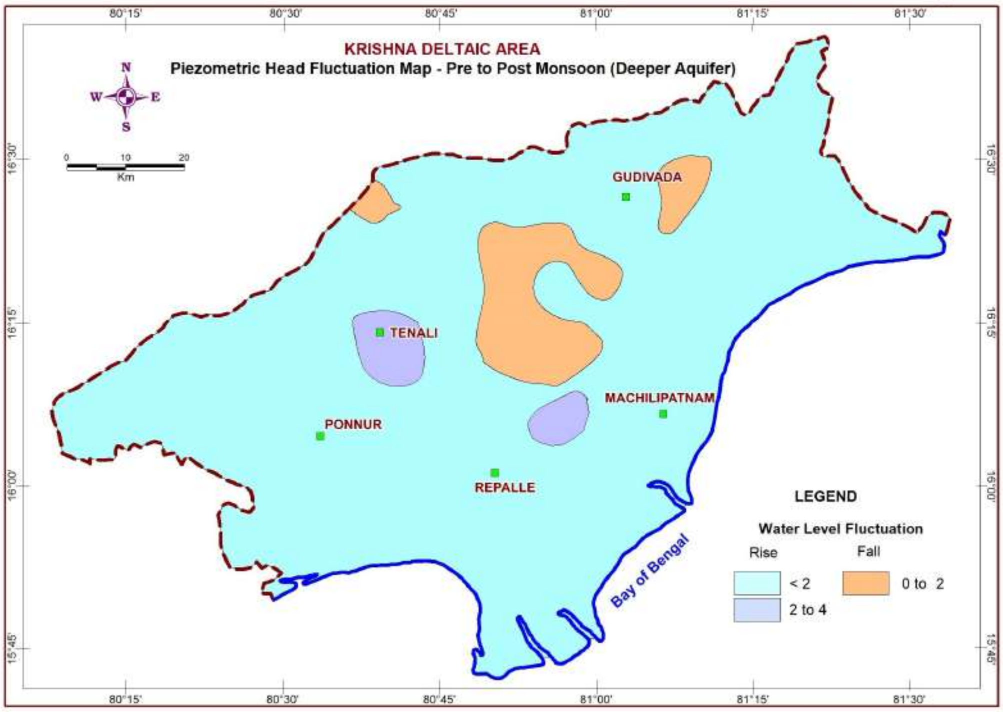


Fig. 24 Deeper Aquifer - Piezometric Head Fluctuation (Pre to Post monsoon, 2019)

Long Term Water Level Trend:

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.

Table–2   Long-term Water Level Trends

S_No	Location	Premonsoon Trend (m/yr)	Post monsoon Trend (m/yr)
1	Sekuru	-0.0723	-0.0476
2	Cheruvu_Jamulapalem	-0.0847	0.0100
3	Inturu	-0.0773	-0.0437
4	Kolakaluru	-0.0525	-0.0900
5	Guntur	-0.0090	-0.0169
6	Repalle	0.0016	0.0027
7	Motupalem	0.0038	-0.0352
8	Varagami	0.0207	-0.0007
9	Pallapatla	0.0256	0.0116
10	Prattipadu	0.0576	0.0232
11	Nijampatnam	0.0609	0.0630
12	Govada	0.0693	0.0068
13	Chebrolu	0.0786	0.0227
14	Lankapalli	-0.0907	0.0314
15	Nadupur	-0.0732	0.0777
16	Mandapakala	-0.0656	0.0549
17	Guduru	-0.0636	0.0158
18	Singarayapalem	-0.0589	0.0527
19	Avanigadda	-0.0504	0.0100
20	Movva	-0.0476	0.0028
21	Kaikaluru1	-0.0412	-0.0256
22	Pedana_New	-0.0347	-0.0530
23	Balliparru	-0.0259	-0.0103
24	Bantumilli1	-0.0225	0.0300
25	Challapalli	-0.0222	0.0004
26	Koduru	-0.0217	0.0792
27	Munjuluru	-0.0138	-0.0335
28	Gudivada	-0.0117	-0.0208
29	Sultan_Nagar	-0.0061	-0.0071
30	Mandavalli	-0.0030	0.0127
31	Kurumaddali	0.0155	0.0426
32	Konakallu	0.0434	0.0741
33	Kautaram	0.0873	0.0501
34	Kolluru	0.1194	0.0012
35	Kollipara	0.1198	0.0805
36	Pitlavanipalem	0.1319	-0.0131
37	Tadanki	0.0219	0.1292
38	Nimmakuru	0	0.1180
39	Kattempudi	-0.0654	0.1211

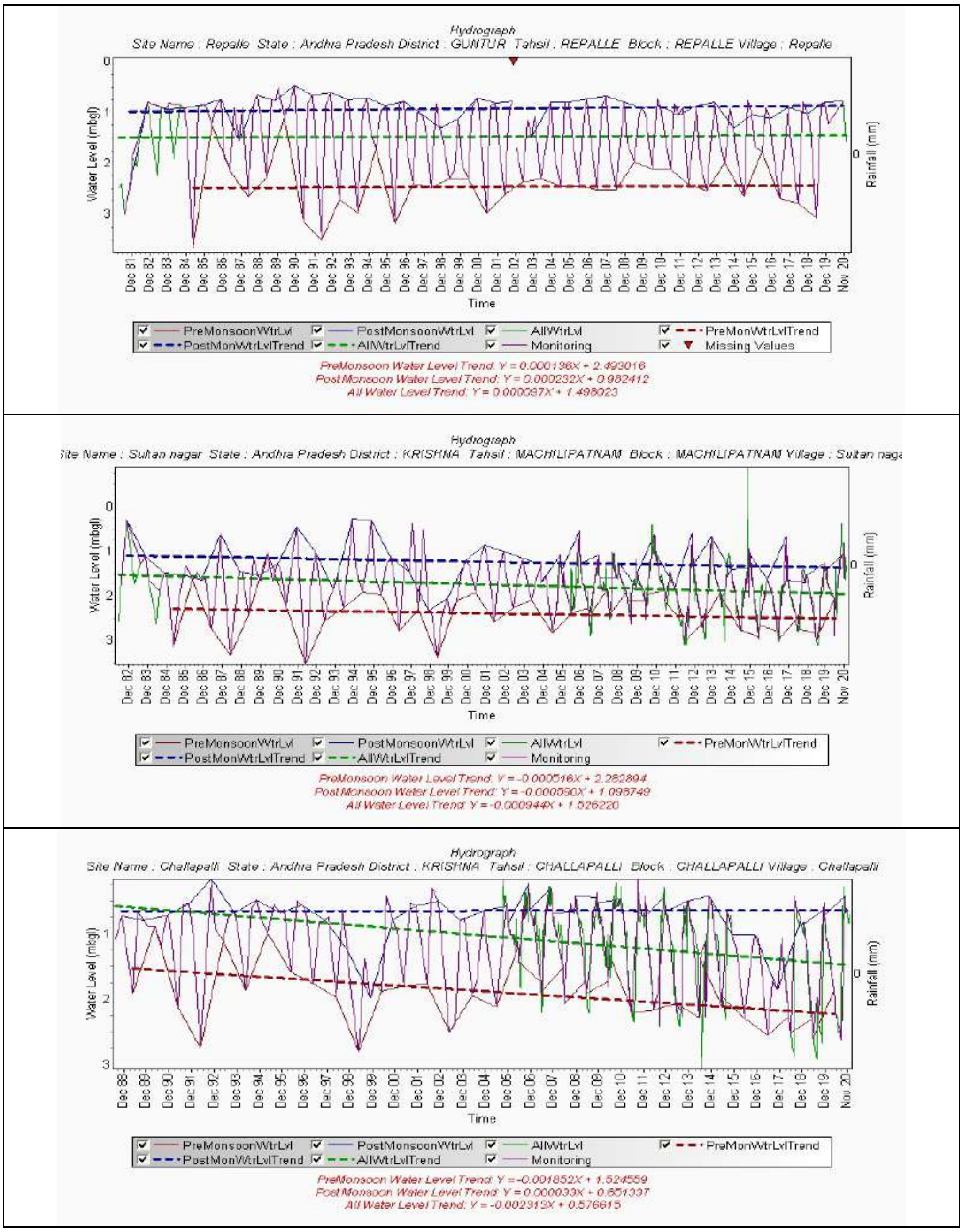


Fig. 25 Hydrographs of the Ground Water Monitoring Stations

The pre and post monsoon trend maps prepared from the long-term data are presented as Fig. 26 and 27. The perusal of these trend maps indicates that there is a conspicuous decline in major area of eastern part and western part of the area during pre monsoon season and during post monsoon, it is only in small areas in north western and south eastern and small area in the south of Gudivada in eastern part. In general, even though there is a decline during pre monsoon season it was being recouped during post monsoon season in the major part of the area. Hence the situation is not of alarming. But in parts of Gudlavalleru, Mudinepalli mandals of Krishna district and Bhattiprolu, Cherukupalli, Chebrolu of Guntur district, in both the seasons, the water levels are declining slightly giving rise to alarming situation.

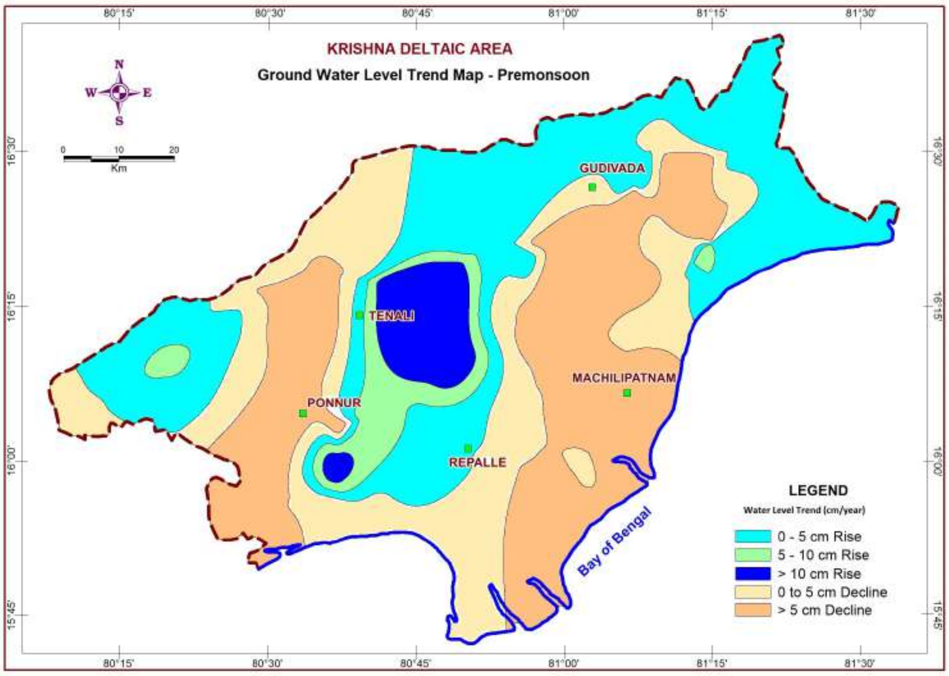


Fig 26 Ground Water Level Trend in the Area During Pre monsoon Season

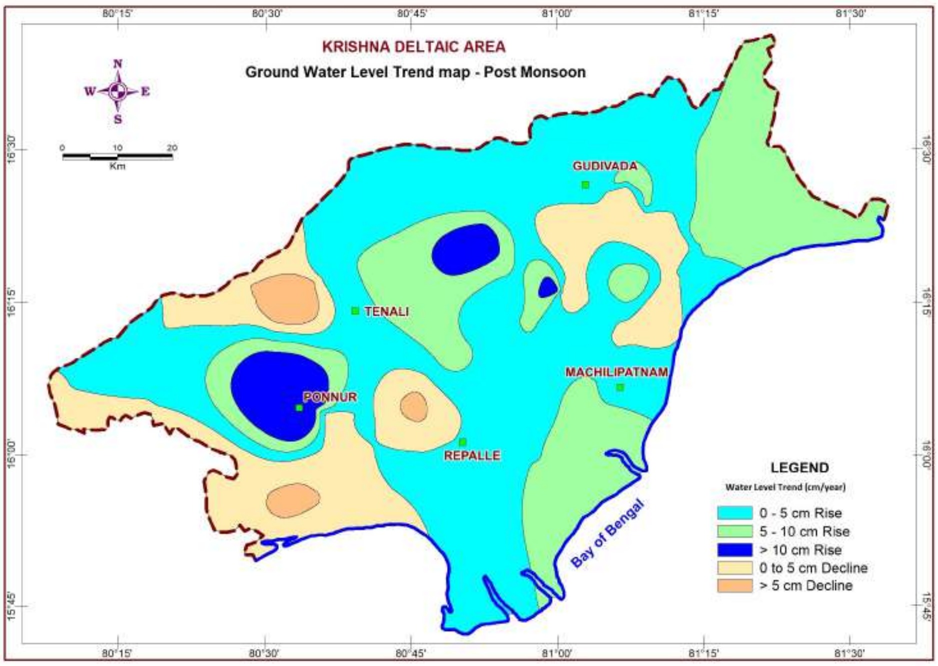


Fig 27 Ground Water Level Trend in the Area During Post monsoon Season

Ground Water Quality:

In order to understand the quality of ground water in the area, the chemical quality data of the ground water samples collected from shallow aquifers during pre monsoon period (2019) from monitoring stations is studied.

