केंद्रीय 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

EAST GODAVARI AND WEST GODAVARI DISTRICT, ANDHRA PRADESH

दक्षिणी क्षेत्र, हैदराबाद

Southern Region, Hyderabad

REPORT ON

AQUIFER MAPPING AND MANAGEMENT PLAN OF GODAVARI DELTAIC AREA PARTS OF EAST GODAVARI AND WEST GODAVARI DISTRICTS ANDHRA PRADESH

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REPORT ON

AQUIFER MAPPING AND MANAGEMENT PLAN OF GODAVARI DELTAIC AREA PARTS OF EAST GODAVARI AND WEST GODAVARI DISTRICTS ANDHRA PRADESH

Area at a Glance

1	Districts Area Location	:	Parts of East Godavari and West Godavari 6,950 Km^2 16° 18' to 17° 15' N 80° 57' to 82° 33' E
2	Mandals Villages	:	67 (Full = 52, Part = 15) 920
3	State	:	Andhra Pradesh
4	Normal Rainfall (mm)	:	840 – 1580 mm Monsoon : ~ 70% Non-Monsoon : ~ 30%
5	Major Drainage	:	Godavari
6	Gross area sown	:	6,25,000 ha Major crop : Paddy Irrigation is mainly based on surface water
7	Ground water levels (2016)		Shallow Aquifer: < 1 - 9 m Deeper Aquifer : 2 – 12 m (Piezometric head)
8	Aquifer - characteristics	:	Alluvium General depth range of wells = 3 – 12 m Yield = 25 – 90 m^3/hr
9	Ground water Resources (MCM)	:	Dynamic Resources : • Net GW availability : 3116 • Gross GW draft : 335 • Stage of GW Development : 11% • Category : Safe
9	Chemical quality of ground water	:	• Shallow Aquifer : Fresh • Deeper Aquifers : Brackish to Saline
10	Major Ground Water Issue	:	• Ground Water Salinity • Aquaculture • Water Logging

REPORT ON

AQUIFER MAPPING AND MANAGEMENT PLAN OF GODAVARI DELTAIC AREA PARTS OF EAST GODAVARI AND WEST GODAVARI 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 Godavari deltaic area covering parts of East Godavari and West Godavari districts of Andhra Pradesh as per AAP 2017-18 of CGWB, SR, Hyderabad. The main objective of the study is to prepare aquifer maps and to suggest ground water management plans of the area.

Study Area :

Godavari Delta is one of the major delta systems along the east coast of India. The naturally formed two major branches of Godavari River called Gauthami Godavari and Vasishta Godavari divide it into three units viz., Eastern Delta, Central Delta and Western Delta. Administratively the Eastern Delta and Central Delta are in East Godavari District and the Western Delta is in West Godavari District of Andhra Pradesh. Only after construction of

the Anicut on river Godavari at Dowlaiswaram by Sir Arthur Cotton in 1852, gradual and regulated development took place in terms of irrigation and agricultural production thus making the area as the Granary of Andhra Pradesh.

Administratively the area is with 920 habitations covering fully 52 and partially 15 mandals of East Godavari and West Godavari districts of Andhra Pradesh (Fig. 1). The area is located between North latitude 16°18' to 17°15' and East longitude 80°57' to 82°33' covering an area of 6,950 km^2 falling in parts of Survey of India Toposheets 65 D/13 &14, 65 H/01, 02, 05, 06, 07, 09, 10, 11, 13, 14 & 15, 65L/01, 02, 03, 05 & 06, 65K/4, 8, 11 & 12. The area is bounded by Bay of Bengal in the east and in the south where as in the west it is bounded by Krishna district and in the north by remaining mandals of East Godavari and West Godavari districts. The area has a coast line of about 200 km. A prominent bay with a long spit (Hope Island) near Kakinada is prominent morphological feature of the delta.

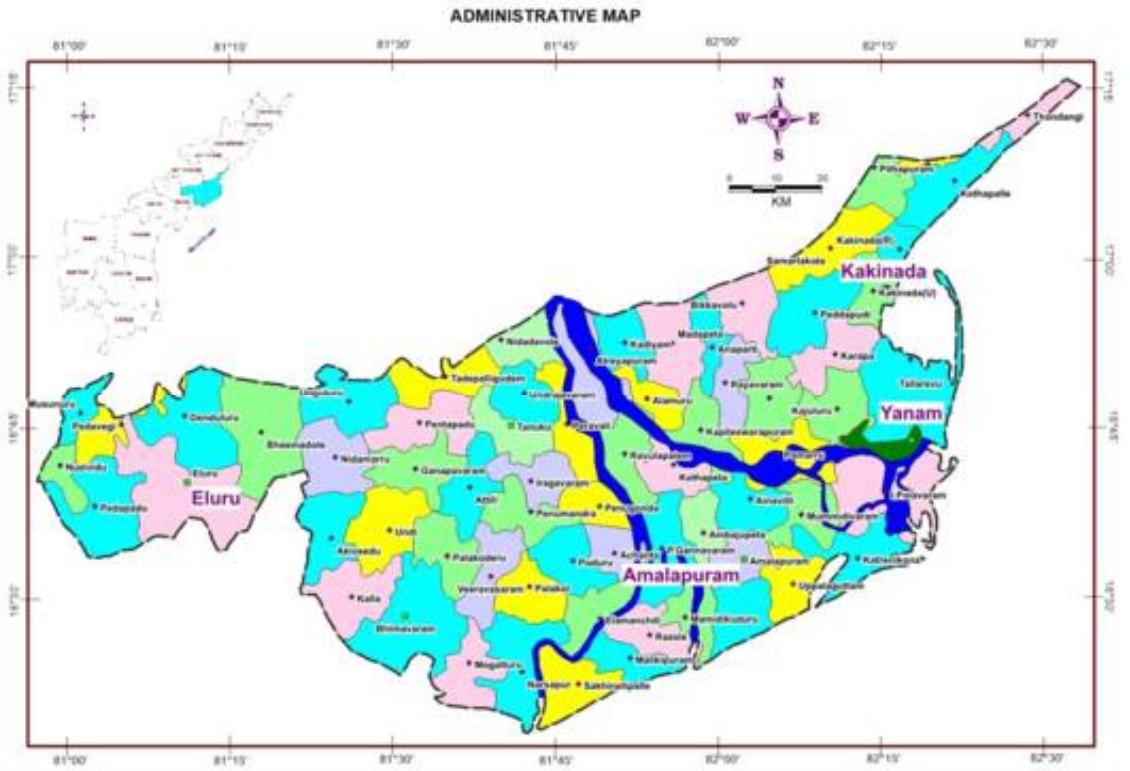


Fig. 1 Location and Administrative Divisions of the Study Area

Climate and Rainfall :

Climatologically 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 upto early June. Hydrometeorological parameters of IMD station of Kakinada are studied in depth. The study of long term rainfall pattern for the rain gauge at Kakinada shows that the long term normal is 1146 mm and 53% of the years in this period the area received normal rainfall and 19 % of years the area received excess rainfall where as the remaining 28% of the years received deficit rainfall. The long term trend analysis of rainfall indicates that the rainfall has an increasing trend of 1.142 mm/year. The normal annual rainfall in the area by considering the data recorded at mandal head quarters is varying from 840 to 1580 mm (Fig. 2). Most of the rainfall (70%) occurs during the south west monsoon season.

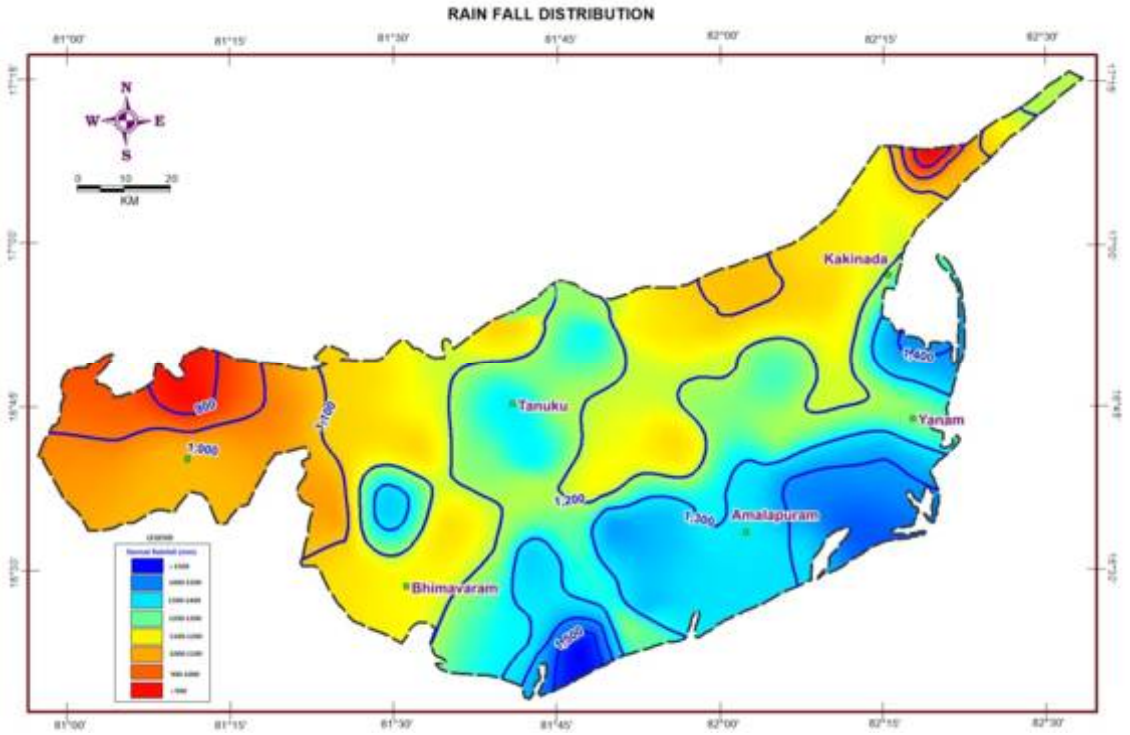


Fig. 2 Normal Rainfall Map of the Study Area

December is the coldest month with the mean daily maximum temperature of about 27.1°C and the mean daily minimum temperature is 19.2°C. Temperature begins to rise after February. May is the hottest month with mean daily maximum temperature of about 36.9°C and mean daily minimum temperature is about 27.7°C. In this area, the highest ever recorded maximum is 47.2°C and the lowest minimum is 13.9°C. Relative humidity in this area is generally high throughout the year. During Pre monsoon season heavy rains and storms occur due to depressions in Bay of Bengal.

Drainage:

The area is drained by Godavari river and flows N to S direction (Fig. 3). South of Rajahmundry the river splits into two viz. Vasishta Godavari in the west and Gowthami Godavari in the east. Further, Vasishta Godavari branches near Gannavaram into Vainateya Godavari which debouches into Bay of Bengal at Vodala Revu where as the Vashishta Godavari debouches into the sea at Pallepalem near Antarvedi. Terminal branching of Gauthami results into a fourth distributary, the Nilarevu. Further the Gauthami Godavari splits into numerous branches and debouches into the sea at Kottapalem and Balusu Tippa. The Kolleru Lake, which is situated in the western part of the area is the biggest fresh water lake and has an outlet to the sea through Upputeru. The upputeru is flowing all along the western boundary of the delta. The area is served by Godavari canal system and numerous other drains. The drainage density in the area is sparse due to high permeability of alluvial soils.

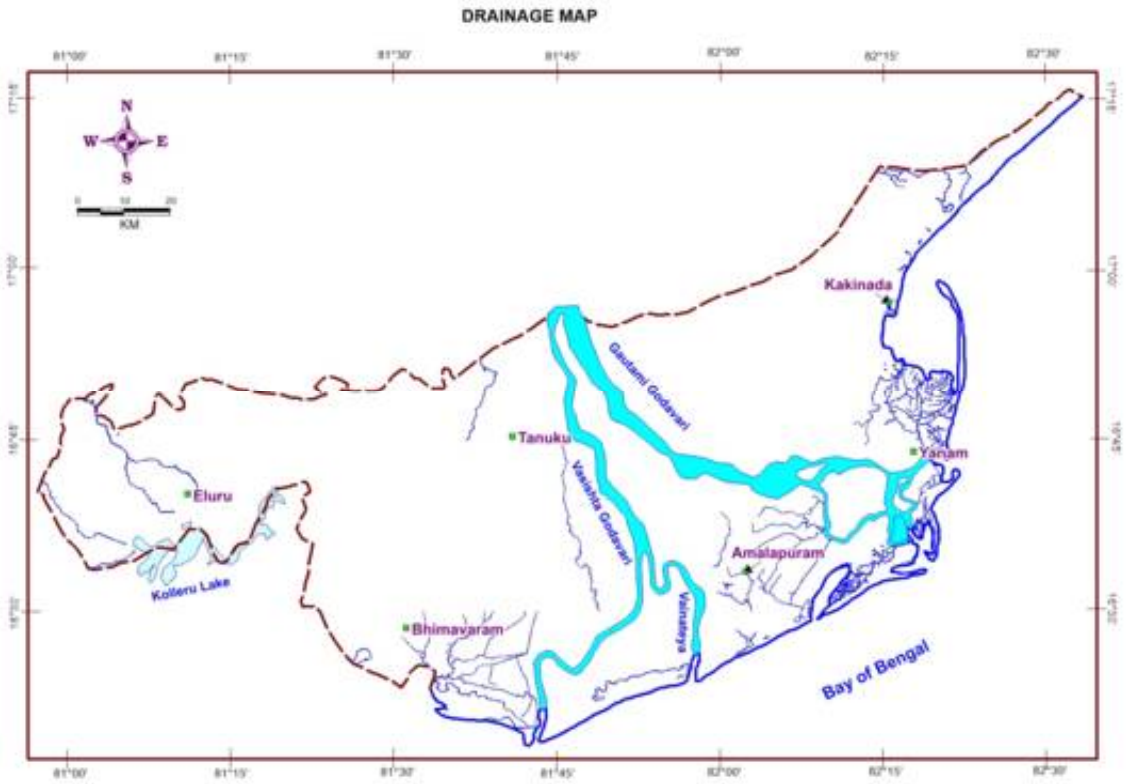


Fig. 3 Drainage Map of the Study Area

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 have some of the important depositional land forms viz. Channel bars, Channel islands, Cut off meanders, Deltaic palins, 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).