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 Ca Mg – $ClSO_4$ to Na K-$ClSO_4$ type (Fig. 28 a & b).

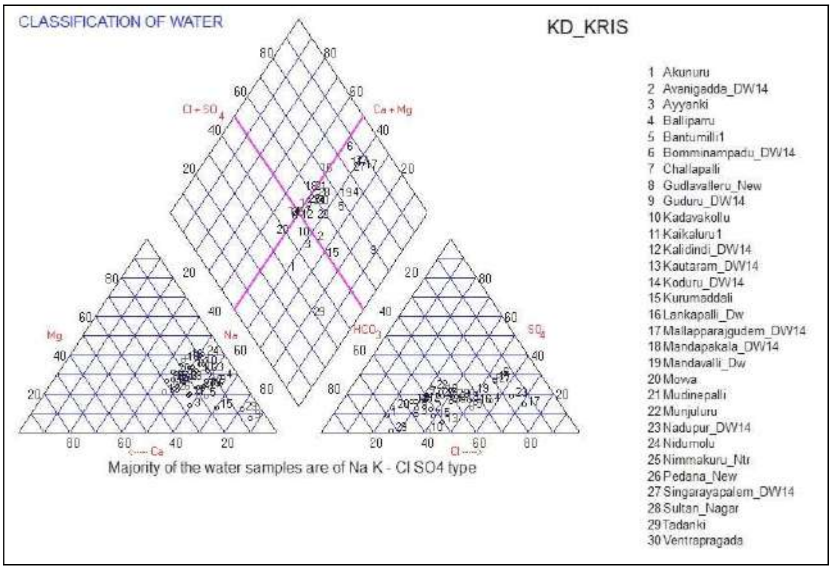


Fig. 28a Classification of Water - Piper's diagram

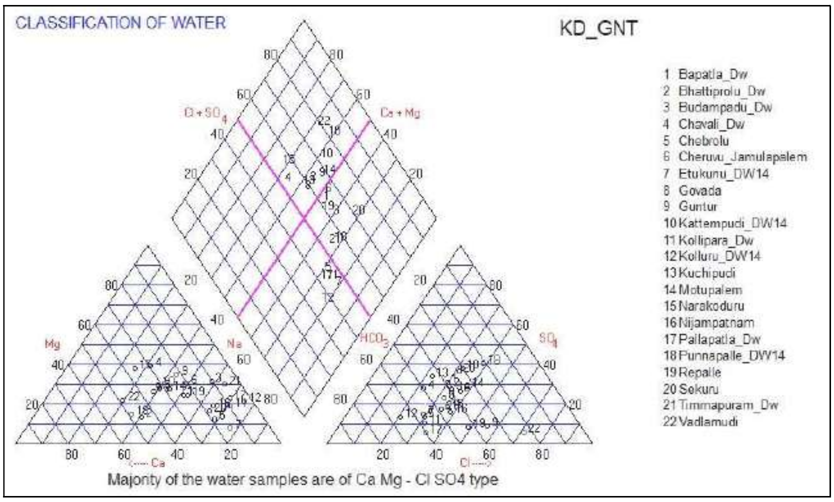


Fig. 28b Classification of Water - Piper's diagram

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.

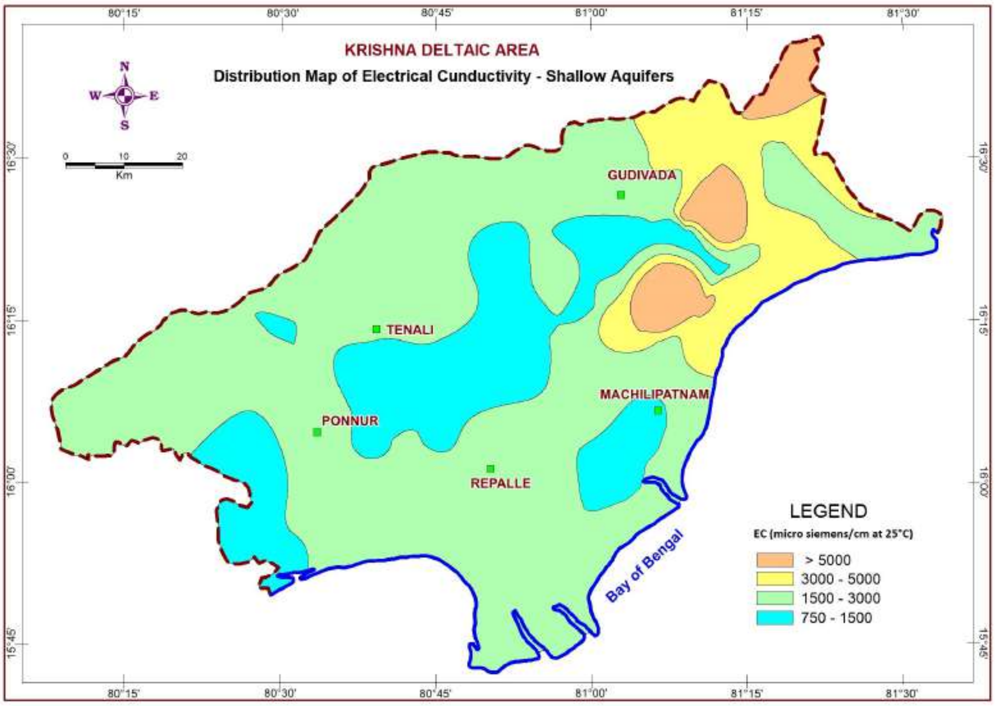


Fig. 29 Distribution of Electrical Conductivity in Shallow Aquifers

The EC distribution map reveals that in major portion of the study area EC values are less than 3000 micro siemens/cm at 25°C except in the eastern parts of the area where higher values recorded. The area near the coast does not have dug wells as the reported quality is bad. Hence the quality deterioration of ground water near the coast was not reflected in these maps. The Chloride distribution map for pre-monsoon period was prepared and presented as Fig. 30. The chloride map reveals that in major portion of the study area, Cl is less than 500 mg/l except in the eastern parts of the area where higher values recorded. The fluoride content in the ground water of the study area is < 1.30 mg/l. In general nitrate content in the ground water of the area is < 100 except at 4 places where it is recorded up to 150 mg/l.

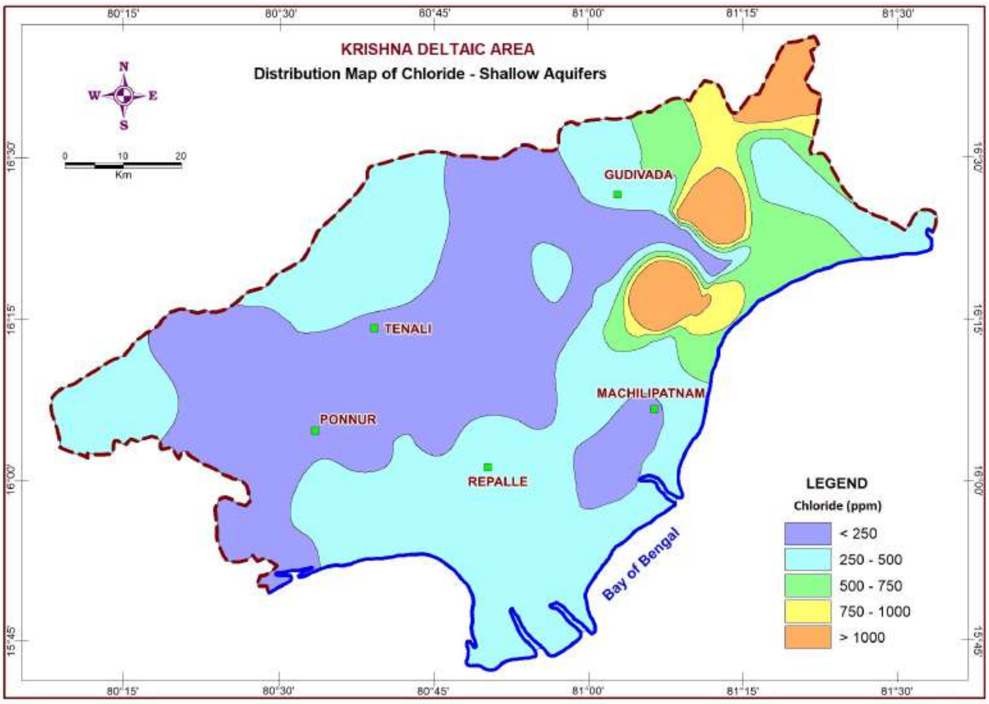


Fig. 30 Distribution of Chloride in Shallow Aquifers

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.

Table – 3 Ranges of Different Chemical Constituents in the shallow aquifer and Drinking Suitability

Constituent	Min.	Max.	Avg.	BSI Standards	
				Desirable Limit	Max. Permissible Limit
pH	7.03	8.05	7.67	6.5	8.5
EC	827	11810	2506	750	3000
TH	90	2600	561	300	600
Ca	6	260	93	75	200
Mg	13	474	80	30	100
Na	70	1500	306		
K	1	340	59		
CO3	Nil	Nil	-		
HCO3	220	1250	563		
Cl	74	2765	425	250	1000
SO4	1	1113	194	200	400
NO3	<1	150	38	45	100
F	0.19	1.42	0.54	1	1.5

Suitability for Irrigation Purpose

Suitability of ground water from the shallow aquifers in the area for irrigation purpose has been insinuated by USSL diagram (Fig. 31 a & b). 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.

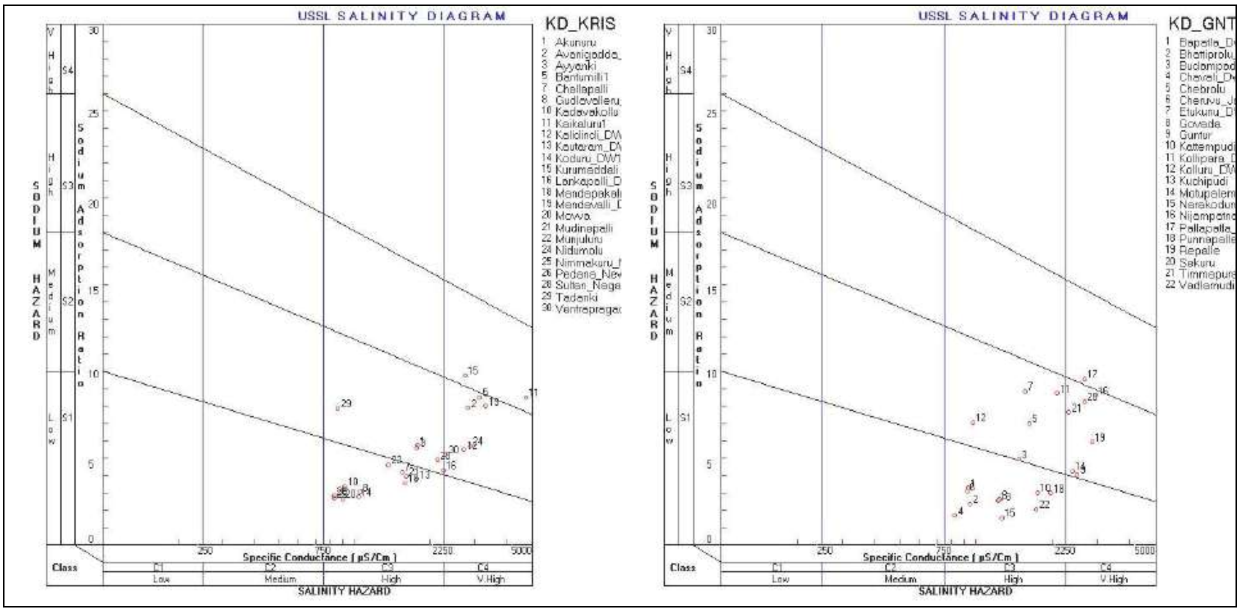


Fig. 31 Irrigation Classification of Ground Water

3. DATA INTERPRETATION, INTEGRATION AND AQUIFER MAPPING

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. Location of exploratory wells and cross section lines are shown as Fig. 11. Details of the data sets compiled for different studies are given below:

Organisation	Water Level		Water Quality		Aquifer Geometry		Geophysical
	Shallow	Deep	Shallow	Deep	EW/PZ	Depth Range(m)	Logging
CGWB	66	57	66	75	76	100 - 600	44
State GW Dept.	-	32	-	-	-	-	-
Total	66	89	66	75	76	100 - 600	44

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 NW parts of the area limited to small area. 3–dimentional lithological model of the area is presented as Fig. 32. 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, fence diagrams showing the aquifer disposition were prepared and presented as Fig. 33.