Shoreline Development : Present is the key to the past. The geomorphic features present in the coast indicate the possible shoreline in the past if similar structures are present on land. In Godavari delta the presence of beach ridge complexes on land indicate the existence of four strand lines or palaeo shore lines, which were delineated using the remote sensing studies. The strand lines and the present day coast were depicted in Fig. 6. Changes in the

present day shoreline are also observed near Kakinada, where the Kakinada spit is becoming cuspate and growing towards the coast and the enclosed Coringa bay is becoming shallower. Where, as on the other hand, the coast near Uppada, North of Kakinada is moving landwards by assimilating the land by erosion.

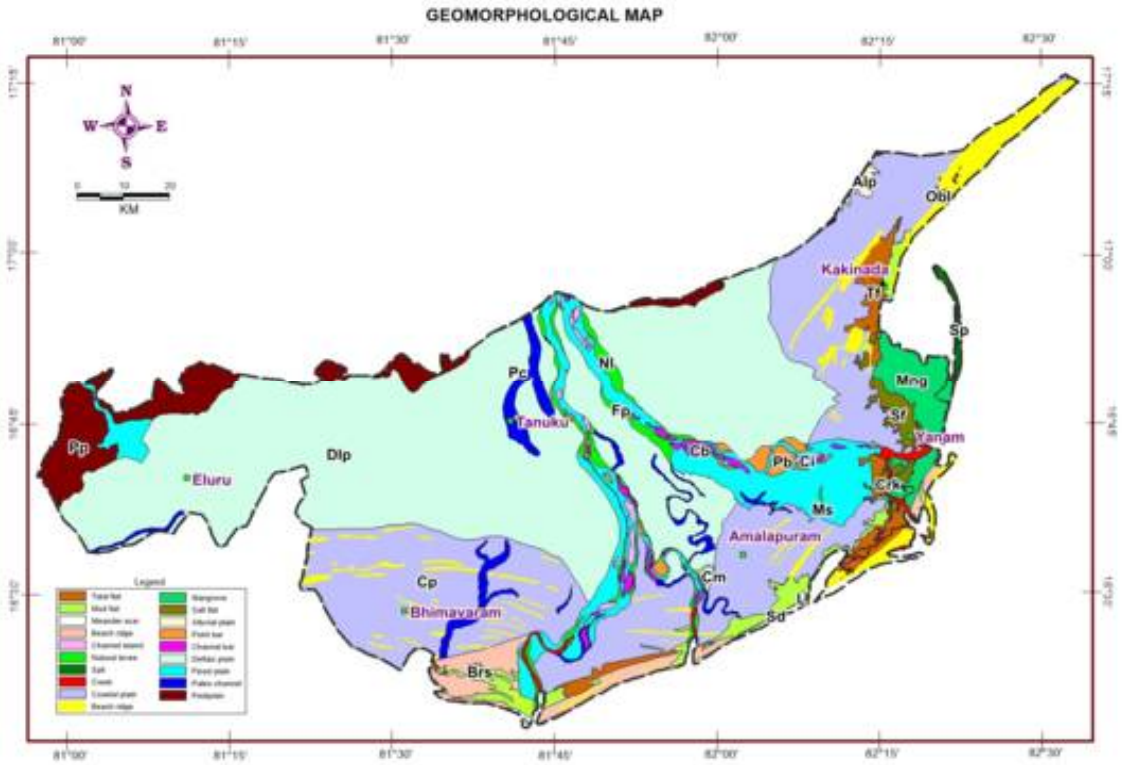


Fig. 4 Geomorphological Map of the Study Area

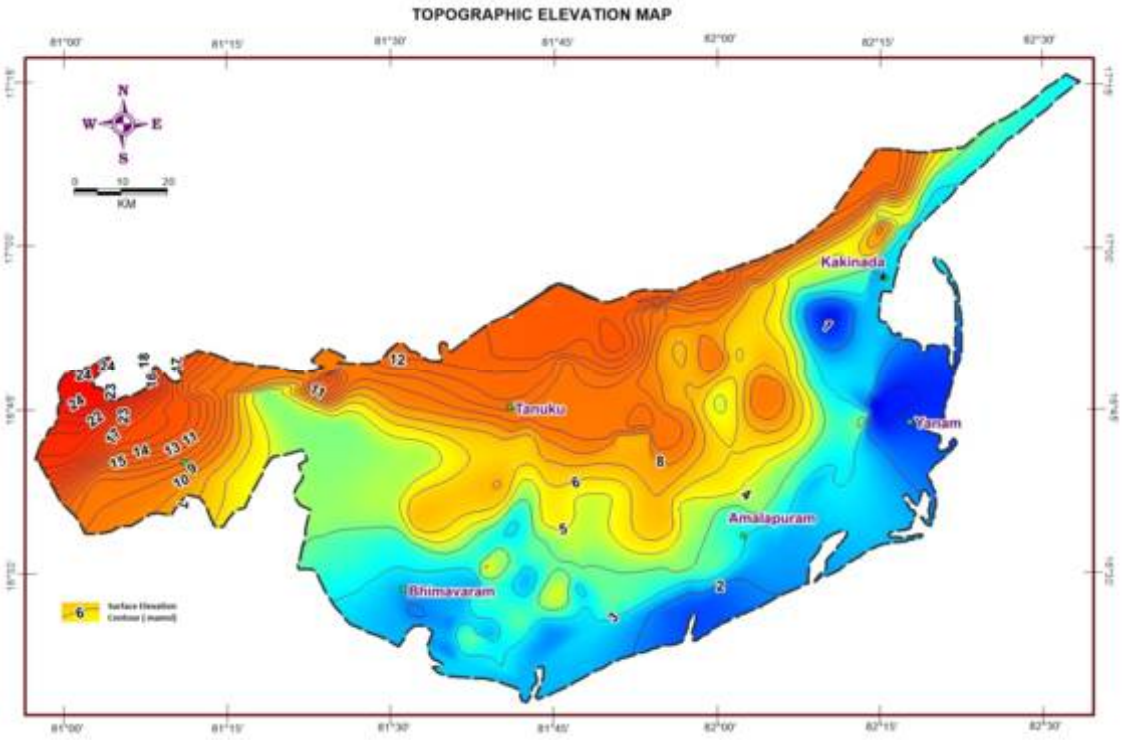


Fig. 5 Topographic Elevation of the Area

Fig. 6 Shoreline Development in Godavari 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 to three crops are harvested every year. Paddy, sugarcane and Coconut, Banana plantations are extensively raised on these lands. The Coastal sands on the other hand are highly porous and lack binding material. The taxonomic classification is depicted in the Fig. 7.

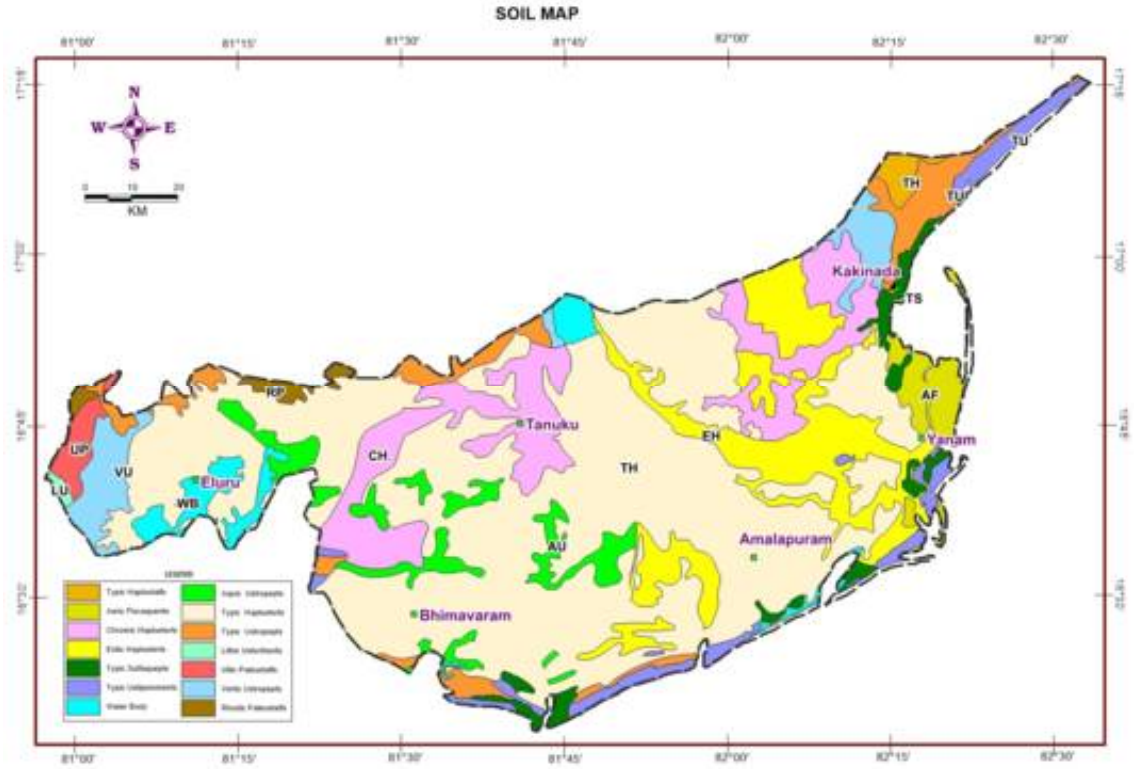


Fig. 7 Pedology of the Area

Land Use, Irrigation & Cropping Pattern:

The land use pattern in the study area indicates that the area is mostly agrarian. About 95 % of the study area is occupied by agricultural land and the remaining 5 % of the area by tree crops, mangroves, aquaculture practices and small water bodies. The area has the distributary network of the river Godavari. The area is crisscrossed by the canal netwok of Godavari Delta Irrigation System. The Godavari Delta Irrigation Project is catering the

irrigation needs of the area both in Kharif and Rabi seasons. The village tanks, ponds and percolation tanks present in the area are very limited. The majority of the ponds are being converted to pisciculture.

The Godavari Delta is under the command of Godavari Canal System. The canal system remains operational for 11 months with a one-month closure period during April-May. The Sir Arthur Cotton Barrage at Dowlaiswaram serving the irrigation needs of the deltaic area since 1852, for both Kharif and Rabi seasons. During Kharif time sufficient or excess flow are available in the river. In general there will not be any problem of shortfall of water for irrigation during Kharif period. The Godavari Eastern, Central and Western Deltas area served by mainly 3 major canal systems. They are the Eastern Delta Canal System, Central Delta Canal System and Western canal system. The total command area of the Delta is 4,08,331 ha. When the irrigation system was first established in 1852, the drainage system was also formulated with the branches of Godavari and the available rivulets. Since then, these natural valleys are called as drains and being utlised for irrigation system.

The principal crops are paddy, sugarcane and banana. The other crops are coconut, cashew, mango, tobacco, turmeric, pulses chillies, and vegetables. Paddy is the main crop in the area both in Kharif and Rabi seasons. In the second ranking crops coconut occupies large part in the coastal plain. Surface water is the main source of irrigation (>90 %). The land use pattern and the area irrigated by different sources in the area are presented as Fig. 8 & 9.

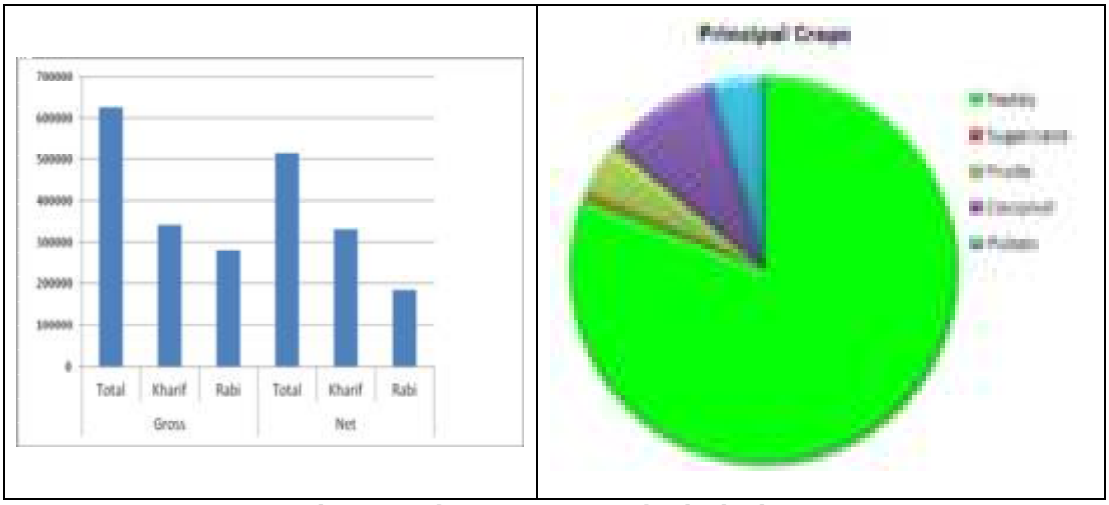


Fig. 8 Land Use Pattern and Principal Crops

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, Andhra Pradesh 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 underlain by the recent to sub-recent alluvium comprising Sand, Gravel, Clay and Silt. The alluvium is underlined by sandstones, where as in the eastern and western fringes are underlined by Khondalites and gneisses respectively. The sandstones formations are encountered at different depth in the boreholes drilled by CGWB in the northern part of the area at shallow depths, and towards coast the sandstone could not encounter even depths beyond 250m. The general geological succession of the area is shown in Table - 1. The geological map of the area is shown as Fig. 10.

Table – 1 : General Geological Succession of the Study 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			Khondalites and Gneisses

Sub-Surface Geology

In the Godavari delta below alluvium, sandstones formations are encountered at shallow depth in the boreholes drilled by CGWB in the northern part of the area, and towards coast the sandstone could not encounter even depths beyond 250m. Subsurface configuration of the formations was studied through different geological cross sections and panel diagrams. A generalised schematic geological cross sections is presented as Fig. 11.

This clearly shows that the alluvium is underlained by Rajahmundry sandstones followed by Deccan Traps, Tirupathi sandstones and Khondalites. Another geological cross section (Fig. 12) from Balavaram to Peddagadimoga and upto the sea coast shows that the Rajahmundry sandstones which were encountered at an altitude of -18 m bmsl near Peddada could not be met even at an altitude of -275 m bmsl through the distance between them is only 17 km. This sudden steep slope in may be due fault thereby causing variations in the altitudes of the formations or due to steep continental slope. The thickness of alluvium varies from a few meters to more than 400 m and it overlies Rajahmundry sandstones. Based on the available data a schematic map is prepared and presented as Fig. 13, which shows depth to sandstone in the Deltaic area. The figure reveals that sandstones occur at shallow depths (< 50 M) in the northern fringes of the deltaic area, where as in the eastern and western parts the thickness of the alluvium is < 300 m. In the central deltaic area the thickness of the alluvium is > 400 m.