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. Hydrogeologic sections are synthesized based on the lithological logs and electrical logs.

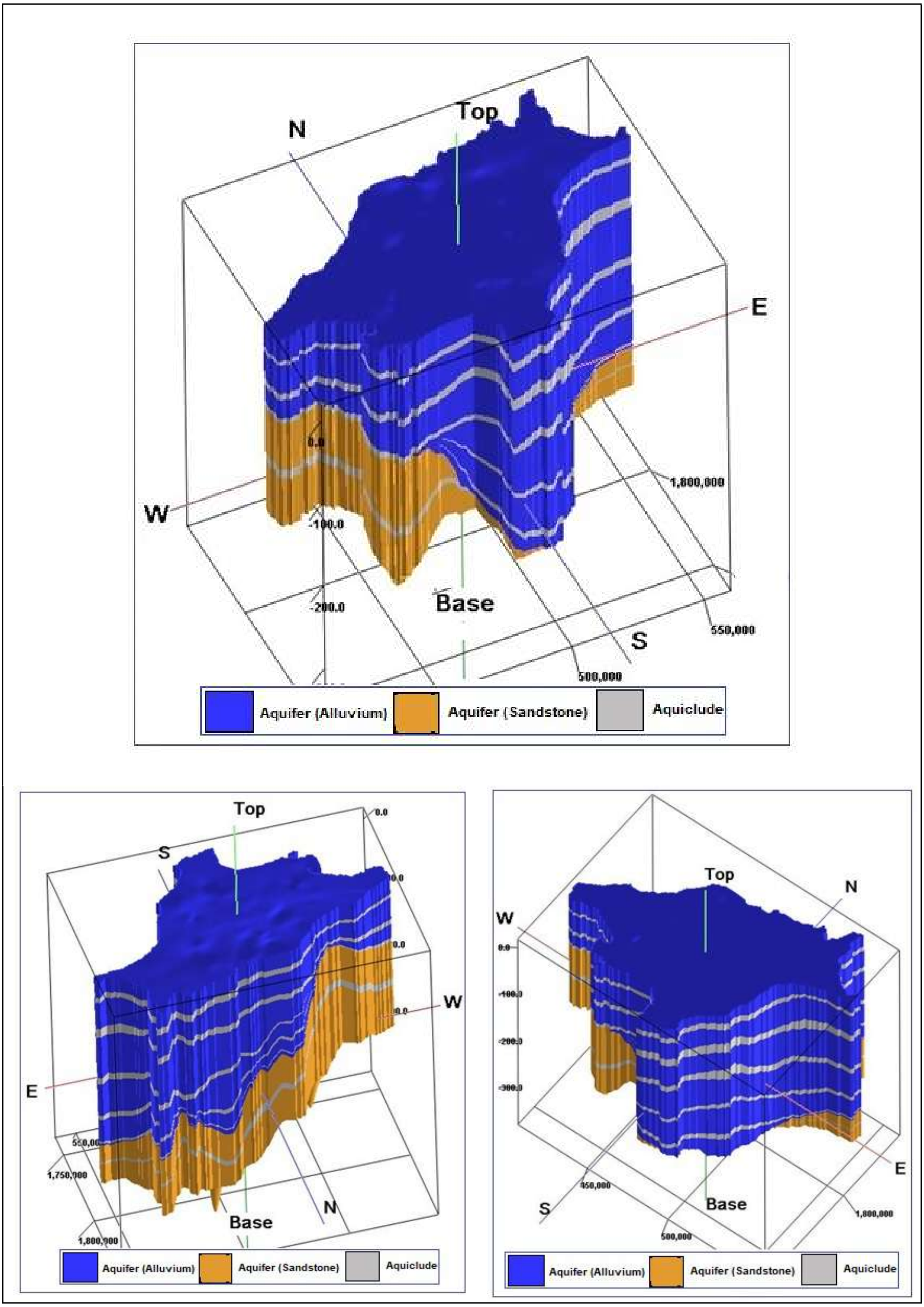


Fig. 32 3D Aquifer Disposition of the Area

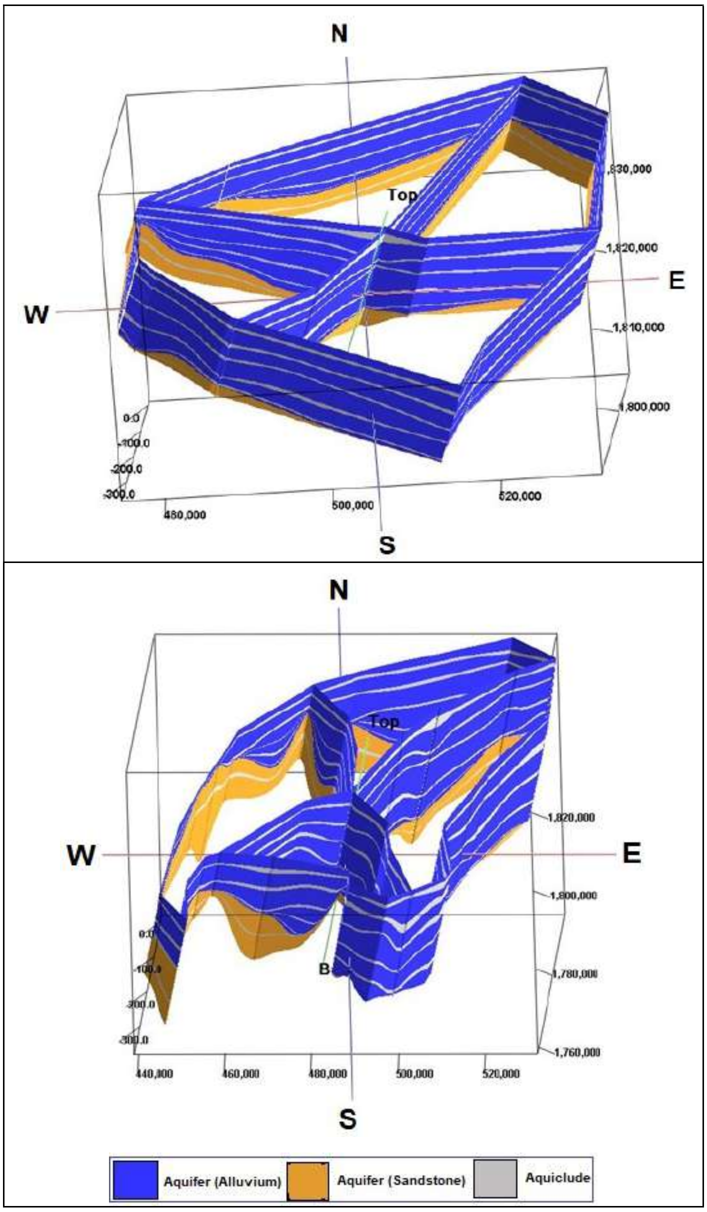


Fig. 33 Fence Diagrams

Hydrogeological cross sections drawn along different directions of the area are presented as Fig. 34 a to f. 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. 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.

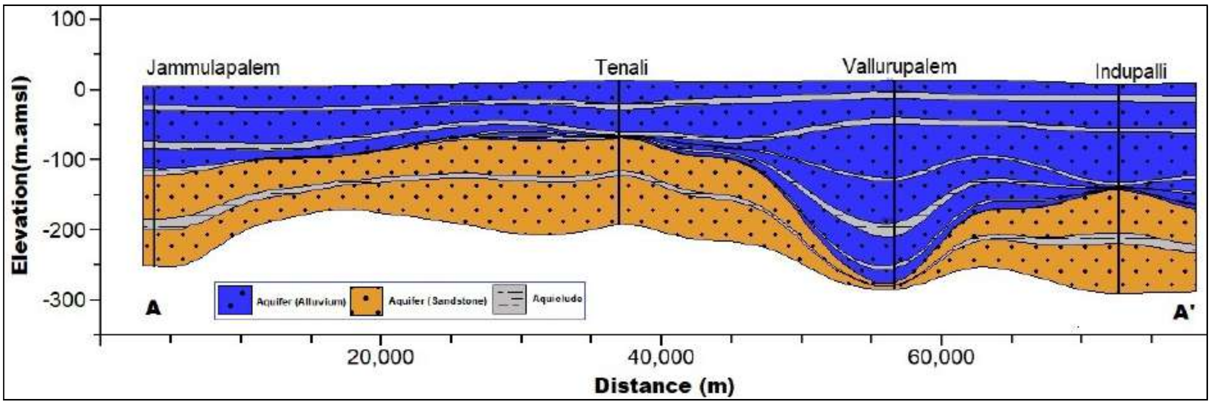


Fig. 34a Hydrogeological Cross Section along A – A'

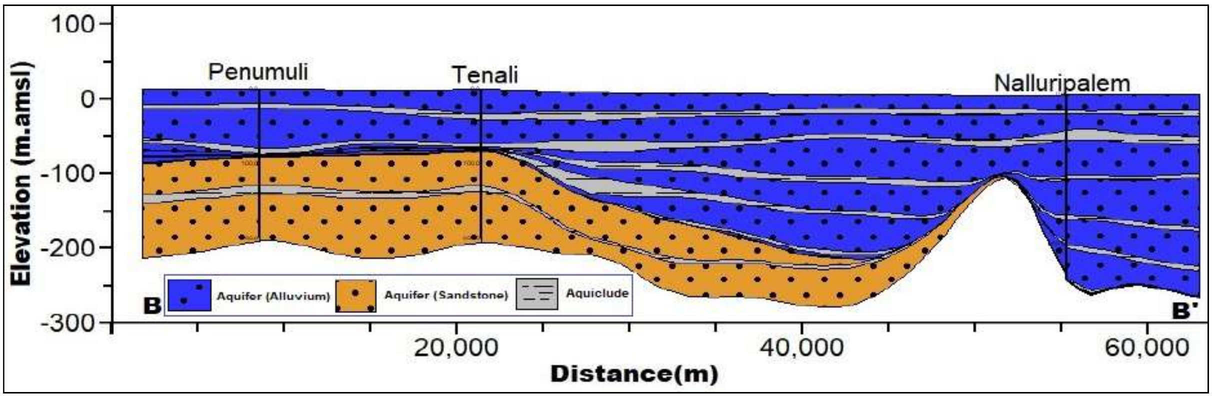


Fig. 34b Hydrogeological Cross Section along B – B'

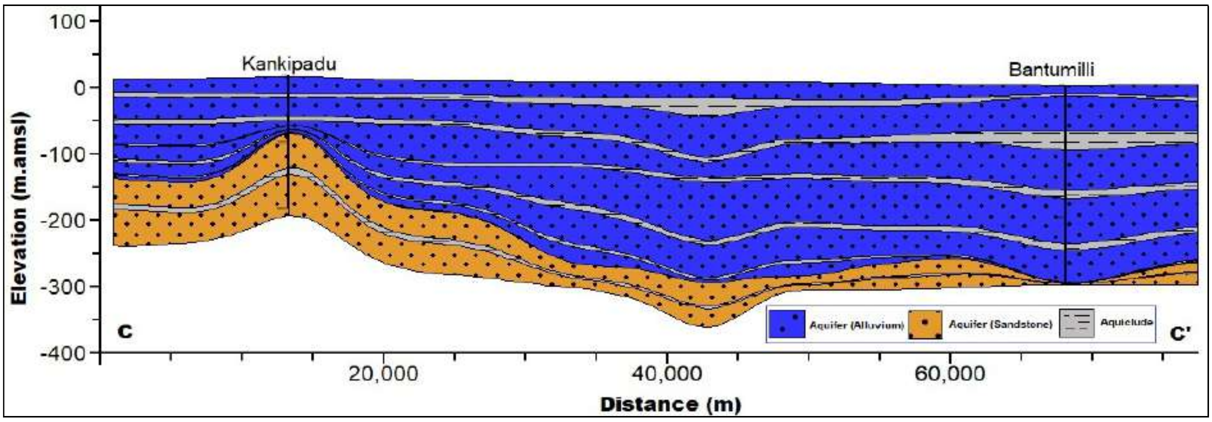


Fig. 34c Hydrogeological Cross Section along C – C'

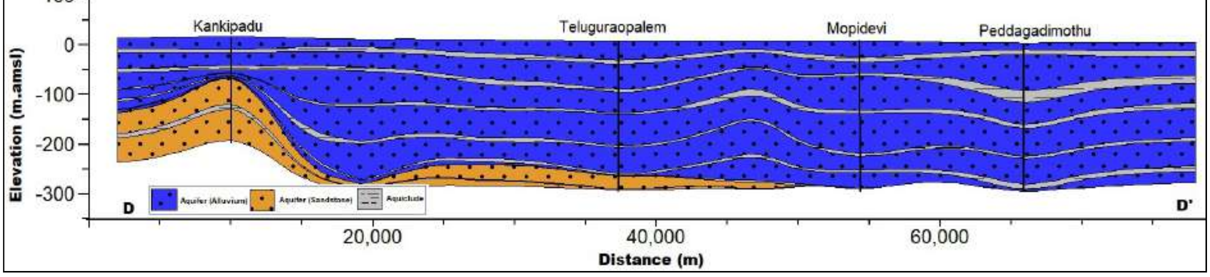


Fig. 34d Hydrogeological Cross Section along D – D'

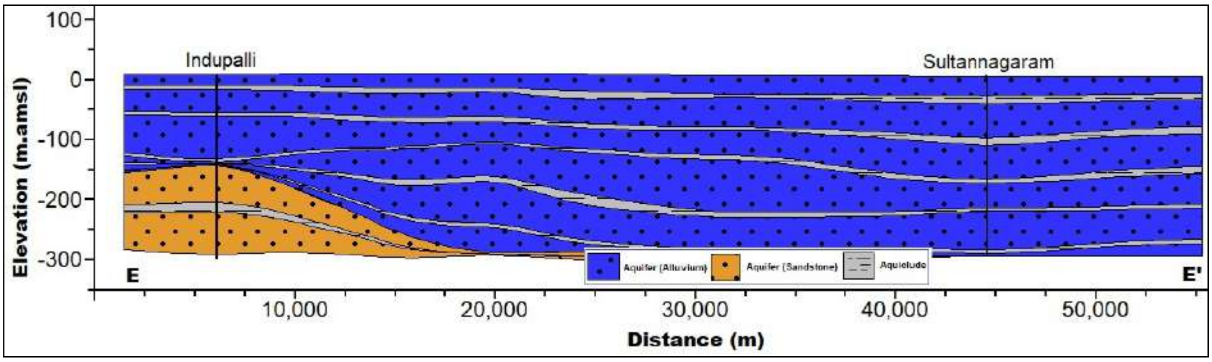


Fig. 34e Hydrogeological Cross Section along E – E'

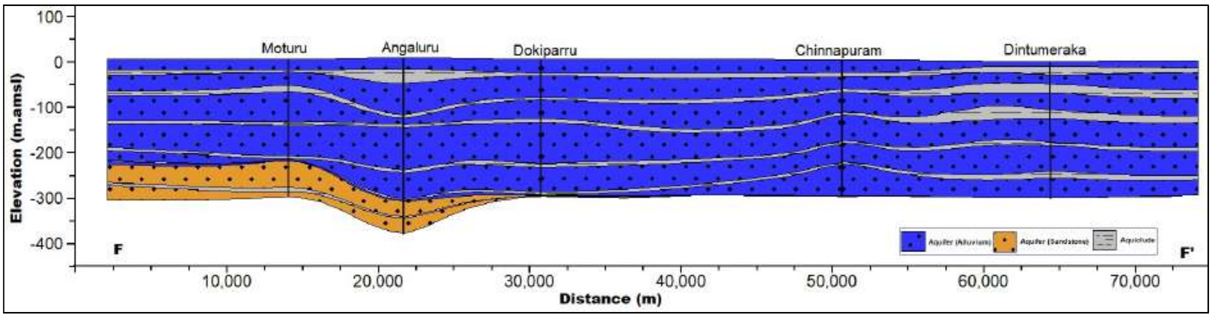


Fig. 34f Hydrogeological Cross Section along F – F'

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 two principal aquifers viz., Alluvium aquifers and Sandstone aquifers. Further these principal aquifers subdivided into different regional 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 Table-4. The Hydraulic parameters of Various Aquifers were statistically analysed and presented in the Table-5. The aquifer wise details are presented below.

Table-4 Disposition of 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

Table-5 Hydraulic Parameters of Different Aquifers

Aquifer	K				Ss			
	min	max	median	mean	min	max	median	mean
C1	9	122	21	42	5.33E-06	2.12E-03	2.19E-05	3.39E-04
C2	9	61	13	22	5.00E-06	5.10E-05	7.95E-06	1.80E-05
C3	3	66	17	20	3.95E-07	4.89E-05	7.59E-06	1.71E-05
C4	1	60	7	16	1.11E-06	6.48E-04	8.33E-06	2.19E-04
C5	2	2	2	2	4.35E-06	4.35E-06	4.35E-06	4.35E-06
	K				Sy			
	min	max	median	mean	min	max	median	mean
UC	9	31	15	18	4.22E-02	2.10E-01	1.26E-01	1.26E-01

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 (Fig. 18). The yield of the wells and Transmissivity (T) values varies from < 5 to 15 lps and 250 to 5500 m^2/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 (Fig. 29).

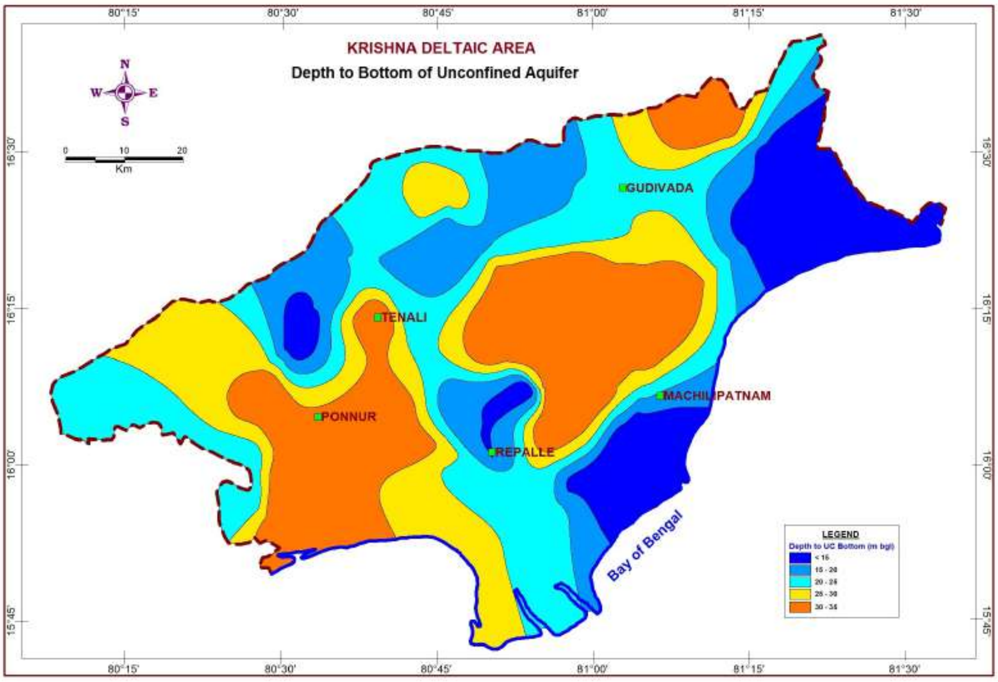


Fig. 35 Depth to Bottom of Unconfined Aquifer

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 (Fig. 36). The yield ranges from 2 to 18 lps. Transmissivity values are in the range of 264 to 3051 m^2/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 (Fig. 37).

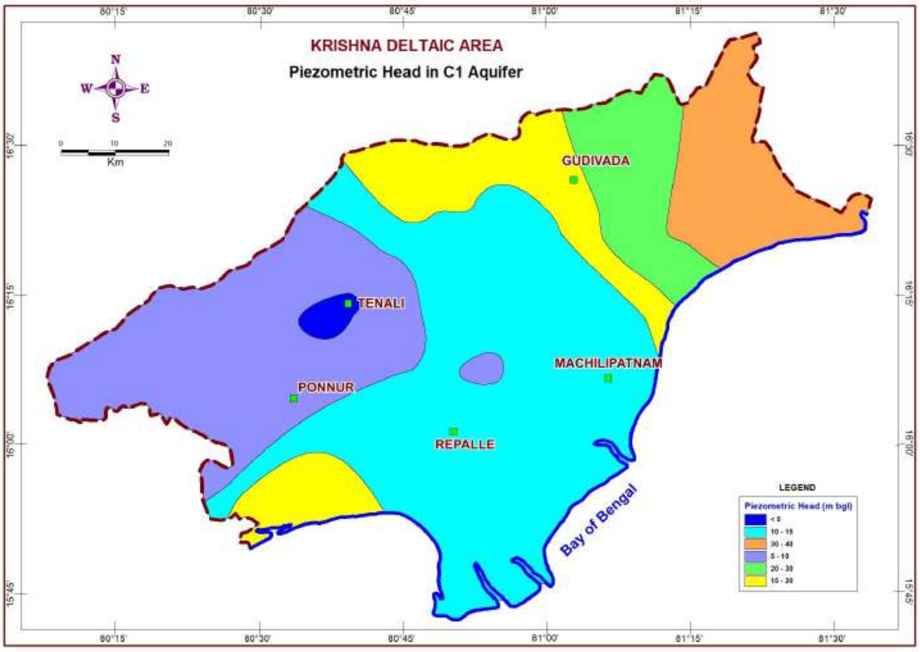


Fig. 36 Piezometric Head in C1 Aquifer

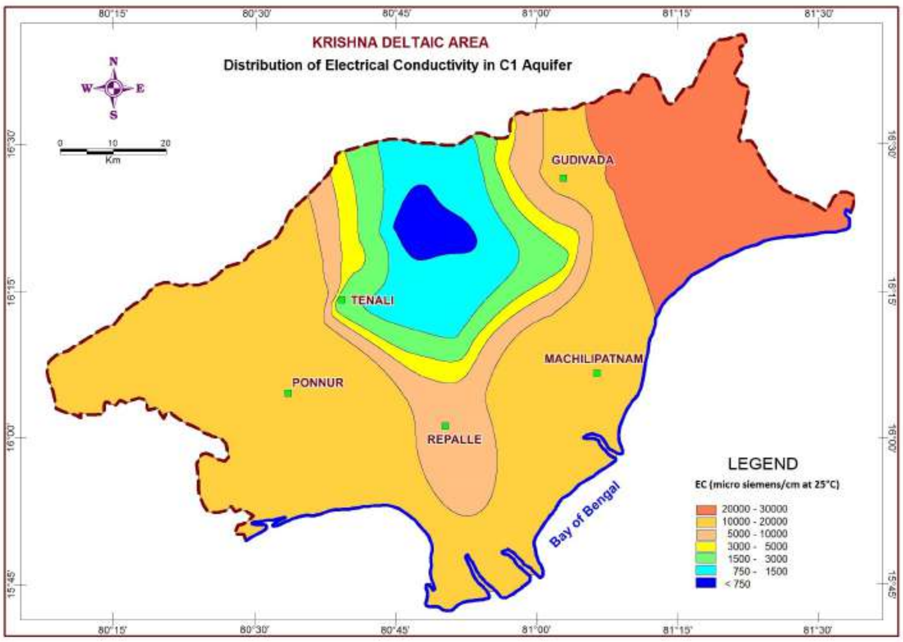


Fig. 37 Distribution of Electrical Conductivity in C1 Aquifers

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 m^2/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 (Fig. 39).