There is a major ENE-WSW lineament in the southern part of the Godavari delta. All the three major distributaries of the river Godavari viz. Gauthami Godavari, Vasishta Godavari and Vainateya Godavari cross this lineament and the obliterated trend of their drainage indicate a continuous movement along this lineament.

Fig. 10 Geological Map of the Study Area

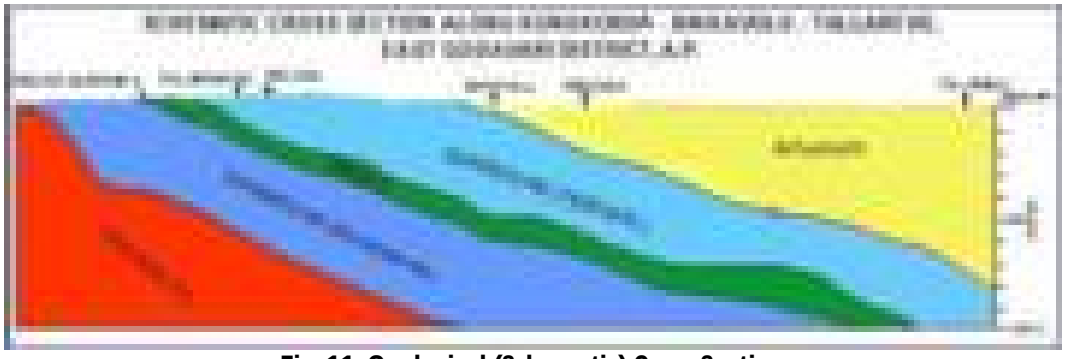


Fig. 11 Geological (Schematic) Cross Section

Fig. 12 Geological Cross Section

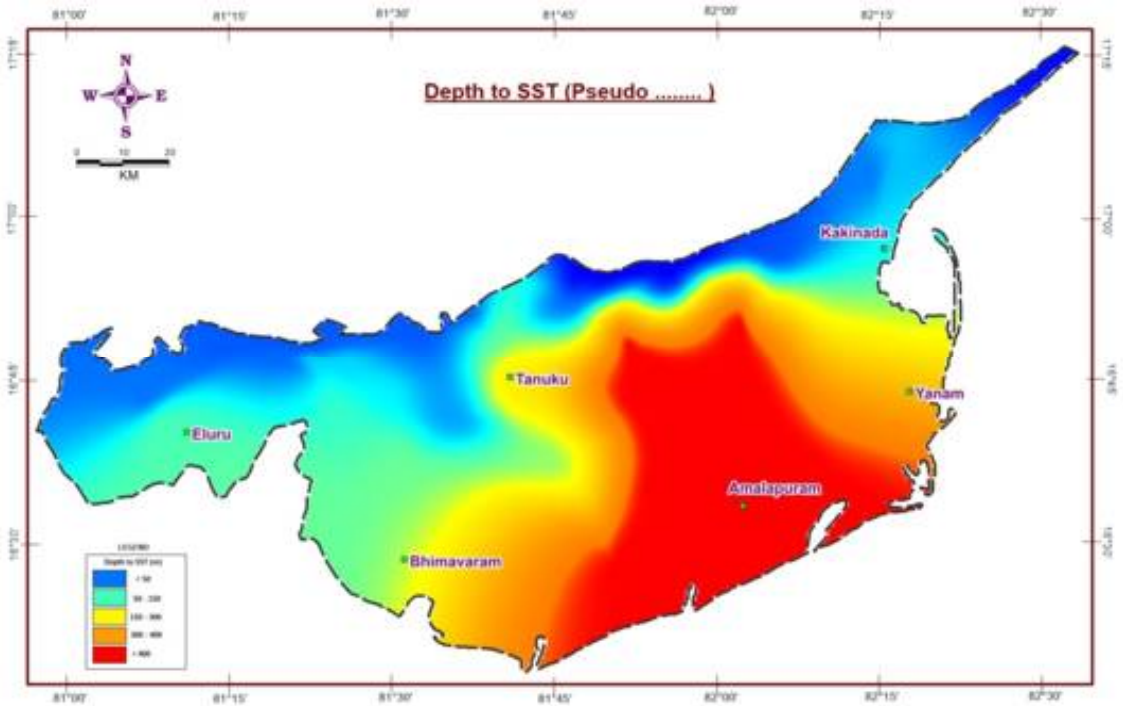


Fig . 13 Schematic Map of Depth to Sand Stone

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. The sandstone formations are not exposed in the deltaic area but encountered at shallow to greater depths. Hydrogeological map of the area is presented as Fig. 14. Ground water in alluvium occurs under unconfined conditions in shallow aquifers, whereas semiconfined to confined conditions in the deeper aquifers. Buried/Paleo channels existing in central delta are promising potential zones. Overall the ground water development is insignificant in the area except in few mandals. Shallow aquifer is being tapped by dug wells and by filter points/ shallow tube wells in the area as and when need arises because of the insufficient availability of surface water, for raising seedbeds during canal closures and to some extent in the high level patches to where canal water cannot reach apart from domestic and drinking purposes. The depth of the wells generally ranges from 3 to 12 m bgl. In the areas near coast wells are restricted 3 to 4 m. The yield of the wells varies inbetween 25 and 90 m^3/hr. T and S are varying from 250 to 6200 m^2/day and $3.14x10^{-3}$ to $5.5x10^{-4}$ respectively. Rainfall, canal system and the river Godavari are the main source of recharge. The fresh ground water is limited to shallow aquifer. The depth of these fresh water shallow aquifers vary considerably from place to place. The exploratory data reveals that the thickness of this aquifer is restricted to a maximum depth of 34 m. The deeper aquifers are not being tapped as the quality of the water is saline. In the Godavari delta the deeper alluviual aquifers explored down to 300 m depth contains saline water, whereas sandstone aquifers encountered below alluvium yielded fresh water.

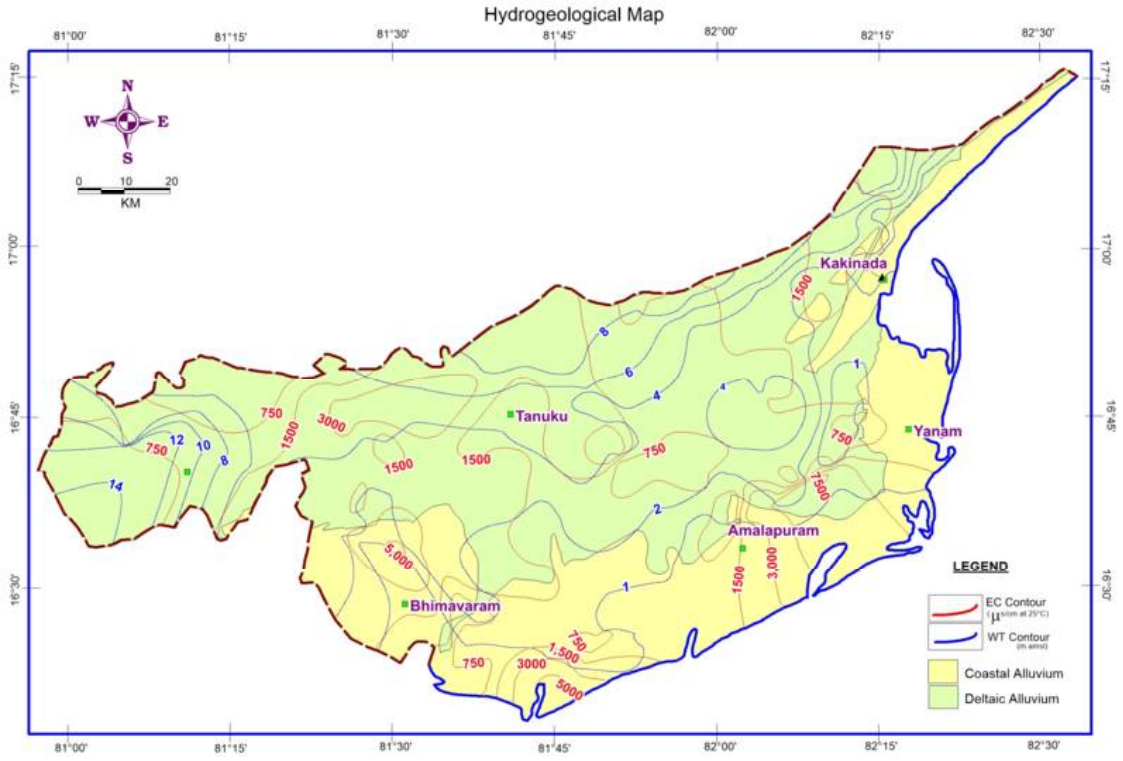


Fig. 14 Hydrogeological Map of the Study Area

Ground Water Levels

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 observation wells maintained by CGWB and State Ground Water 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 (2016) is ranges from < 1 m bgl to a maximum of 9 m bgl. Pre-monsoon depth to water level map reveals that mostly the water levels in the area ranges inbetween 2 and 4 m bgl. All along the coast the water levels are < 2 m bgl, whereas in the central deltaic area where it is upto

6 m bgl (Fig. 15). The depth to water level during post-monsoon (2016) in the majority of the area is < 2 m bgl, whereas in the central deltaic area is in the range of 2 to 4 m bgl (Fig. 16).

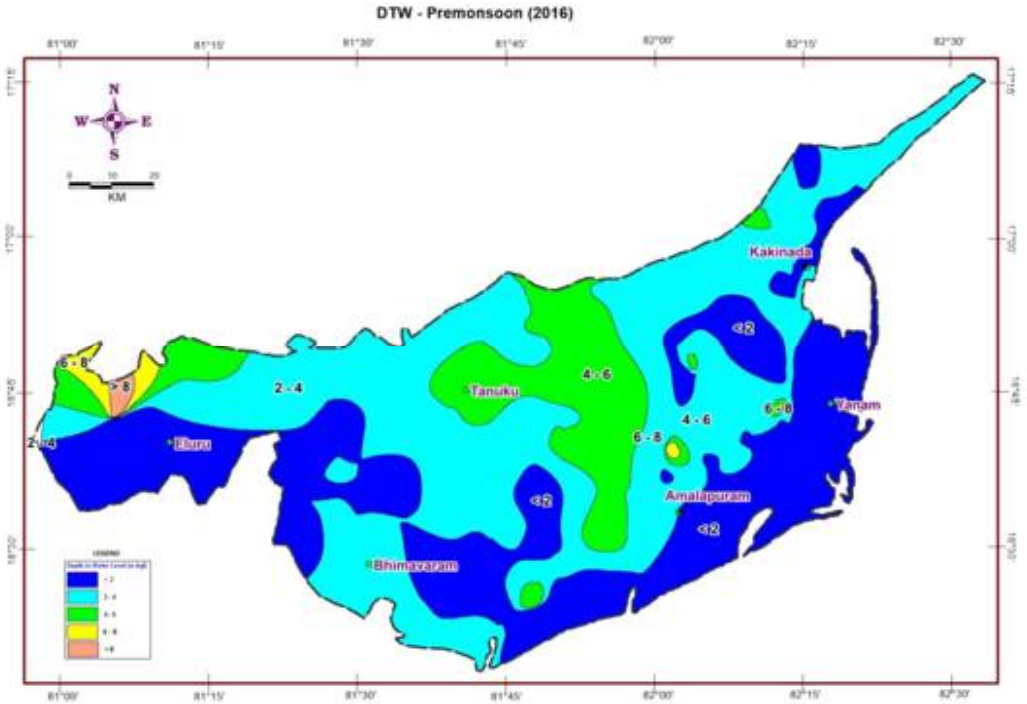


Fig. 15 Depth to Water Level - Pre-Monsoon (2016)

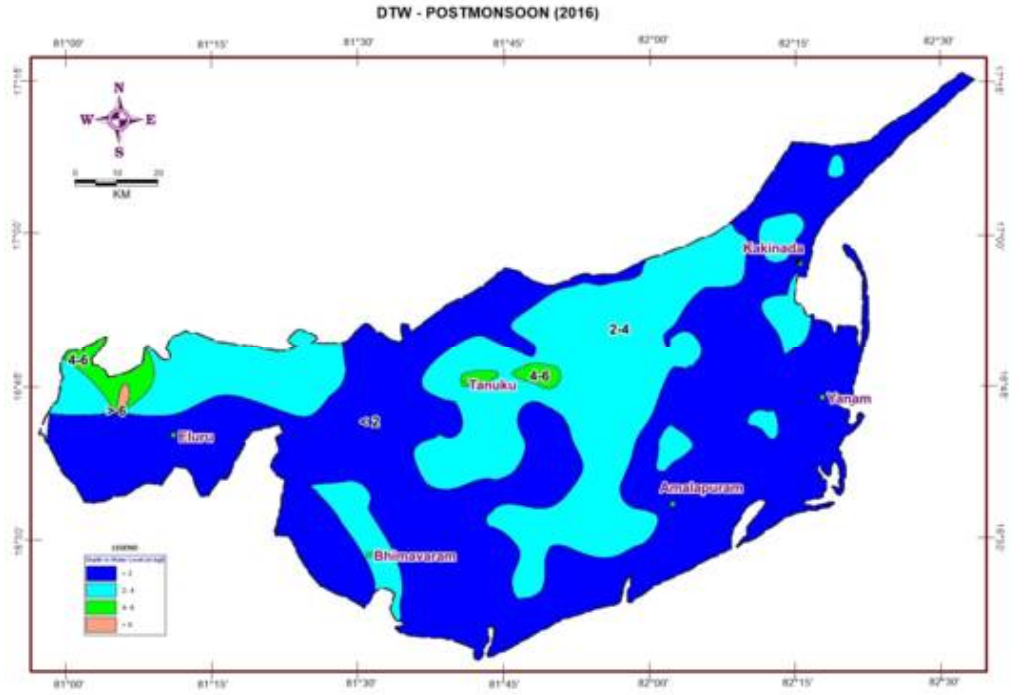


Fig. 16 Depth to Water Level - Post-Monsoon (2016)

The water table elevation ranges between 1 m amsl in the coastal area and 12 m amsl in the north part of the area. The general ground water flow direction is towards sea (Fig. --). The water table contours also indicate that there is conspicuous water discharges into the sea.