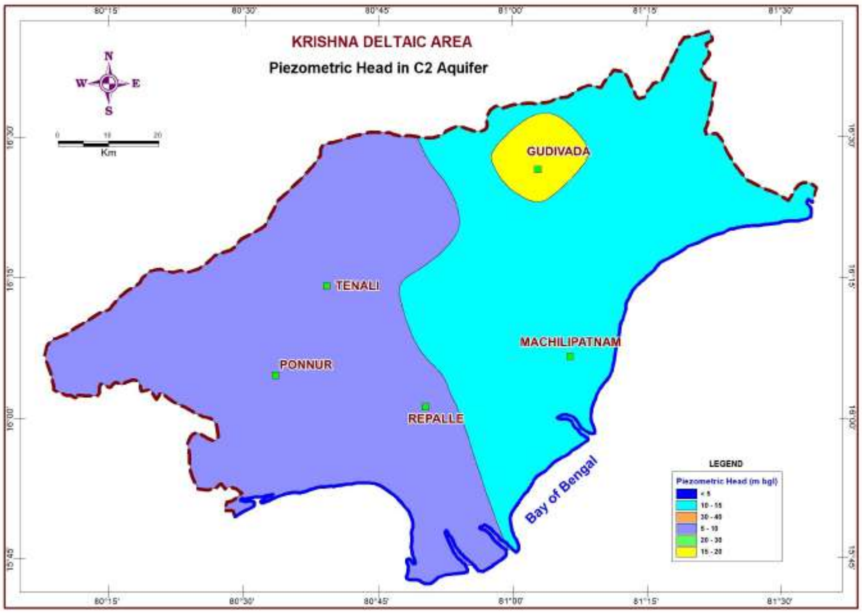


Fig. 38 Piezometric Head in C2 Aquifer

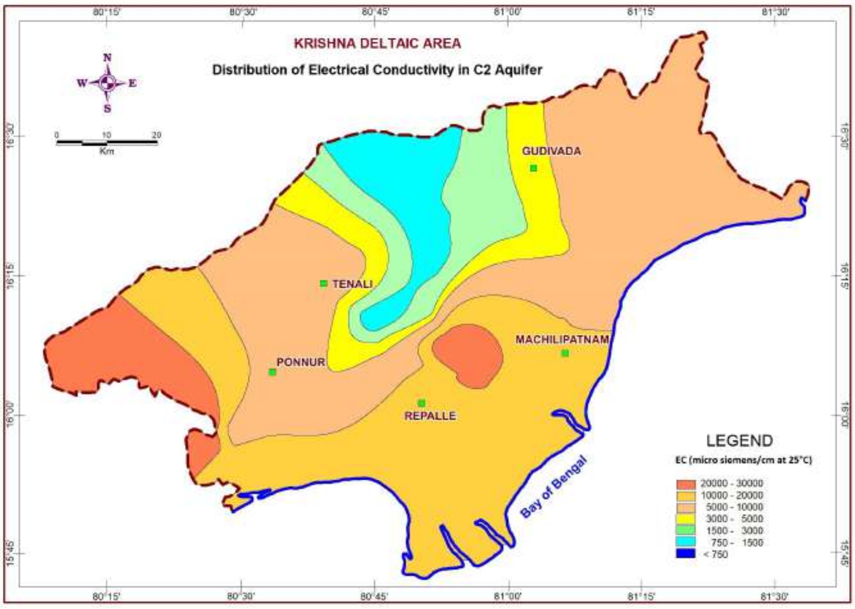


Fig. 39 Distribution of Electrical Conductivity in C2 Aquifers

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 m^2/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 (Fig. 41).

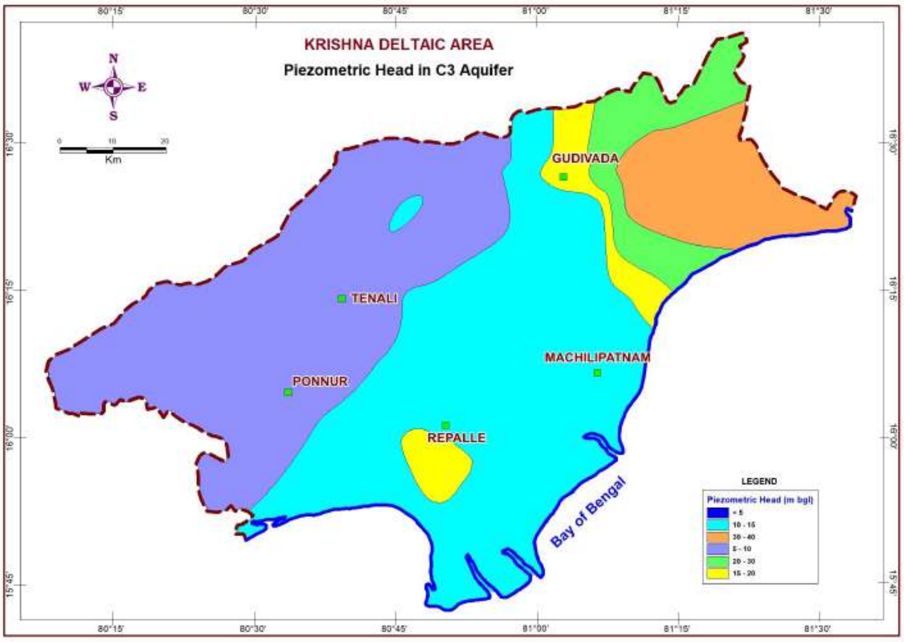


Fig. 40 Piezometric Head in C3 Aquifers

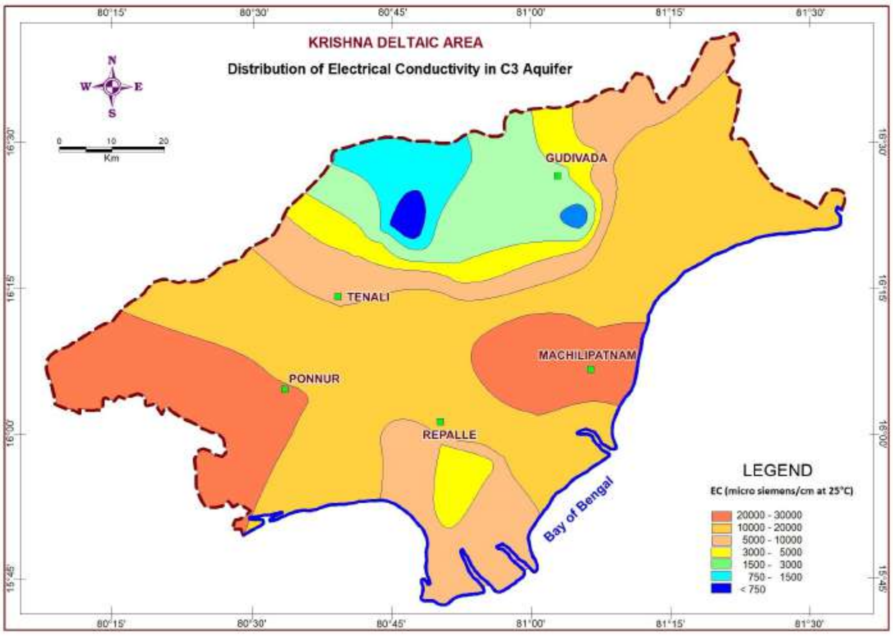


Fig. 41 Distribution of Electrical Conductivity in C3 Aquifers

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 m^2/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 (Fig. 43).

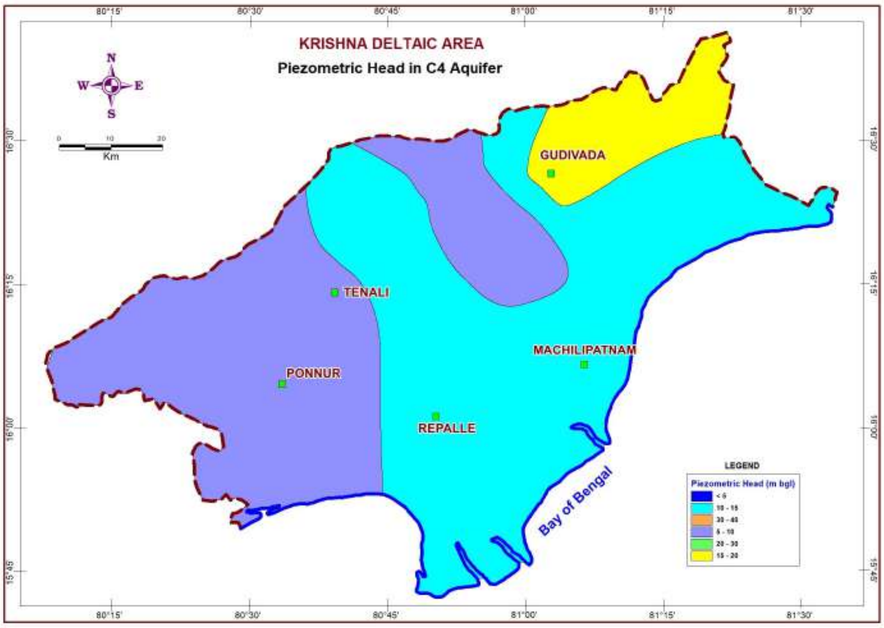


Fig. 42 Piezometric Head in C4 Aquifers

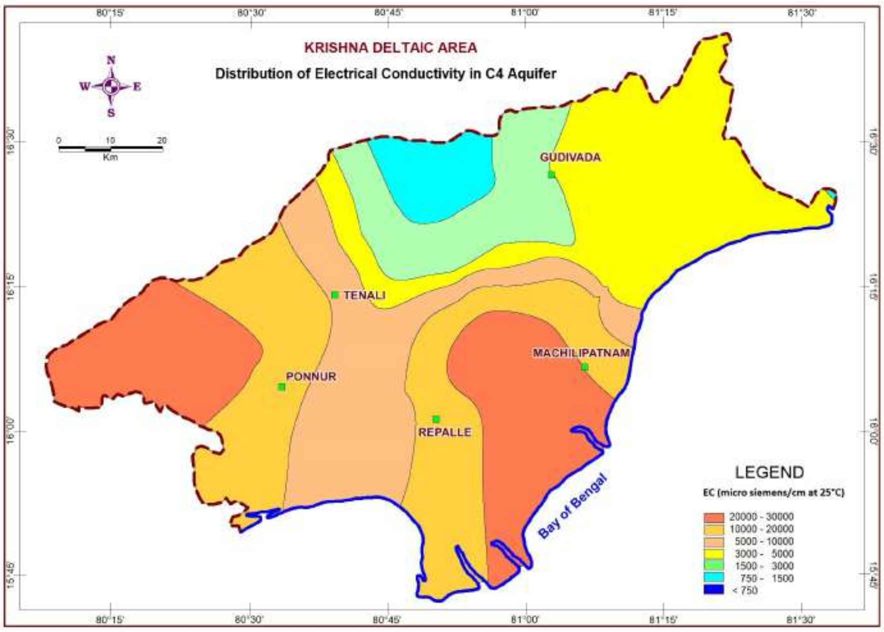


Fig. 43 Distribution of Electrical Conductivity in C4 Aquifers

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 m^2/day. Temperature of ground water from this aquifer varies from 34.40 to 40.60^{0}C. 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 (Fig. 44).

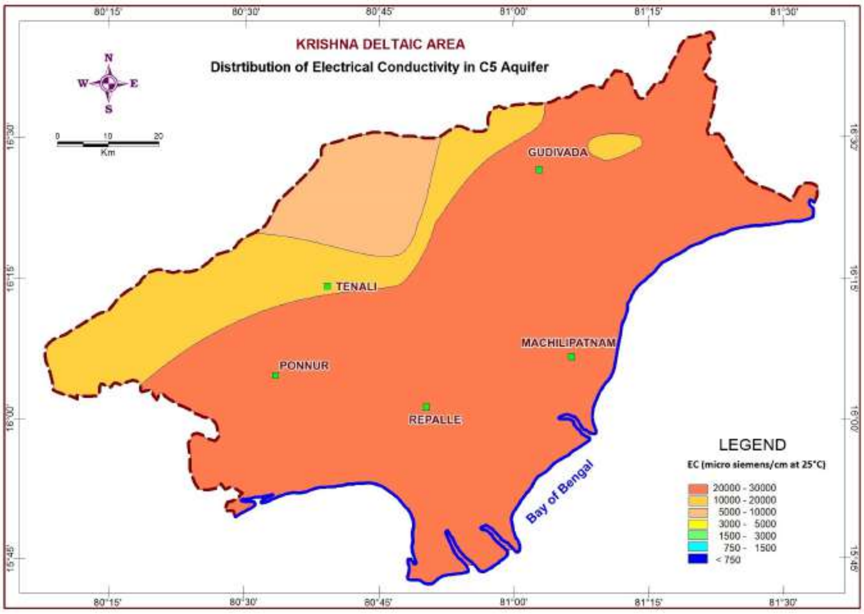


Fig. 44 Distribution of Electrical Conductivity in C5 Aquifers

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 m^2/day. The EC values of ground water vary from 800 to 21100 µS/cm at 25°C.