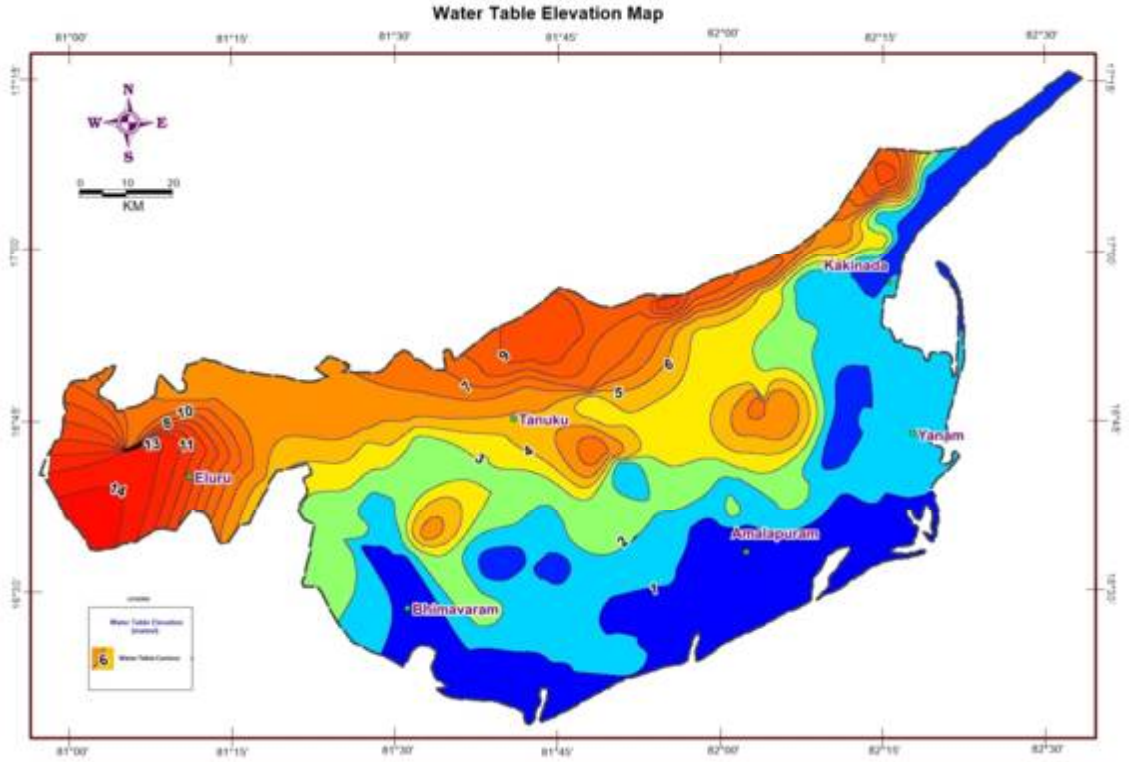


Fig. 17 Water Table Elevation Map

The piezometric head in the deeper aquifers during pre-monsoon (2016) is ranges from 4 m bgl to a maximum of 15 m bgl (Fig. 18). Similar magnitude is observed in the piezometric heads during post monsoon period (Fig. 19).

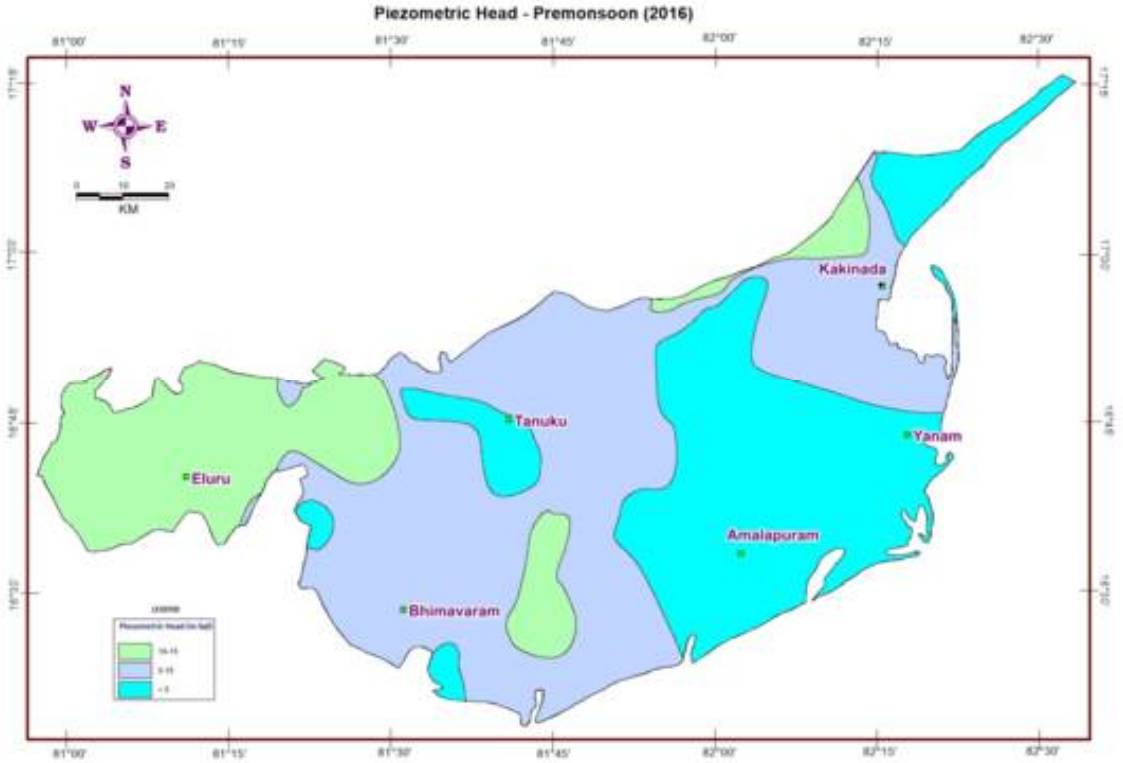


Fig. 18 Pre Monsoon – Piezometric Head (2016)

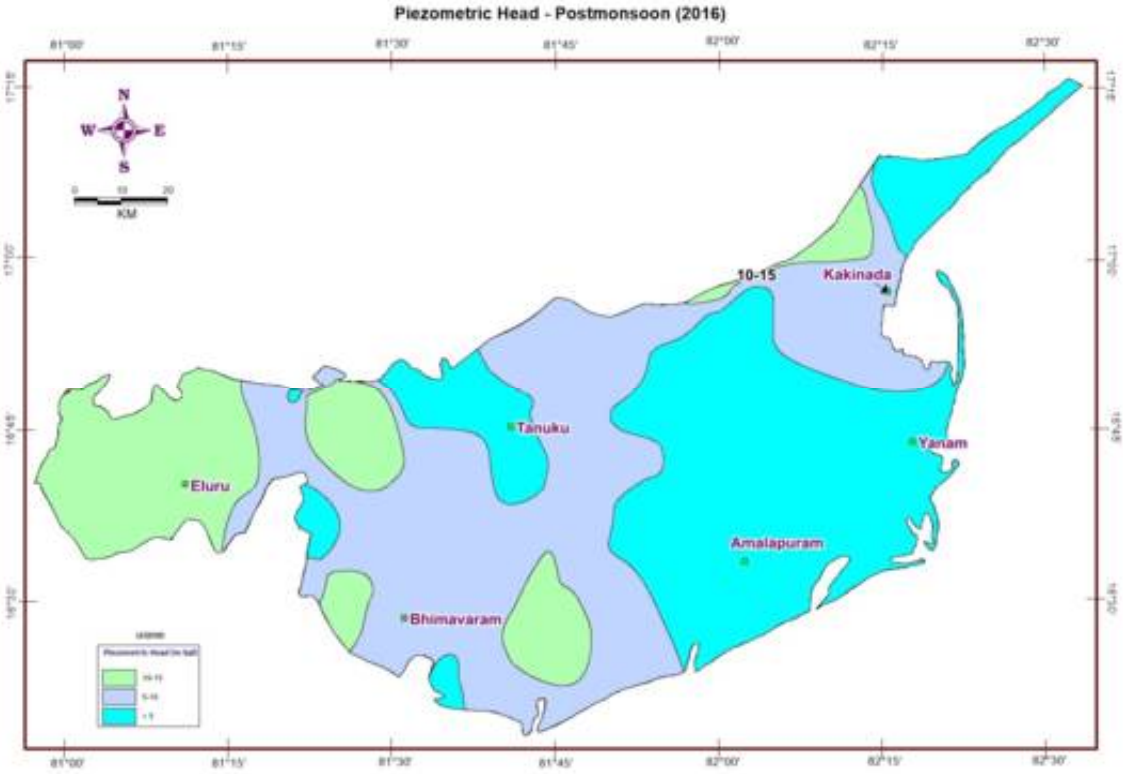


Fig. 19 Post Monsoon – Piezometric Head (2016)

Water Level Fluctuation

The water level fluctuation in shallow aquifers between pre-monsoon and post-monsoon water levels i.e., May and November, 2016 ranges in between -1 and 4 m. The fluctuation map reveals that the majority of the area shows rise of about 2 m in water level, whereas fall recorded at few isolated patches (Fig. 20).

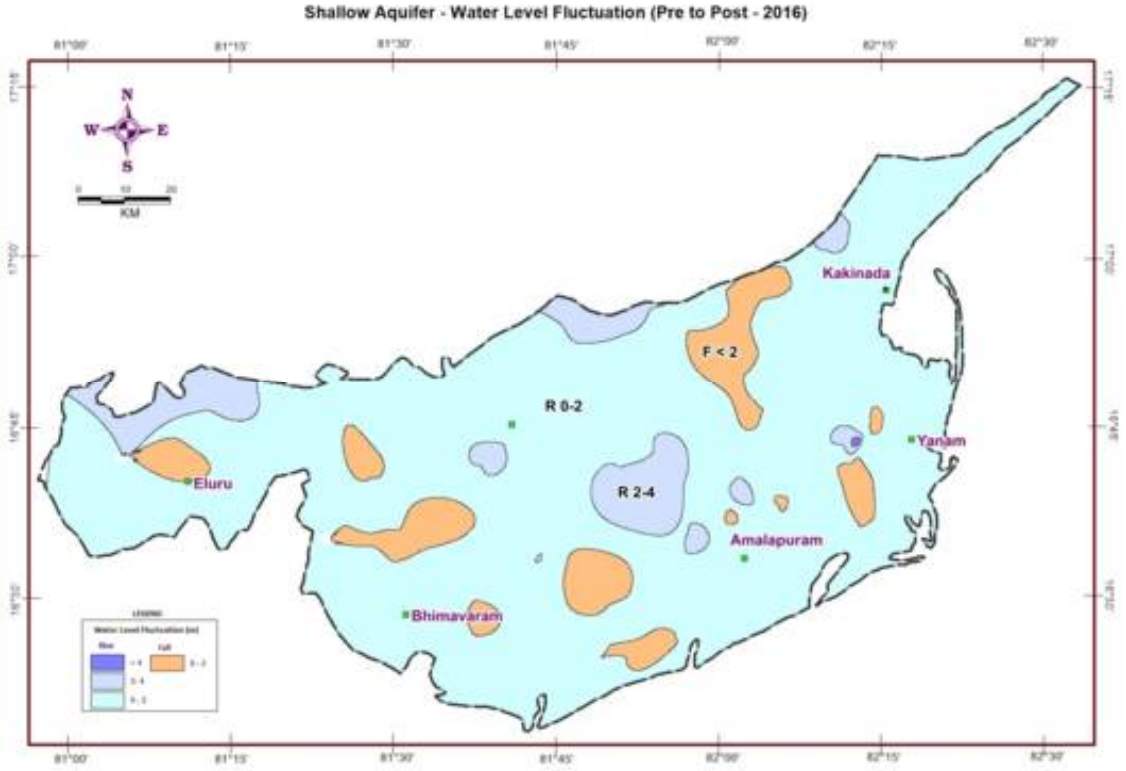


Fig. 20 Shallow Aquifer - Water Level Fluctuation (Pre monsoon to Post monsoon, 2016)

The piezometric head fluctuation in deeper aquifers between pre-monsoon and post-monsoon ranges in general in between -1 and 2 m. The fluctuation map reveals that the major portion of the area shows rise upto 2 m, except in the NW portion of the area where decline of < 2 m exist (Fig. 21).

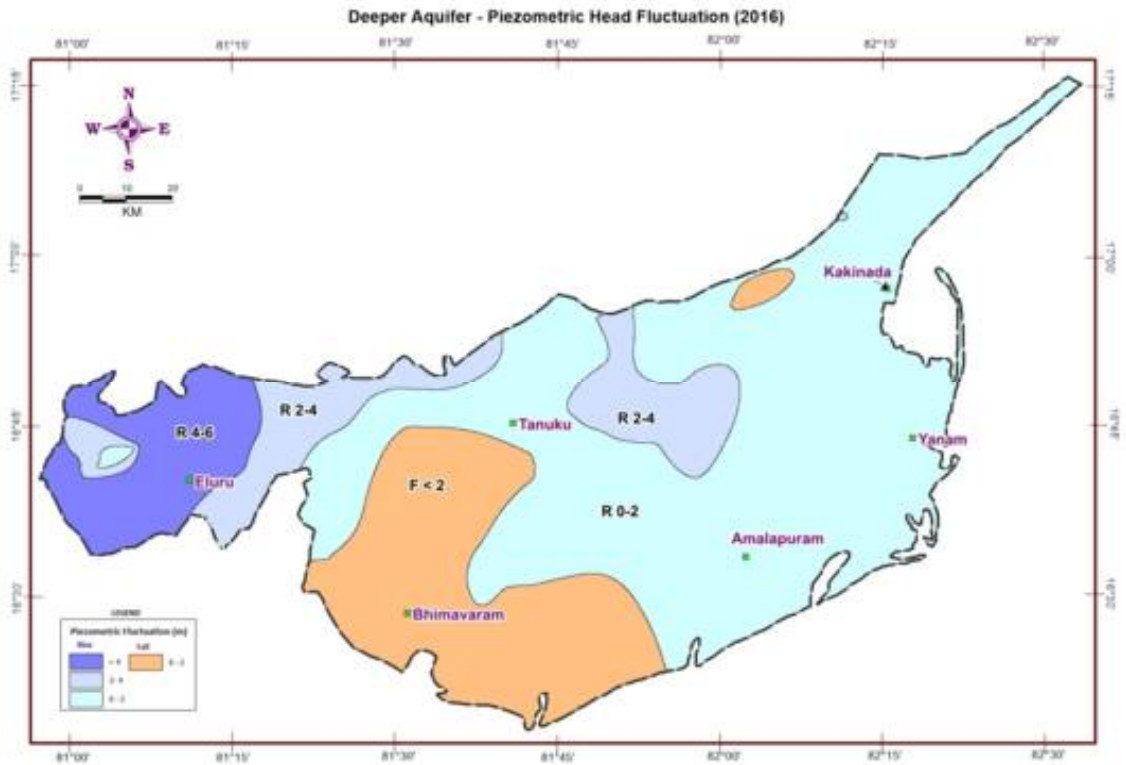


Fig. 21 Deeper Aquifer - Piezometric Head Fluctuation (Pre monsoon to Post monsoon, 2016)