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 m^2/day and the EC of ground water is in the range of 2330 to 31200 µS/cm at 25°C. The temperature of ground water is varying from 31 to 42.20^{0}C. Due to scanty of the data, distribution maps of Piezometric head and quality (EC) not prepared for sandstone aquifers.

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 on both 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 Na K – Cl SO_4 type. Sandstone aquifers encountered below the alluvium are also yielding inferior quality of ground water except in the northern margin of the deltaic area.

The hydro chemical data reveals that the quality of ground water varies vertically among aquifers. Based on the vertical variation of ground water quality, following 9 scenarios identified in the area and shown as Fig. 45.

1. Fresh water aquifers all through
2. Saline water aquifers all through
3. Saline water aquifers overlying Highly Saline
4. Fresh water aquifers overlying Brackish
5. Fresh water aquifers overlying Brackish - Saline
6. Fresh water aquifers overlying Saline - Brackish
7. Brackish water aquifers overlying Saline
8. Saline water aquifers overlying Fresh - Saline
9. Saline water aquifers overlying Brackish – Saline

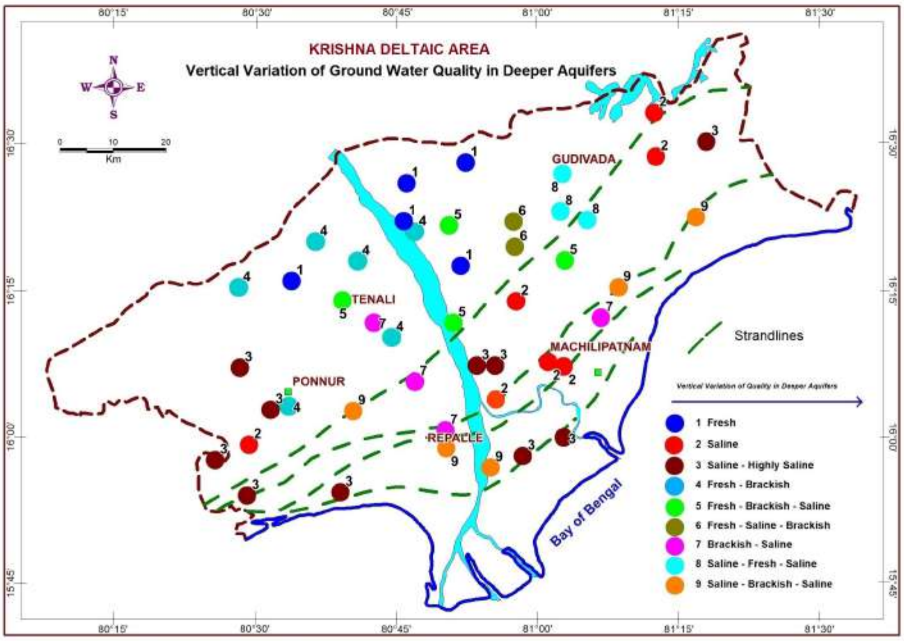


Fig. 45 Vertical Variation of Ground Water Quality in Deeper Aquifers

The above figure reveals that the occurrence of fresh water aquifers all through or at any depth are restricted up to 1st strandline only. A zone tapped from 182 – 198 m bgl at Vinnakota, which is just away from the 1st strandline has yielded fresh water (EC 1130) with a discharge of 13 lps. This fresh water zone is underlain as well as overlain by saline water zones. Away from the 1st strandline quality of ground water in all the aquifers is inferior except at Nagayalanka. A zone tapped from 135 – 141 m bgl at Nagayalanka has yielded brackish water (EC = 3800) with a discharge of 10 lps, whereas the zones above and below this aquifer are saline in nature. The aquifer that contains fresh water in the area up to 1st strandline appears to be charged with saline water away from the 1st strand line towards coast may be due to depositional environment i.e., marine. This clearly reflected in the schematic hydro chemical cross section drawn along Indupalli – Sultannagaram (Fig. 46).

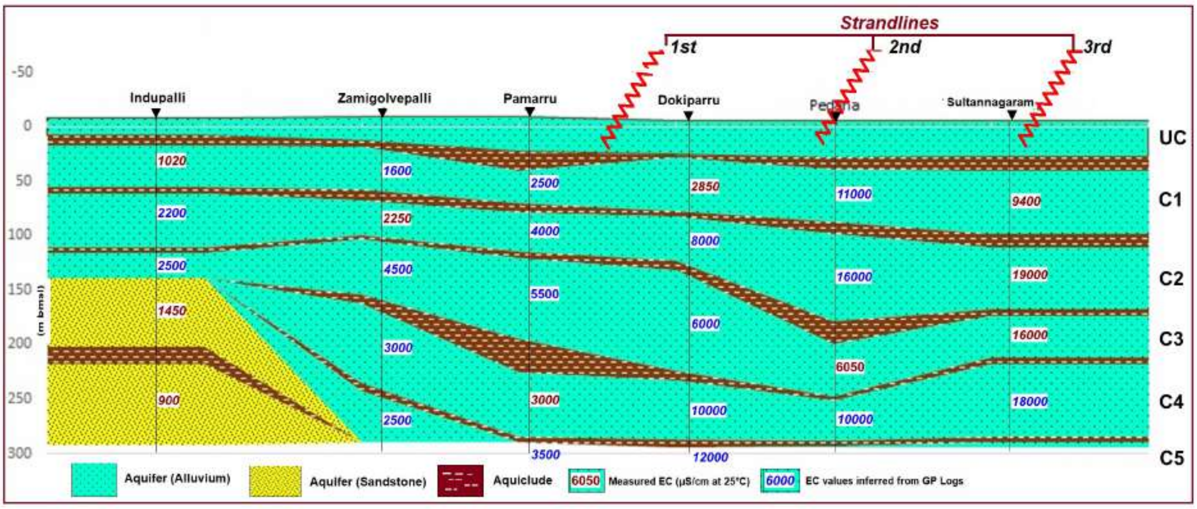


Fig. 46 Schematic Hydro chemical Cross Section Along Indupalli – Sultannagaram (E – E')

This figure clearly supports the hypothesis that the ground water in the deeper aquifers is saline because of its depositional environment. The present day recharge is not sufficient to completely flush the saline water from the aquifer. As the recharge to these aquifers is very less, the ground water movement also became very sluggish which in turn increases the salinity due to more contact period with the aquifer material. The above figure indicates that the recharge is taking place in the west of the section i.e., within 5 to 10 km which is a fresh water zone as it is not in marine environment even in Geological past which is indicated by the strand lines. The fresh water in the aquifer near Indupalli i.e., recharge areas try to flush the palaeo ground water towards sea. As the Quantum of recharge is less, it could not be flushed fully. This process is very well observed in this section by the increasing salinity towards eastern part of the section i.e., towards sea in the deeper aquifers.

The Ground Water Salinity in the deeper aquifers in Krishna Delta is mostly due to in-situ salinity as these sediments are deposited in the marine environment, which is indicated by the strand lines. The Electrical conductivity maps clearly indicate that some dilution of the saline water with fresh water in all aquifers, except the C5 aquifer where the dilution is very minimal. Fresh water zones which are available at depth at few places may be preserved as ground water sanctuaries with proper recharge to arrest any contamination from the saline water, which may be tapped in emergency situations.

By considering the inferior quality of ground water in deeper aquifers, it is felt that there is a requirement for recharging the deeper aquifers, which will in turn flush the saline water and increase the ground water head to reduce the sea water intrusion in these aquifers. The recharge should be specific to the saline aquifers in the area means it should be recharged in the recharge area of these aquifers, mostly which is in the northern side of the delta. With Proper Planning of recharge, these aquifers can be used as sanctuaries of Fresh water and can be tapped for domestic requirements in case of severe droughts. There should be proper control on the extraction from the sanctuary aquifers as people come to know the improvement in quality and start extracting for various purposes especially for irrigation and Industry which will defeat the purpose of the sanctuary.

Hydrogeological, hydro chemical and geophysical studies reveal that the existence of six distinct aquifers within 300 m bgl in the Krishna deltaic area. The maximum thickness of the alluvium/ sandstone is not established. The first aquifer is under unconfined conditions whereas the remaining aquifers are confined in nature. Shallow fresh water aquifer exists to a maximum depth of 35 m bgl, whereas quality of ground water in the deeper aquifers is in general saline. The occurrence of deeper fresh water aquifers all through or at any depth are restricted up to 1st strandline.

4. GROUND WATER RESOURCES

The study area is being the part of command of Krishna Irrigation system, the requirement of ground water for irrigation is limited and when required is met through dug wells and filter point. The Net annual ground water availability in the area is 1998 MCM. The gross ground water draft for all uses in the area is 387 MCM. Net ground water availability for future irrigation use is 988 MCM. The stage of ground water development in the area is 19%. Mandal wise unit recharge and draft details are presented as Fig. 47 & 48. The summarised details of the ground water resources (dynamic) of the area are given in Table-6. The entire area is categorised as safe (Fig. 49 & Table-7).

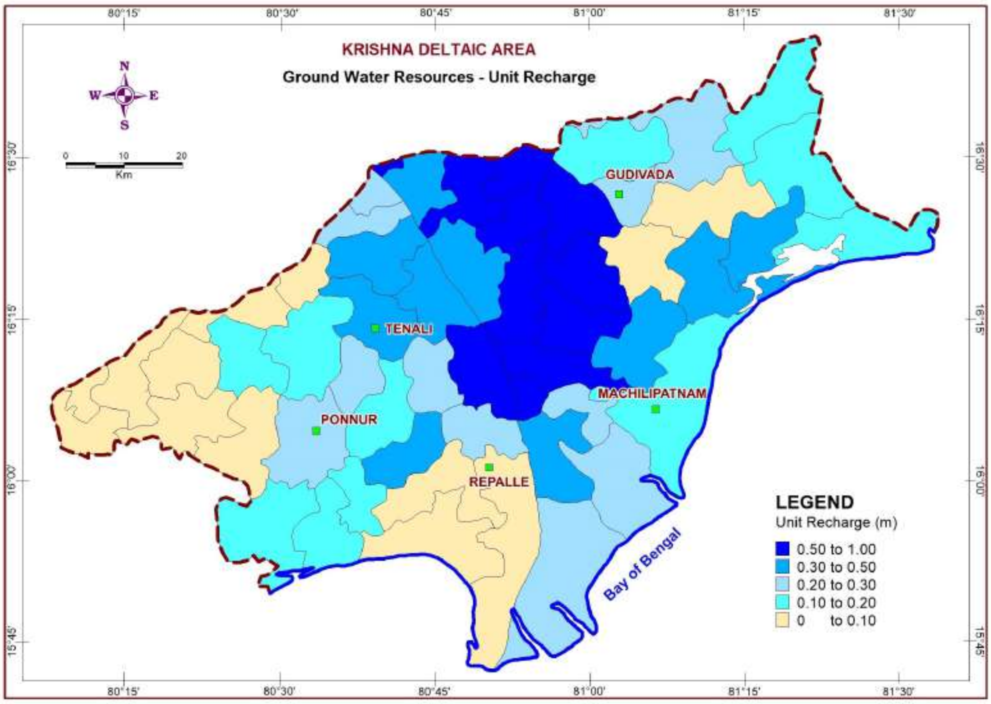


Fig. 47 Ground Water Resources – Unit Recharge of the Area

Water table contour maps were prepared using the reduced level. They show that the ground water is having a sea ward gradient, and there are conspicuous ground water discharges into the sea during pre & post monsoon seasons. Using the water table maps, the ground water discharges into sea were computed during both the pre and post monsoon seasons. The first approximation reveals that the lateral ground water flow from the aquifers is 1,02,284 m^3/day and 1,03,216 m^3/day during pre-monsoon and post monsoon periods respectively.

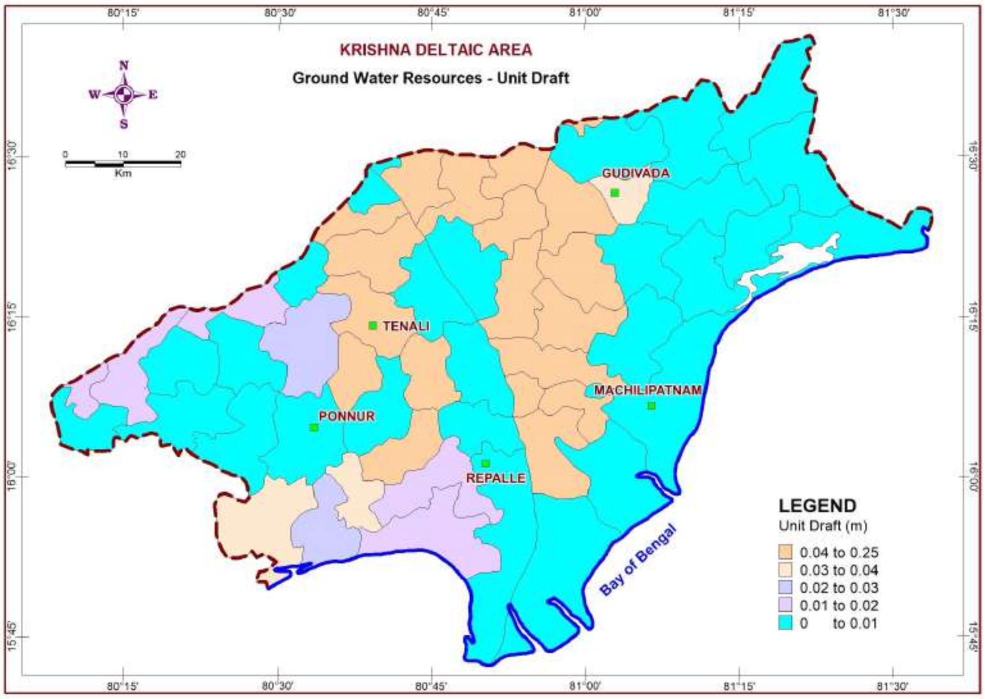


Fig. 48 Ground Water Resources – Unit Draft of the Area

Table-6 Summarised Ground Water Resources of the Area

Net annual ground water availability (MCM)	1998
Existing gross ground water draft for all uses (MCM)	387
Provision for domestic and industrial requirement supply to 2025 (MCM)	71
Net ground water availability for future irrigation development (MCM)	988
Stage of groundwater development (%)	19
Category	Safe

Table-7 Ground Water Resources - Mandalwise

S.No	District	Mandal/ Block	Net annual ground water availa-bility (Ham)	Existing gross ground water draft for all uses (Ham)	Provision for domestic and industrial requirement supply to 2025 (Ham)	Net ground water availability for future irrigation develop-ment (Ham)	Stage of groundwater develop-ment (%)	Cate-gory	Re-marks
1	Guntur	Amrutaluru	1241	493	77	749	40	safe	
2	Guntur	Bapatla	3812	817	204	2894	21	safe	PPQ
3	Guntur	Bhattiprolu	3234	987	231	2262	31	safe	
4	Guntur	Chebrolu	1522	362	157	1016	24	safe	
5	Guntur	Cherukupalle	3563	458	253	2962	13	safe	
6	Guntur	Chilakaluripeta	94	29	215	46	31	safe	
7	Guntur	Duggirala	6644	1506	269	5088	23	safe	
8	Guntur	Edlapadu	372	151	109	214	40	safe	
9	Guntur	Guntur	331	139	107	205	42	safe	
10	Guntur	Kakumanu	319	13	18	300	4	safe	
11	Guntur	Karlapalem	1482	266	124	1136	18	safe	PPQ

12	Guntur	Kolliparra	4983	1944	252	2985	39	safe	
13	Guntur	Kolluru	6281	3260	241	3872	52	safe	
14	Guntur	mangalagiri	1661	581	171	1159	35	safe	
15	Guntur	Nadendla	105	55	41	48	52	safe	
16	Guntur	Nagaram	1347	255	151	1073	19	safe	PPQ
17	Guntur	Nizampatnam	561	176	100	370	31	safe	PPQ
18	Guntur	Pedanandipadu	466	17	13	459	4	safe	
19	Guntur	Peddakakani	1041	165	139	915	16	safe	
20	Guntur	Pittalavanipalem	1407	299	171	1071	21	safe	
21	Guntur	Ponnur	3772	1600	460	2244	42	safe	
22	Guntur	Prattipadu	122	47	28	64	39	safe	
23	Guntur	Repalle	1407	214	320	1132	15	safe	PPQ
24	Guntur	Tadepalli	913	472	147	386	52	safe	
25	Guntur	Tenali	6110	1660	1032	4704	27	safe	
26	Guntur	Tsundur	2987	1114	216	1821	37	safe	
27	Guntur	Vatticherukuru	2314	25	24	2289	1	safe	
28	Guntur	Vemuru	3172	1025	193	2121	32	safe	
29	Krishna	Avanigadda	3291	403	76	2885	12	safe	
30	Krishna	Bantumilli	5289	0	0	0	0	safe	PQ
31	Krishna	Challapalli	2523	1388	97	1135	55	safe	
32	Krishna	Ghantasala	7060	983	79	6063	14	safe	
33	Krishna	Gudivada	2321	444	228	1744	19	safe	
34	Krishna	Gudlavalleru	988	0	0	0	0	safe	PQ
35	Krishna	Guduru	6414	0	0	0	0	safe	PQ
36	Krishna	Kaikaluru	2319	0	0	0	0	safe	PQ
37	Krishna	Kalidindi	2571	0	0	0	0	safe	PQ
38	Krishna	Kankipadu	5997	2317	125	3716	39	safe	
39	Krishna	Koduru	6682	0	0	0	0	safe	PQ
40	Krishna	Krutivennu	3053	0	0	0	0	safe	PQ
41	Krishna	Machilipatnam	6482	0	0	0	0	safe	PQ
42	Krishna	Mandavalli	3848	0	0	0	0	safe	PQ
43	Krishna	Mopidevi	5049	1678	114	3527	33	safe	
44	Krishna	Movva	8746	1448	110	7259	17	safe	
45	Krishna	Mudinepalli	7400	0	0	0	0	safe	PQ
46	Krishna	Nagayalanka	8843	0	0	0	0	safe	PQ
47	Krishna	Nandivada	1720	0	0	0	0	safe	PQ
48	Krishna	Pamarru	7253	1059	118	6183	15	safe	
49	Krishna	Pamidimukkala	7290	2430	177	4881	33	safe	
50	Krishna	Pedana	7249	0	0	0	0	safe	PQ
51	Krishna	Pedaparupudi	6964	1339	60	5622	19	safe	
52	Krishna	Penamaluru	2928	1607	145	1423	55	safe	
53	Krishna	Thotlavalluru	5118	2565	112	2582	50	safe	
54	Krishna	Unguturu	3767	733	65	3034	19	safe	
55	Krishna	Vijayawada	569	123	23	445	22	safe	
56	Krishna	Vuyyuru	6787	2101	156	4678	31	safe	
		Total	**199785**	**38747**	**7146**	**98766**	**19**	**Safe**	

PQ = Poor-Quality area; PPQ = Partially Poor-Quality area

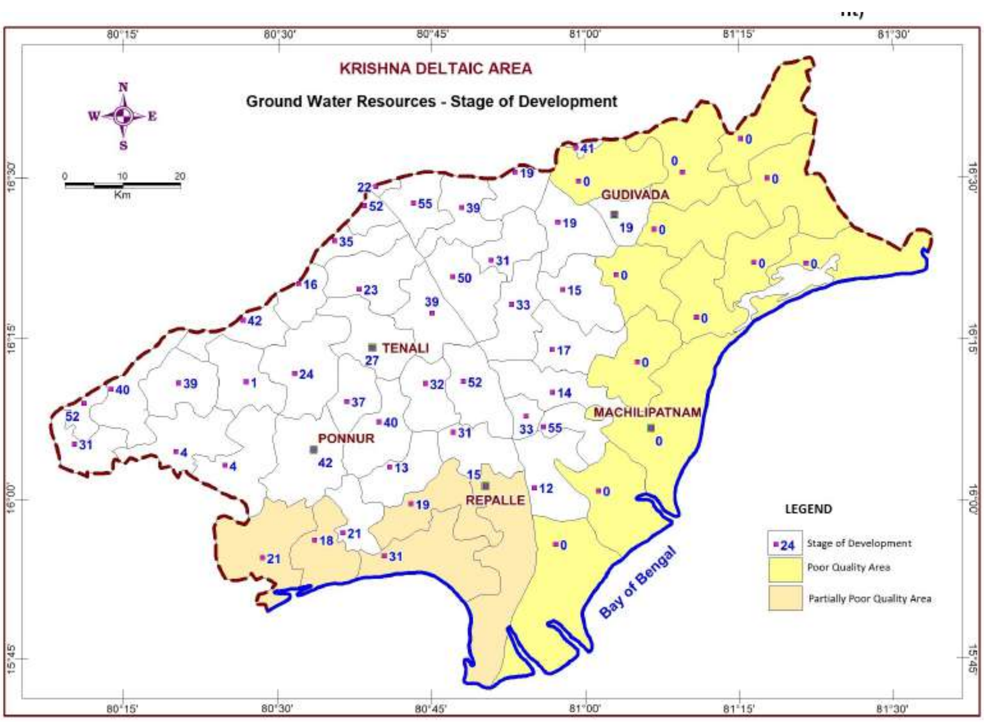


Fig. 49 Ground Water Resources – Stage of Development in the Area

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 Aquafeed 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 500 km^2 (7%) is under water logged condition during pre-monsoon period, whereas during post-monsoon period it is extended to 4,800 km^2 (66%) (Fig. 18 & 19). The area prone to water logging during pre-monsoon and post-monsoon periods is 3,000 km^2 (41 %) and 1,300 km^2 (18 %) respectively. Irrigation by surface water, minimal withdrawal of ground water, 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 300 m bgl and the top one is up to maximum of 35 m 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 15 m and 104 m 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 CGWB 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 1,02,284 m^3/day and 1,03,216 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 baseflow 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: Ground Water 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 upconing 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 upconing 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 ~ 35 m 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.

For estimating the status of sea water ingress Ghyben-Hertzberg surface was prepared for both the pre and post monsoon seasons at different places. The perusal of the Ghyben-Hertzberg surface during pre monsoon season indicates that in general the saline water occurs at a depth of 40 - 400 m in general in the area. During post monsoon season saline water occurs at deeper level compare to pre-monsoon season. The aquifer has an extension upto ~ 35 m below MSL hence normally in the interior areas there will not be any effect of this current day intrusion. To identify the extent of damage, different sections were prepared and studied. The distance from the coast Vs Depth to Ghyben-Hertzberg surface was made. The study indicates that in general the toe of the interface is effective up to 3700 to 5500 m from the coast during pre-monsoon season and 3500 to 3800 m from the coast during post monsoon season (Fig. 50, 51 & 52).

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.