Long Term Water Level Trend :

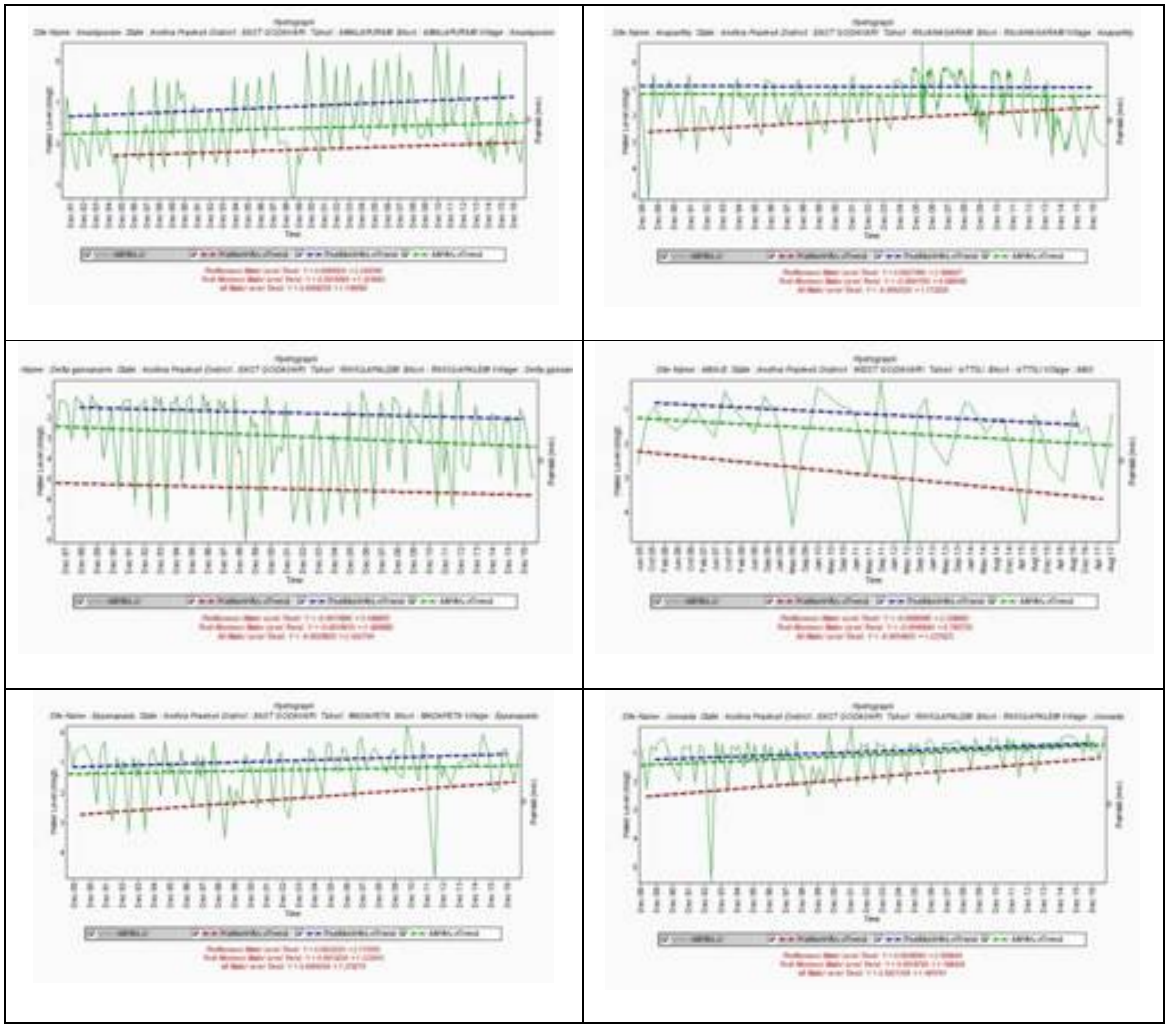
Long term water level data indicates that the water levels in general stable. In the majority of the area declining trend is prominent in piezometric heads. The details of the trend analysis and hydrographs are presented in the Table - 2 and Fig. 22 respectively. The trend of ground water levels by considering all season data it is observed that decline in the range of 0.003 to 0.096 m/year whereas rise observed in the range of 0.002 to 0.033 m/year. The magnitude of trend values indicates that significant change is not occurred in the ground water scenario except at few places.

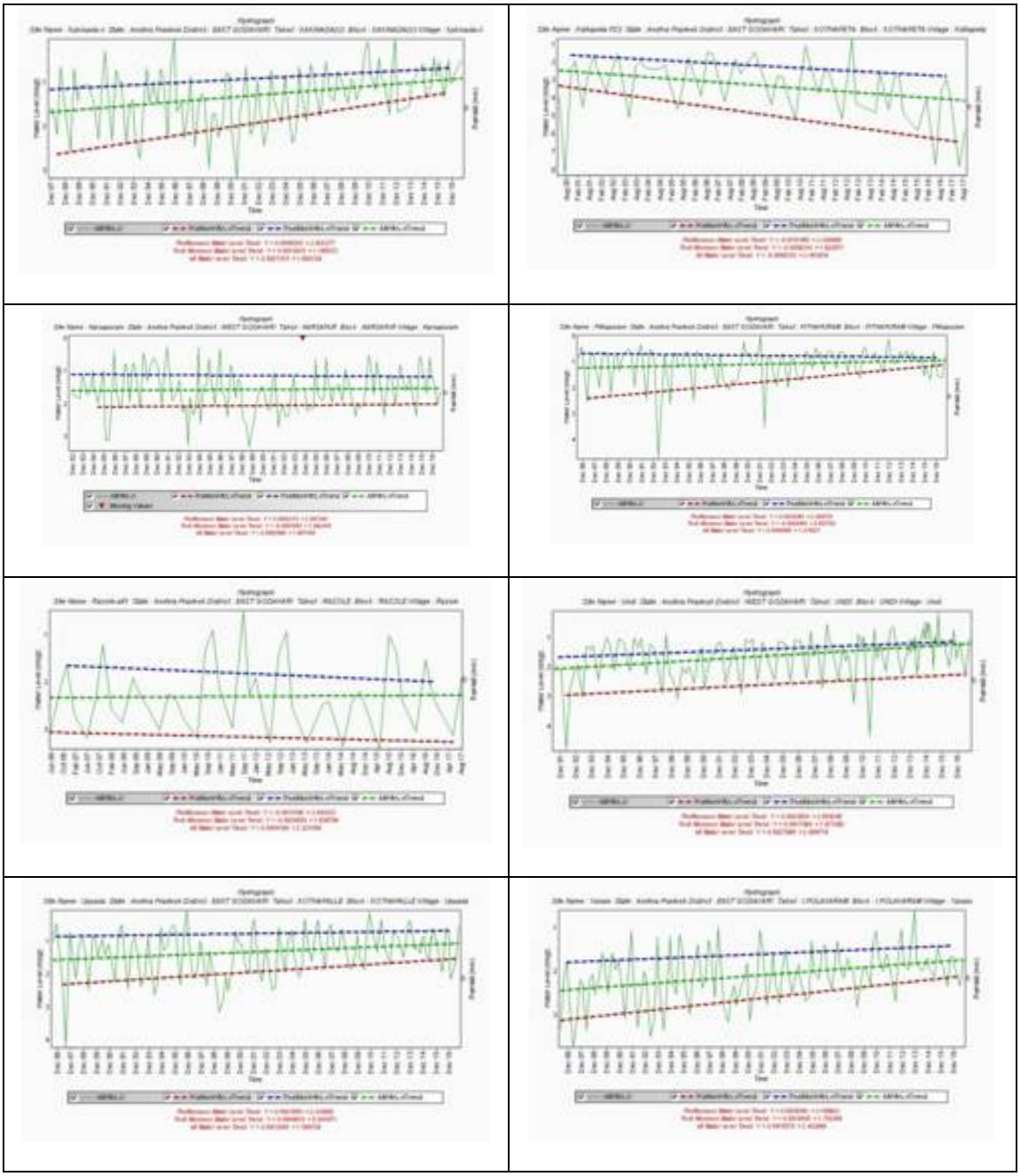
Table–2 Long-term Water Level Trends

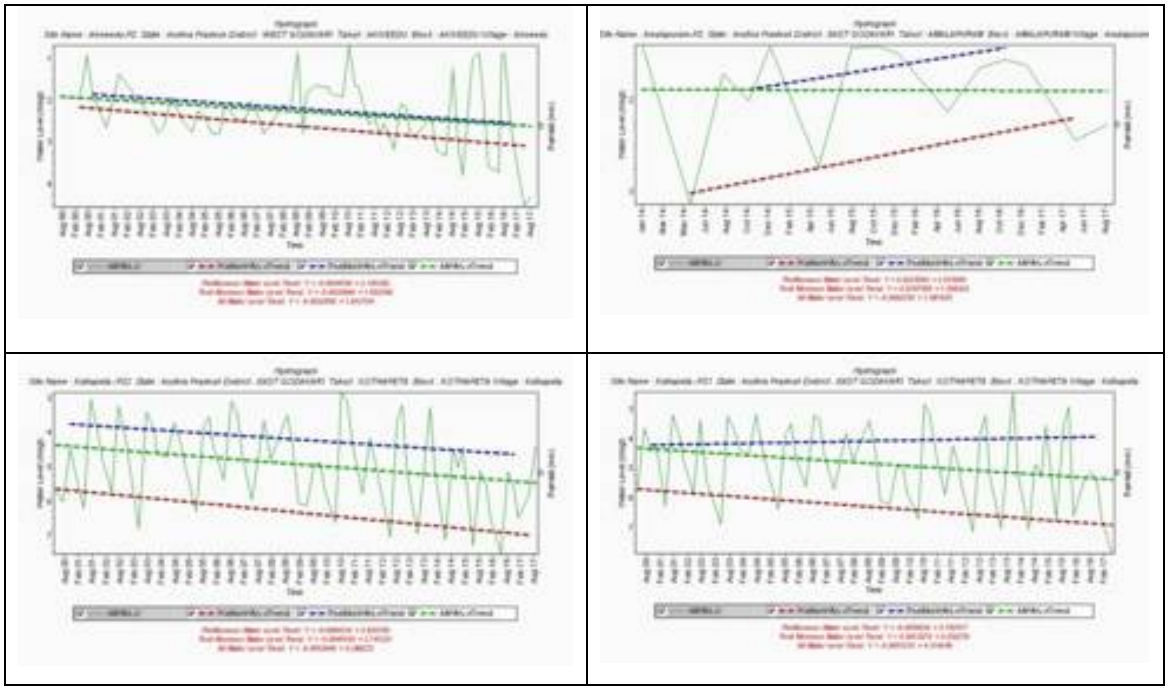
S.No	Location	Trend (m/yr)	Remarks
1	Amalapuram	0.008	Shallow aquifer
2	Anaparthy	- 0.003	Shallow aquifer
3	Attili	-0.066	Shallow aquifer
4	Delta Gannavaram	-0.032	Shallow aquifer
5	Eppanapadu	0.010	Shallow aquifer
6	Jonnada	0.025	Shallow aquifer
7	Kakinada	0.026	Shallow aquifer

8	Kothapeta	-0.096	Shallow aquifer
9	Narsapuram	0.002	Shallow aquifer
10	Pithapuram	0.010	Shallow aquifer
11	Razole	0.005	Shallow aquifer
12	Undi	0.033	Shallow aquifer
13	Uppada	0.017	Shallow aquifer
14	Vegayammapeta	-0.022	Shallow aquifer
15	Yanam	0.022	Shallow aquifer
16	Akivedu	-0.039	Shallow aquifer
17	Gurajanapalli	0.034	Shallow aquifer
18	Vakalapudi	0.055	Shallow aquifer
19	Kothapeta	-0.064	Deeper aquifer

Fig. 22 Long-term Water Level Trends







Ground Water Quality:

In order to understand the quality of ground water in the area the chemical data of the ground water samples collected from shallow aquifers during pre monsoon period (2016) 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 waterat major part of the area is Ca Mg - HCO_3 type followed by Na K-ClSO_4 type (Fig. 23).