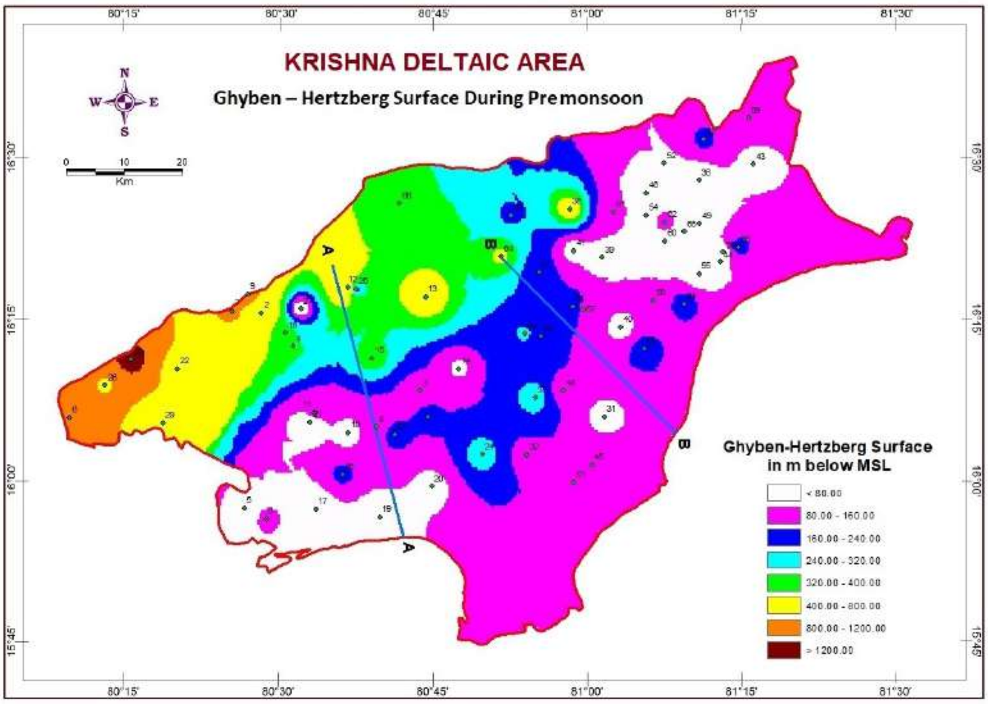


Fig. 50 a Ghyben – Hertzberg Surface in the Area During Pre monsoon

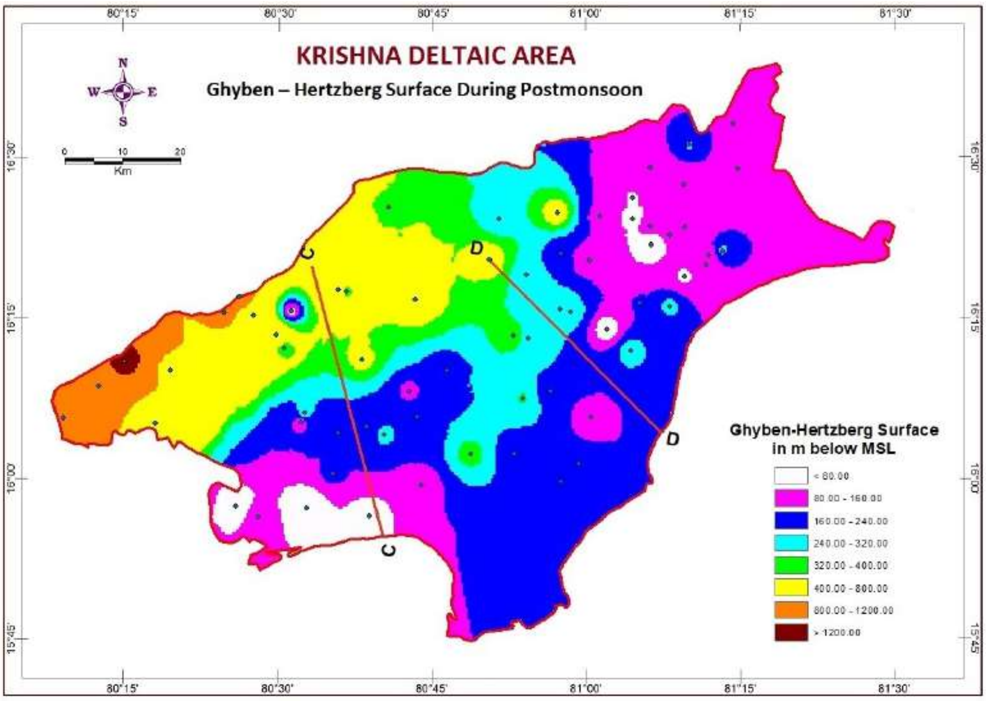


Fig. 50 b Ghyben – Hertzberg Surface in the Area During Post monsoon

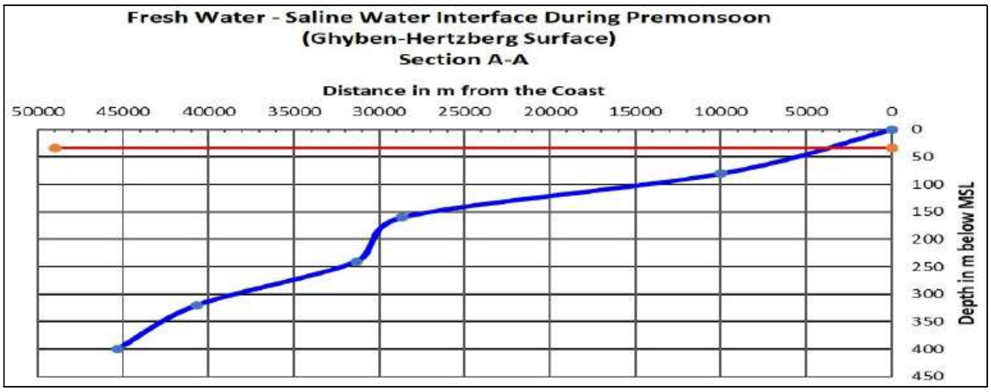


Fig. 51 a Location of the Toe of Fresh Water – Saline Water Interface During Pre monsoon

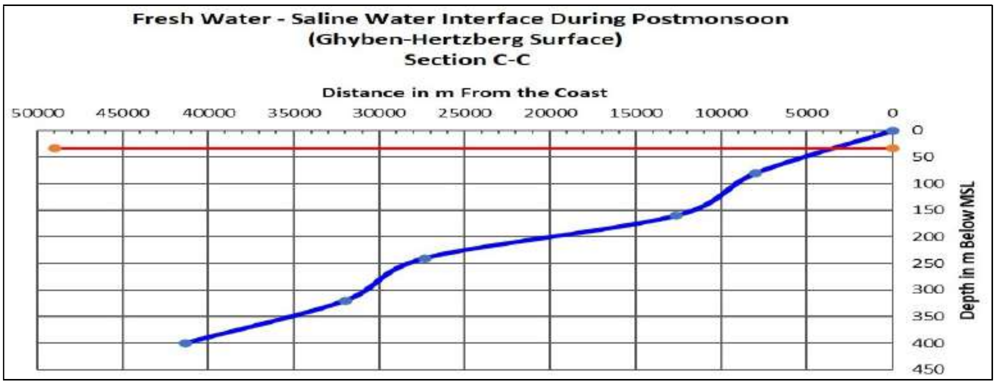


Fig. 51 b Location of the Toe of Fresh Water – Saline Water Interface During Post monsoon

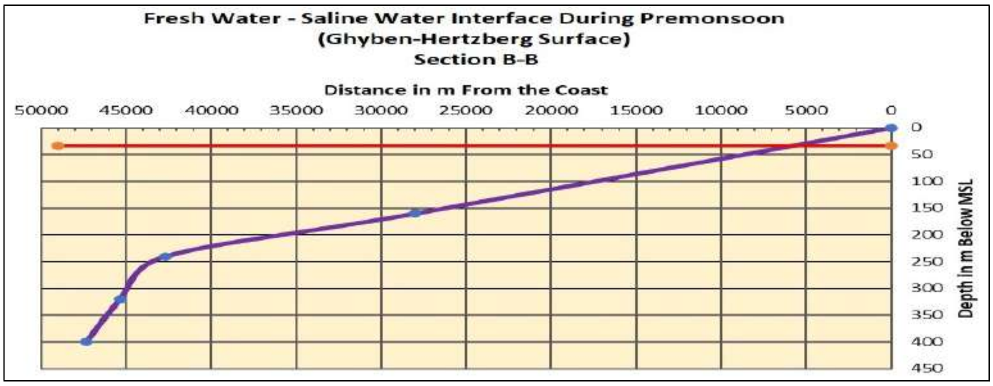


Fig. 52 a Location of the Toe of Fresh Water – Saline Water Interface During Pre monsoon

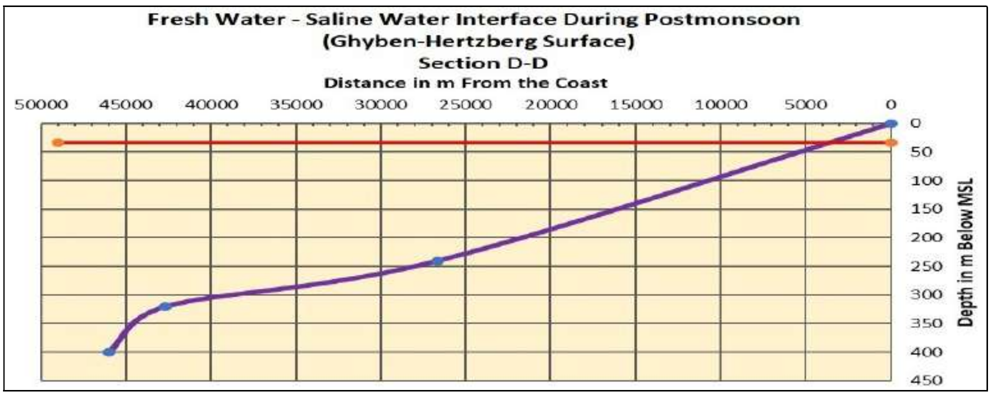


Fig. 52 b Location of the Toe of Fresh Water – Saline Water Interface During Post monsoon

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 (Uppputeru) 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 neighbouring areas.

6. MANAGEMENT PLAN

The Problems in the Krishna Delta can be summarised 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 utilised 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 utilising 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 GW 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 utilised 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 2 m above MSL 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 2 kms 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 2 kms 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 2 kms 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 interbasin 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 Should not be encouraged beyond 2 kms 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 2 kms from the sea. Artificial Recharge measures should be encouraged to be practised in upper reaches such that the ground water head is always 2 m above MSL.

Management Plan for the areas which are water logged 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.

7. SUM UP

- Krishna deltaic area is covering an area of 7278 km^2.
- Topographically the area is gently undulating to near flat.
- The normal rainfall of the area is 1052 mm. The area depicts marine landforms like beach, spit, mudflats etc. and aeolian landforms like sand dunes and fluvial landforms like channel bars, meander scars, oxbow lakes and deltaic plains. The presence of beach ridge complexes on land indicates the existence of four strand lines.
- Paddy is the main crop and the surface water is main source of irrigation.
- The area is underlined by alluvium which is followed by sandstones at varying depths and at places by crystallines. The thickness of alluvium varies from a few meters to more than 400 m.
- Alluvium is the principal aquifer, which is followed by sandstone aquifer.
- Six aquifers exist up to a depth of 300 m in alluvium, whereas two aquifers exist in sandstone.
- The shallow aquifer (UC) are limited in thickness and varying between <10 m to 35 m bgl. and is being tapped by dug wells, filter points/ shallow tube wells and the depth of the wells generally ranges from 3 to 12 m and the yields are up to 15 lps.
- The deeper aquifers are (C1, C2, C3, C4 & C5) are in confined conditions and not being tapped as the quality of the water is saline except the areas in the northern part of the area in the near vicinity of the river Krishna.
- Over all, the ground water development is low in the delta area and being developed as and when need arises.
- In general ground water levels in shallow aquifer are < 6 m and < 4 m during pre monsoon and post monsoon seasons respectively. No significant changes exist in the long term water level trend. Piezometric head in deeper aquifers is varying from < 5 m to 40 m bgl.
- The variation in ground water quality in the area is observed in space and time. The quality of ground water in shallow aquifers is fresh except the area near coast, where as the deeper aquifers in general are saline. Sandstone aquifers encountered below the alluvium are also inferior in ground water quality except in the northern margin of the deltaic area. The occurrence of deeper fresh water aquifers all through or at any depth are restricted up to 1st strandline.
- Net ground water availability is 1998 MCM and the stage of development is 19%.

- The hydraulic gradient is towards sea and the fresh water discharges into sea were computed as 102284 m^3/day and 103216 m^3/day during the pre and post monsoon seasons respectively.
- An area of 500 km^2 (7 %) and 4800 km^2 (66%) under water logged condition during pre monsoon and post monsoon periods respectively. Whereas the area prone to water logging is 3000 km^2 (41 %) and 1300 km^2 (18 %) during pre monsoon and post monsoon periods respectively.
- Ground water salinity problem in shallow aquifers exist mainly in the coastal area and some inland pockets area. Sea water intrusion is observed at few places in the coastal area due to the exploitation of ground water during water scarce periods.
- The quality of ground water is getting deteriorated due to aquaculture activities particularly in the area near the coast.
- There is a need for proper monitoring of the saline water - fresh water interface in the area by establishing purpose-built piezometers with predefined monitoring parameters of ground water level and quality with reference to depth.
- In the area along the coast, it is very much essential to demarcate the dynamic boundary of saline and fresh water interface and proper measures should be taken up, to restrict the interface below the maximum pumping water level.
- Navigable coastal/tidal regulators may be installed on the creeks to check the quality deterioration where the direct recharge of saline water is taking place due to back waters.
- Conjunctive use of surface water and ground water should be adopted to minimize the water logging problem.
- Excess surface water to be utilised for recharging the deeper aquifers in the recharge area of the deeper aquifers to make them 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.
- Existing regulations must be adhered strictly to avoid ecological imbalances and environmental problems arise due to aquaculture.

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