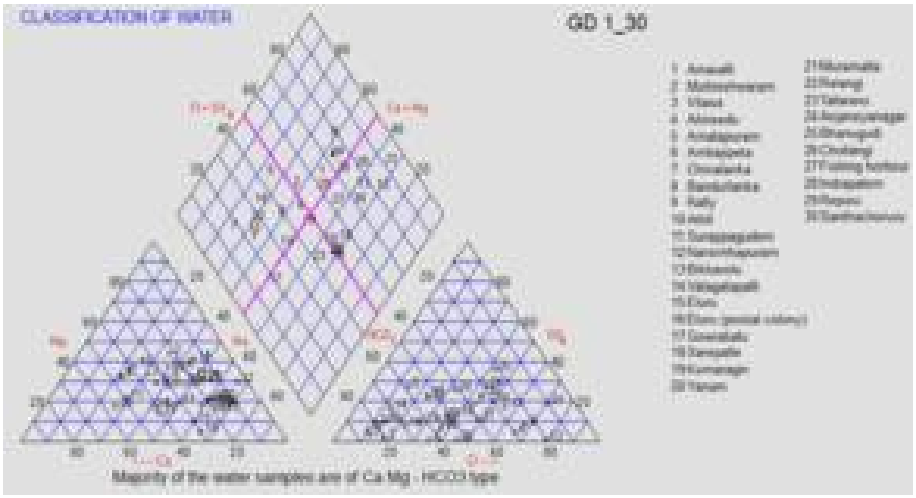


Fig. 23a Classification of Water - Piper's diagram

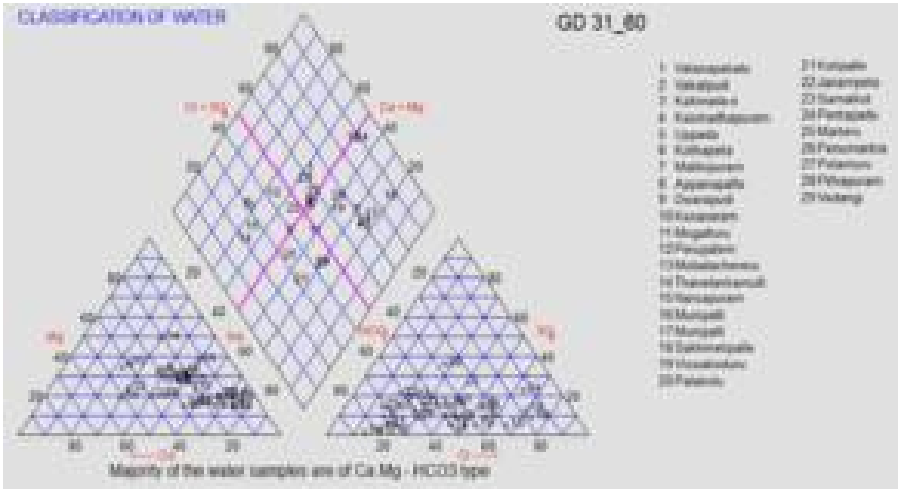


Fig. 23b Classification of Water - Piper's diagram

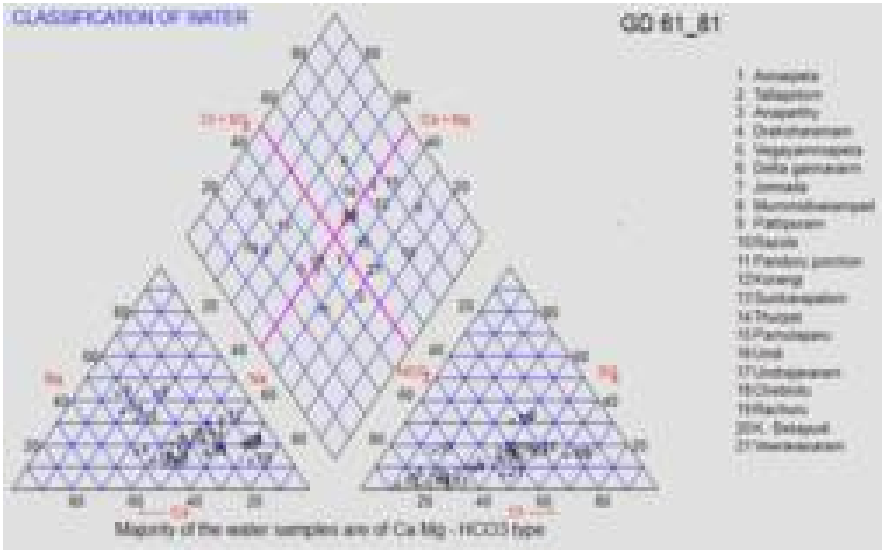


Fig. 23c Classification of Water - Piper's diagram

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 7.51 and 8.5 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. 24. The EC distribution map reveals that in major portion of the study area EC values are less than 1500 micro siemens/cm at 25°C except in the area near coast and in western parts of the area where higher values recorded. The Chloride distribution map for pre-monsoon period was prepared and presented as Fig. 25. The chloride map reveals that in major portion of the study area Cl is less than 250 ppm except in the Southern part near coast and in western parts of the area where higher values recorded. The fluoride content in the ground water of the study area is < 1 ppm. The maximum nitrate content in the ground water of the study area is recorded as 95 ppm.

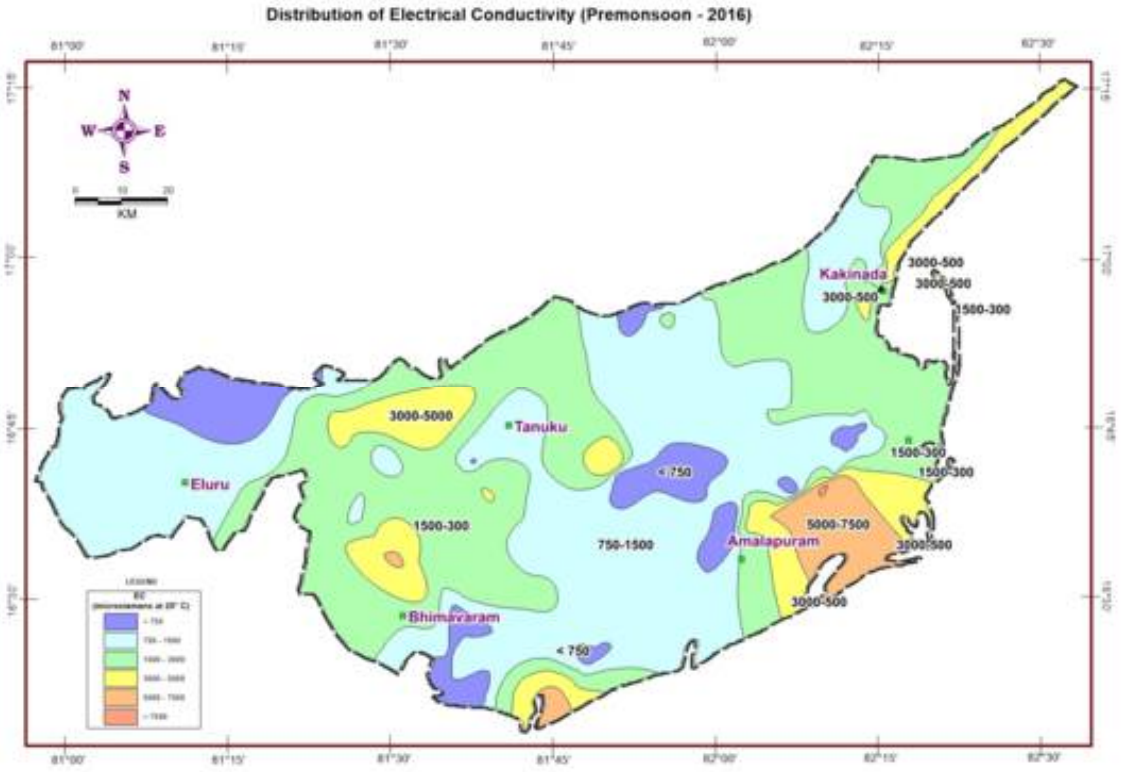


Fig. 24 Distribution of Electrical Conductivity in Shallow Aquifers

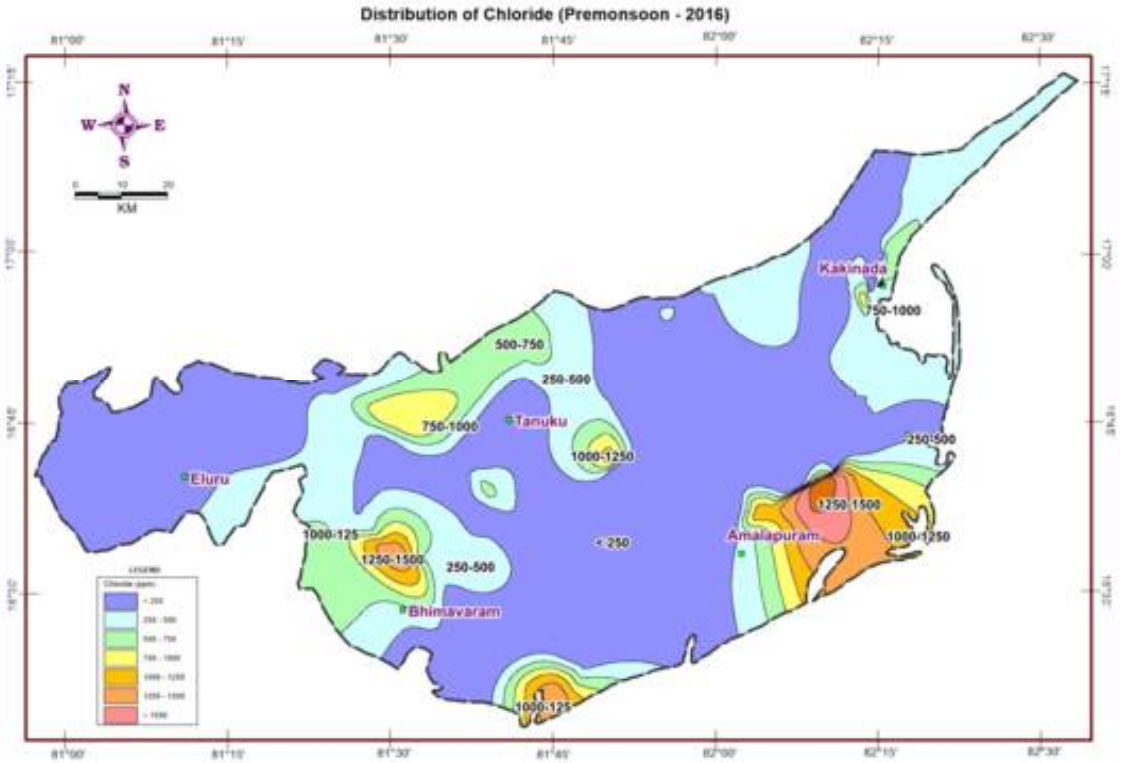


Fig. 25 Distribution of Chloride in Shallow Aquifers

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 NW part of the area where EC values > 3000 micro siemens/cm at 25°C exist.

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	7.51	8.50	7.95	6.5	8.5
EC	158	7670	1749	750	3000
TH	65	1400	380	300	600
Ca	18	220	72	75	200
Mg	1	207		30	100
Na	5	1110	202		
K	1	450	40		
CO3	Nil	60	2		
HCO3	85	927	417		
Cl	7	1914	286	250	1000
SO4	<1	704	98	200	400
NO3	<1	95	21	45	100
F	0.06	0.75	0.27	1	1.5

Suitability for Irrigation Purpose

Suitability of ground water in the area for irrigation purpose has been insinuated by USSL diagram (Fig. 26). 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.

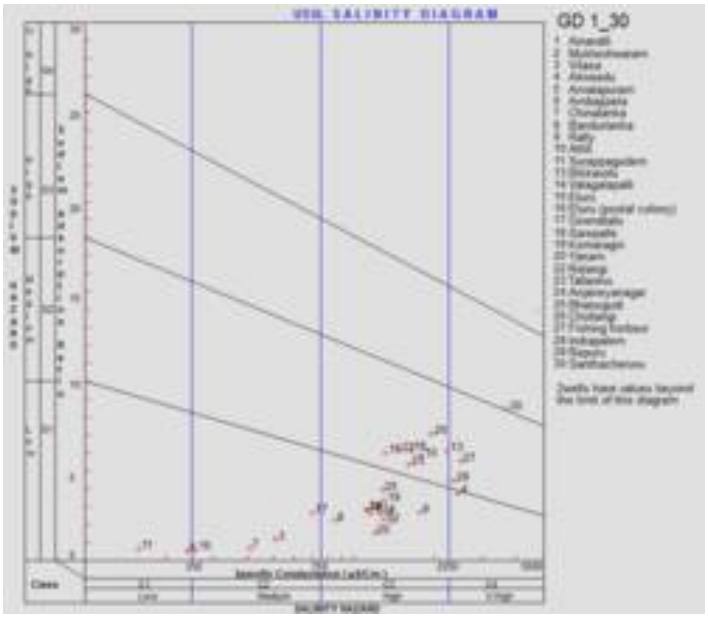


Fig. 26a Irrigation Classification of Ground Water

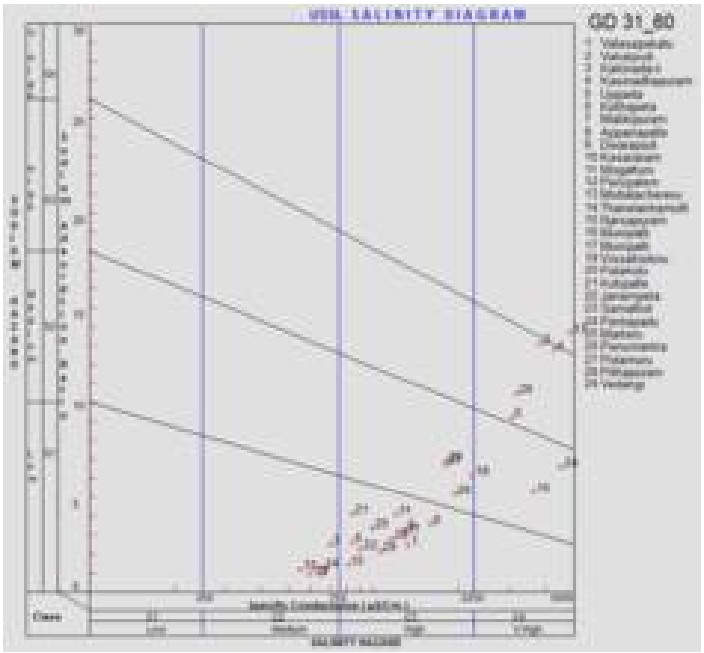


Fig. 26b Irrigation Classification of Ground Water

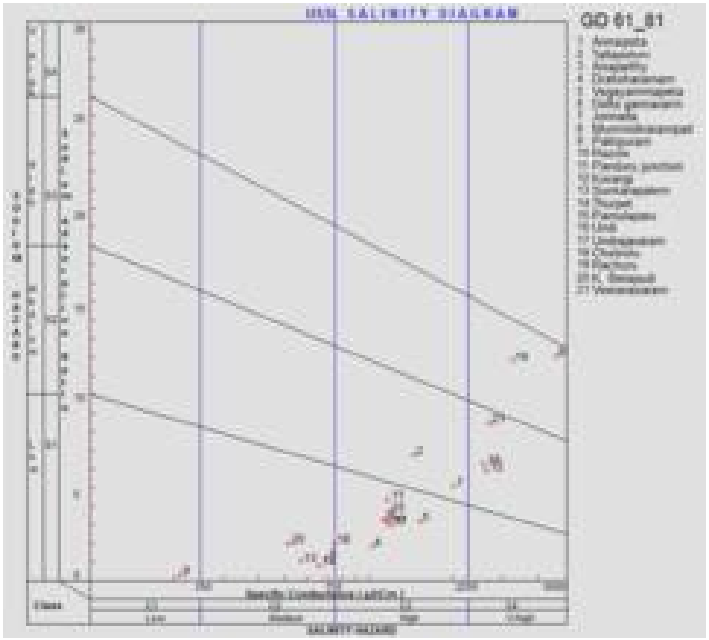


Fig. 26c Irrigation Classification of Ground Water

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. 27. Details of the data sets compiled for different studies are given below:

Organisation	Water Level		Water Quality		Aquifer Geometry		Geophysical
	DW	PZ	DW	PZ	EW/PZ	Depth Range(m)	VES
CGWB	77	11	81	-	49	20-650	125
State GW Dept.	-	61	-	-	-	-	
Total	77	72	81	-	-	20-650	125

The detailed analysis of the data reveals that the alluvium is the principal aquifer system. 3–Dimentional model of the area is presented as Fig. 28. It clearly shows that the thickness of the alluvium is less in the northern fringe, eastern and westernmost areas. Ground water occurs in unconfined, semi-confined and confined conditions in the study area depending on the availability of impervious beds. Based on the available hydrogeological data a fence diagram and a panel diagram showing the aquifer disposition were prepared and presented as Fig. 29 & 30.

The perusal of the data indicates that there are multi aquifers in the area with intervening thick clay beds. These sand beds which act as aquifers in the area and there are five distinct beds which behave as regional aquifers. Thin beds and pinched beds are neglected in making out the regional aquifer system. Hydrogeological cross sections drawn along different directions of the area are presented as Fig. 31a to d. The study of the different sections indicate that the alluvium thickness is increasing from north to south and there are five aquifers exist upto a depth of 300m in the Godavari deltaic area. The shallow aquifer thickness is varying from place to place. The first aquifer which is present upto a maximum of 34m below MSL is unconfined where as the other aquifers are confined.

The ground water quality of shallow aquifer is fresh, where as the deeper alluvial aquifers of are saline. Sandstone aquifers encountered below the alluvium are yielding fresh quality of ground water. The disposition of aquifers in the area is as given below in Table-4.

Table-4 Disposition of Aquifers in the Godavari Delta

Depth range	Type of Aquifer	Quality of water
Upto 34 m	Unconfined Aquifer	Fresh
22 m - 60m	Confined Aquifer I	Brackish to Saline
68 m – 106 m	Confined Aquifer II	Saline
124 m – 203 m	Confined Aquifer III	Saline
212 m – 305 m	Confined Aquifer IV	Saline

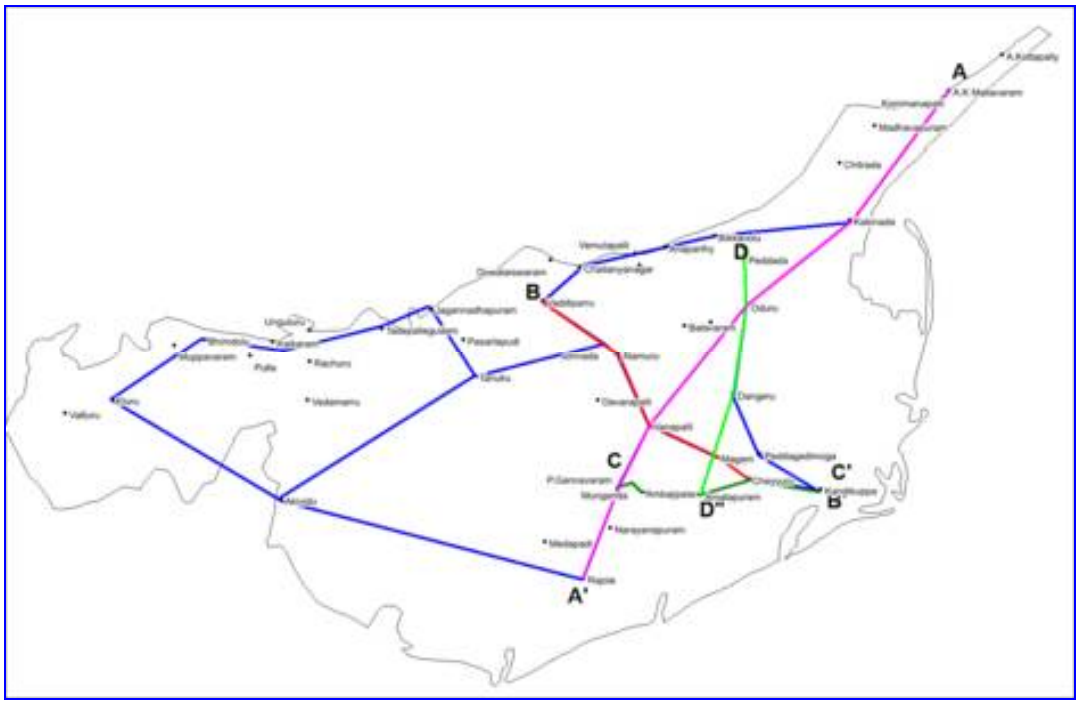


Fig. 27 Location of Exploratory Wells and Hydrogeological Cross Sections

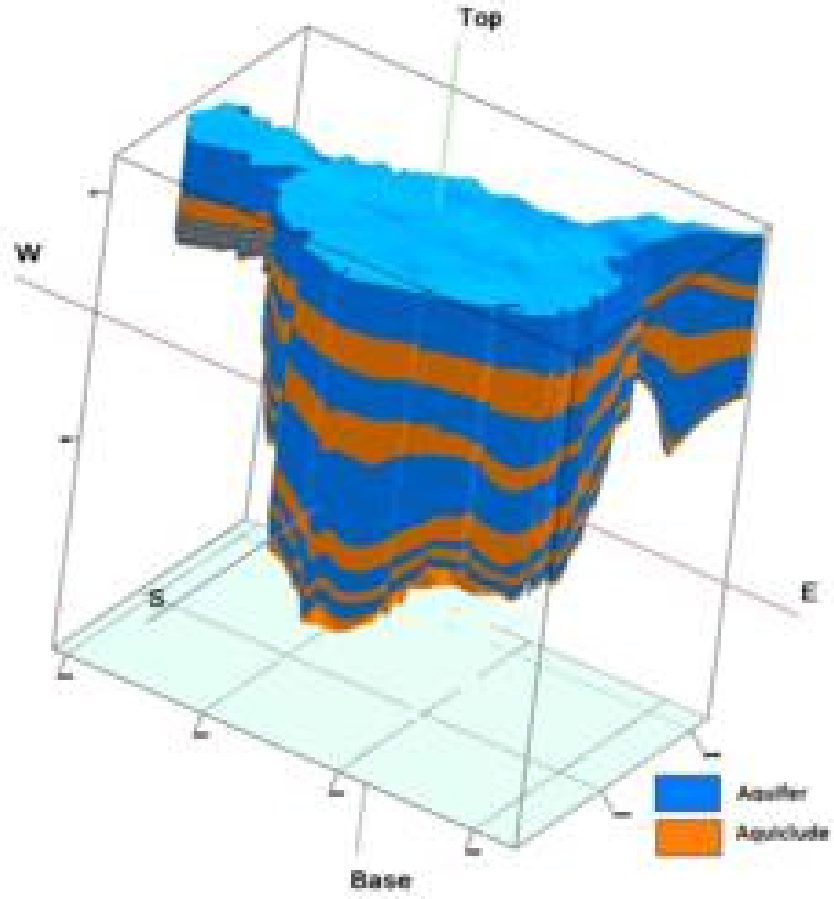


Fig. 28 3 Dimentional Model of the Godavari Delta

Fig. 31a Hydrogeological Cross Section (A – A')

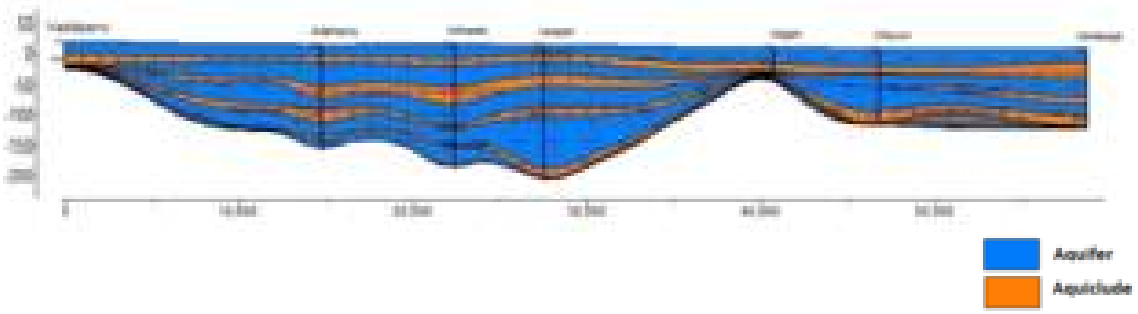


Fig. 31b Hydrogeological Cross Section (B-B')

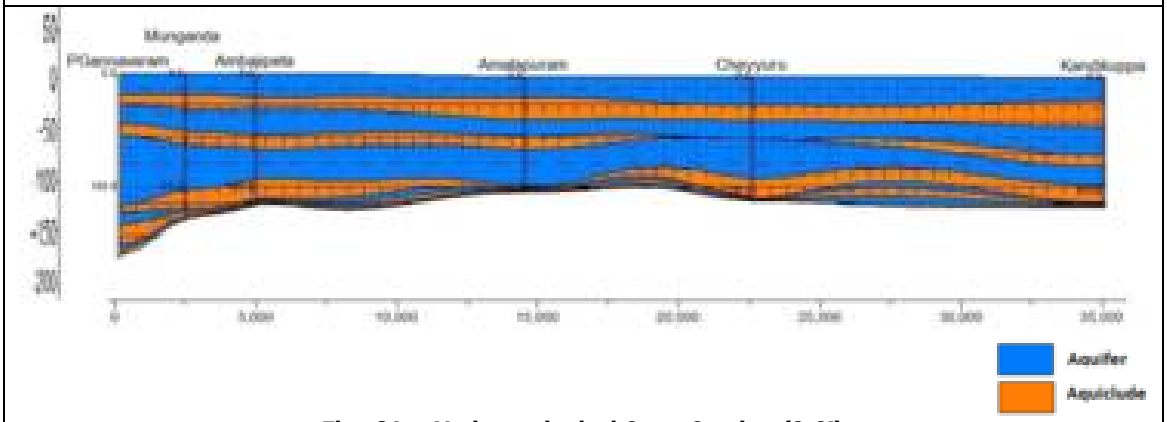


Fig. 31c Hydrogeological Cross Section (C-C')

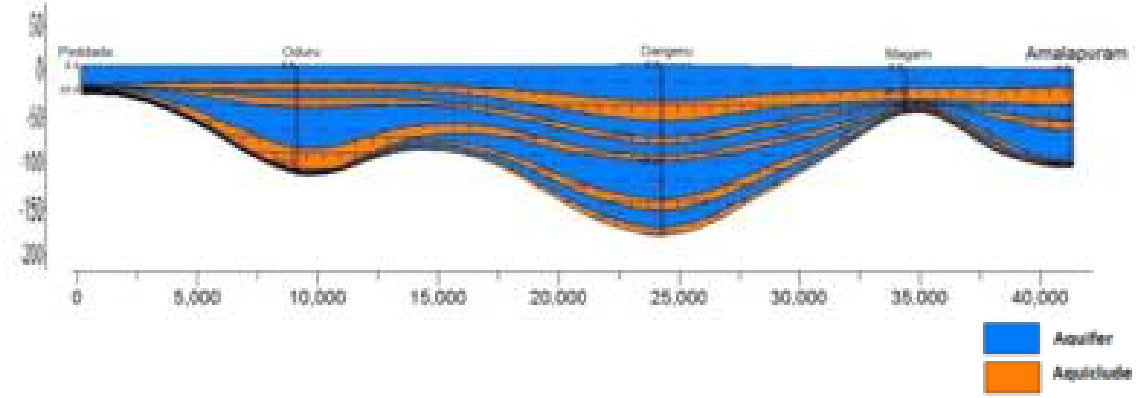


Fig. 31d Hydrogeological Cross Section (D-D')

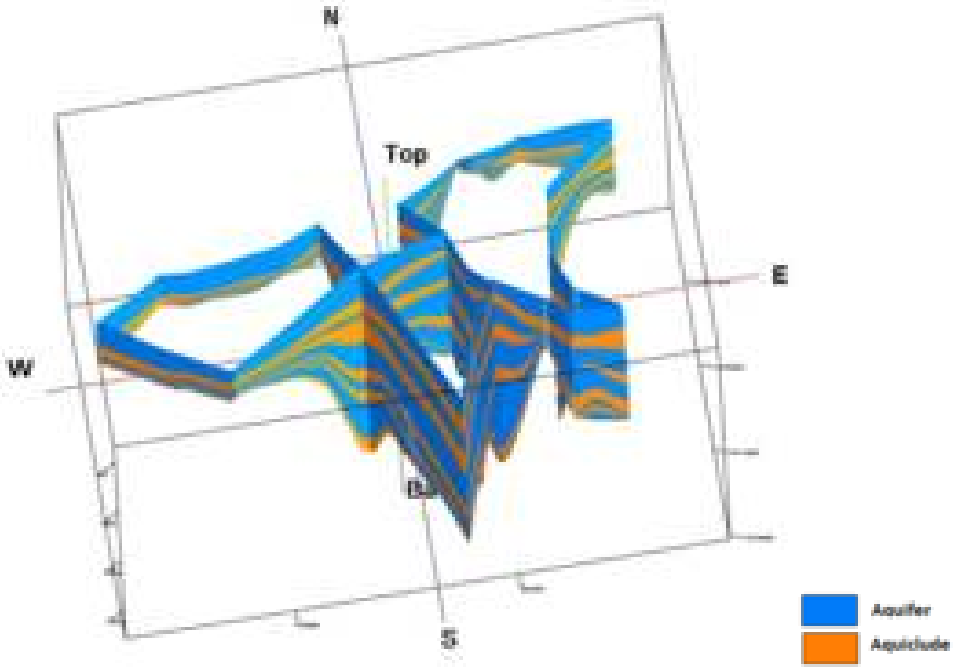


Fig. 29a Fence Diagram

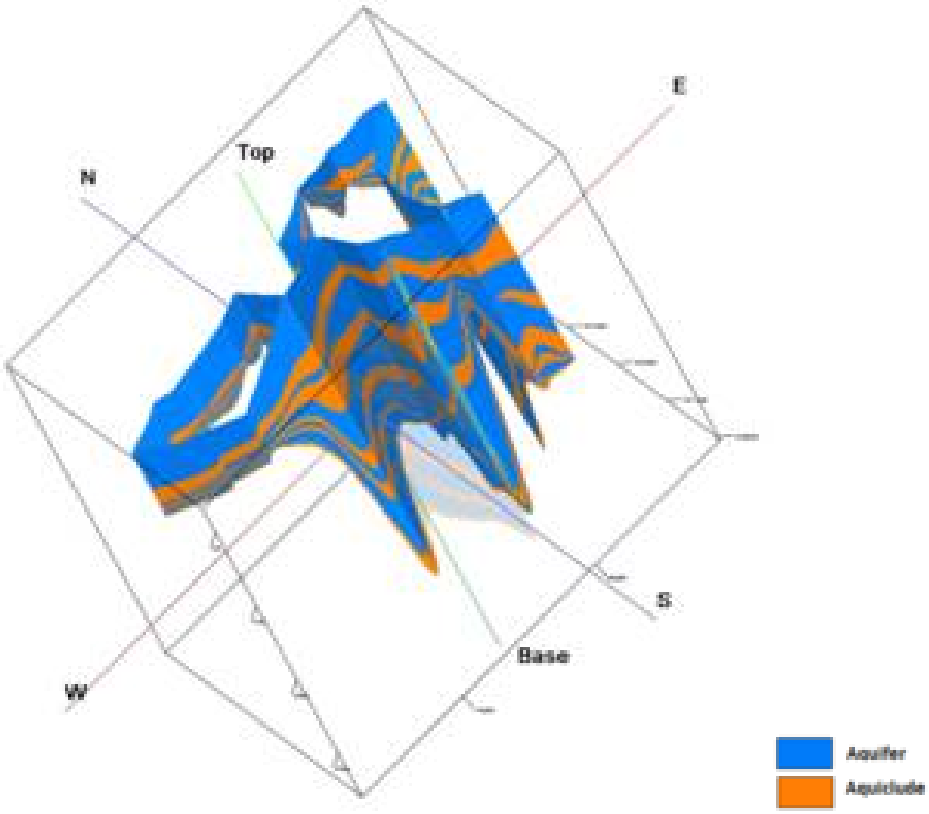


Fig. 29b Fence Diagram

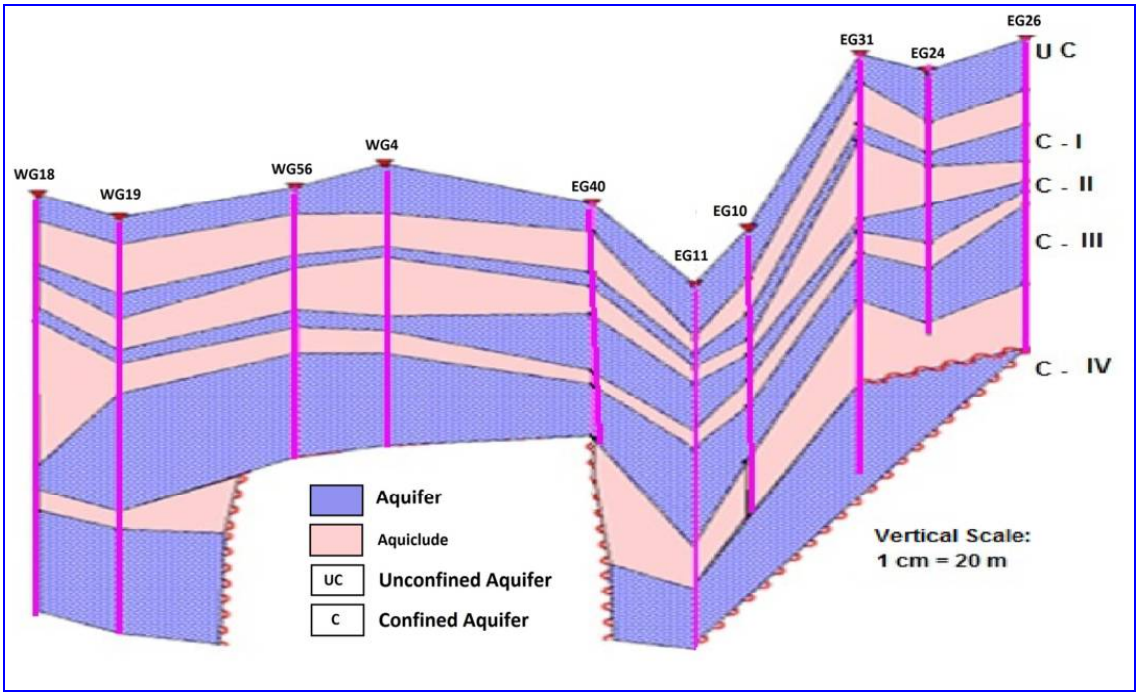


Fig. 30 Panel Diagram – Aquifer Disposition in Godavari Delta

Based on the detailed studies carried out in the central Godavari delta different hydrogeological cross sections are prepared and presented as Fig. 32a & b. These studies reveal that deterioration of quality of ground water from shallow to deeper aquifers. Shallow aquifer is in unconfined condition and having the fresh ground water with EC ranges from 540 to 1700 micro siemens/cm at 25°C. The second aquifer is confined in nature and quality of the ground water is brackish to saline, where the EC ranges from 3000 to 5650 micro siemens/cm at 25°C. The deeper aquifers are saline with EC ranges from 10600 to > 20000 micro siemens/cm at 25°C and confine in conditions.

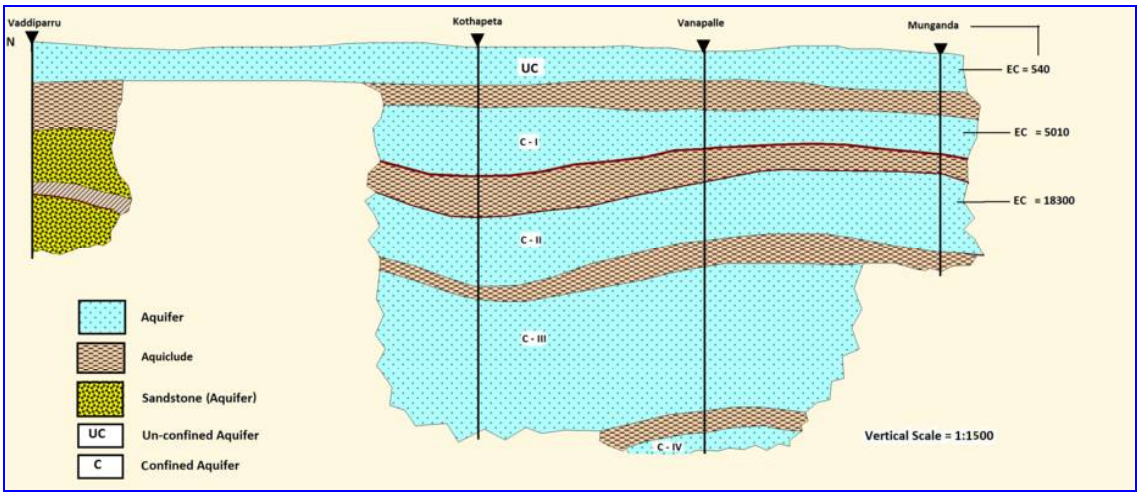


Fig. 32a Hydrogeological Cross Section (Vaddiparru to Munganda)

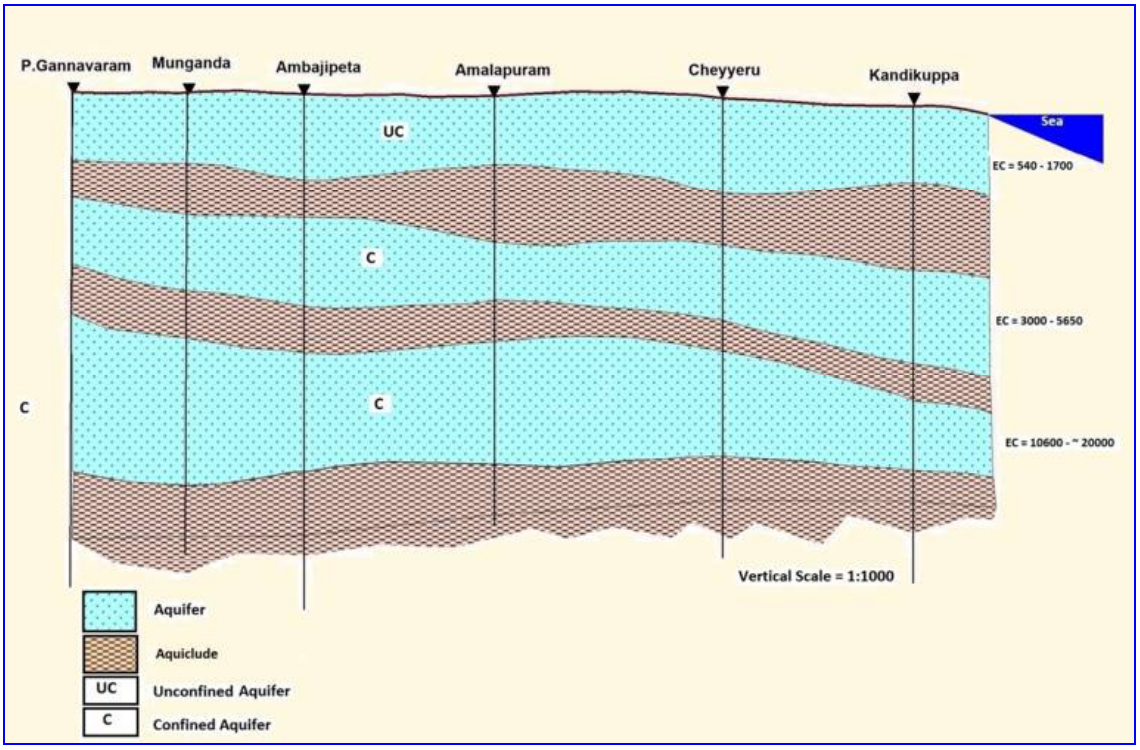


Fig. 32b Hydrogeological Cross Section (P.Gannavaram to Kandikuppa)

The geophysical studies i.e., VES indicate a three to four layered geoelectric model. The top soil is characterised by the resistivity from 4 to 22 ohm.m and the thickness varies from <1 to 3m. The second layer is characterised with a resistivity of 7 to 52 ohm.m and is of fresh in quality. The data reveals that most of the area beyond 25 m bgl is of saline except in

some localized patches, where the resistivity values are varying from 30 to 60 ohm.m with a thickness of 10 to 25 m. The data reveals that in general the quality of ground water deteriorates with depth.

Hydrogeological, hydrochemical and geophysical studies reveal that the existence of five distinct aquifers within 300 m bgl in the Godavari deltaic area. The maximum thickness of the alluvium is not established. The first aquifer is under unconfined conditions where as the remaining aquifers are confined in nature. Shallow fresh water aquifer exists to a maximum depth of 34 mbgl, whereas quality of ground water in the deeper aquifers is saline.

4. GROUND WATER RESOURCES

The study area is being the part of command of Godavari Irrigation system, the requirement of ground water for irrigation is limited and when required is met through dug wells and filter point. In the area during monsoon season recharge from rainfall and other sources is 670 MCM and 1055 MCM respectively. During non-monsoon season recharge from rainfall and other sources is 447 MCM and 1276 MCM respectively. The Net annual ground water availability in the area is 3116 MCM. The gross ground water draft for all uses in the area is 335 MCM. Net ground water availability for future irrigation use is 2726 MCM. The stage of ground water development in the area is 11%. The unit recharge and draft details are presented as Fig 33 & 34. The summarised details of the ground water resources (dynamic) of the area are given in table-5. The entire area is categorised as safe (Fig. 35 & Table-6). 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 907365 m^3/day and 1419894 m^3/day during premonsoon and postmonsoon periods respectively.

Table-5 Summarised Ground Water Resources of the Godavari Deltaic Area

	Total Area	Excluding Poor Quality Area
Net annual ground water availability (MCM)	3116	1408
Existing gross ground water draft for all uses (MCM)	335	287
Provision for domestic and industrial requirement supply to 2025 (MCM)	146	107
Net ground water availability for future irrigation development (MCM)	2726	1066
Stage of groundwater development (%)	11	20
Category	Safe	Safe

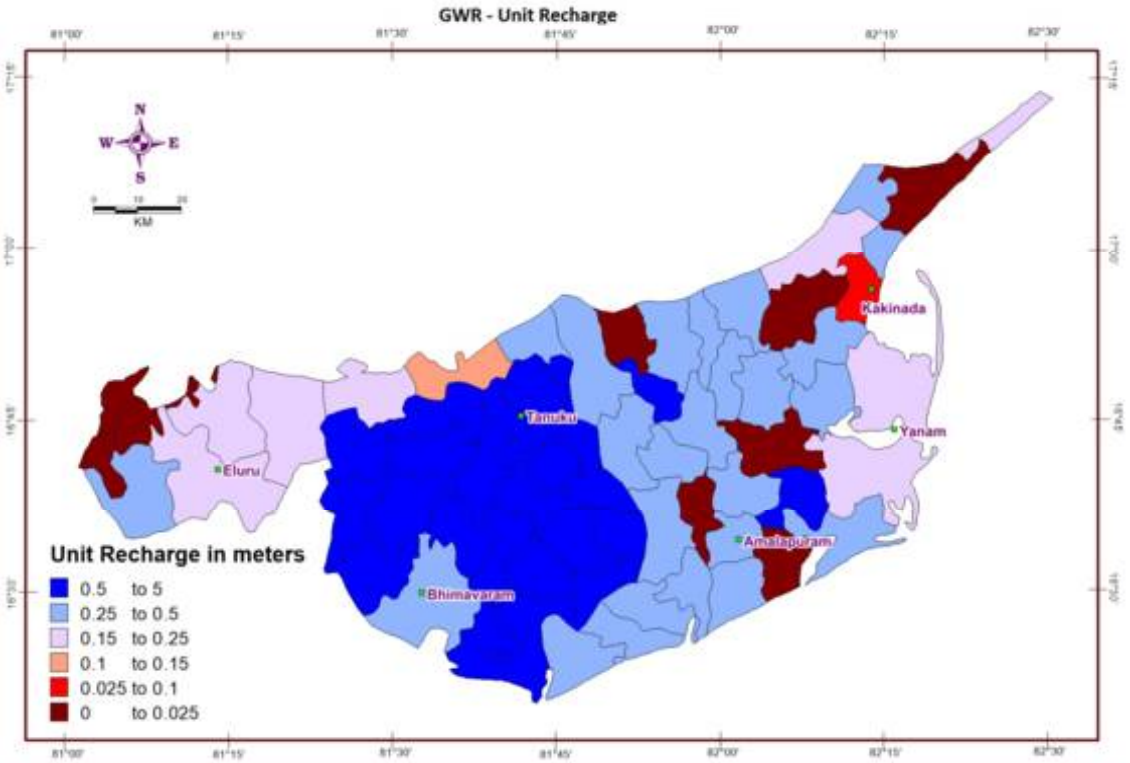


Fig. 33 Ground Water Resources – Unit Recharge of the Area

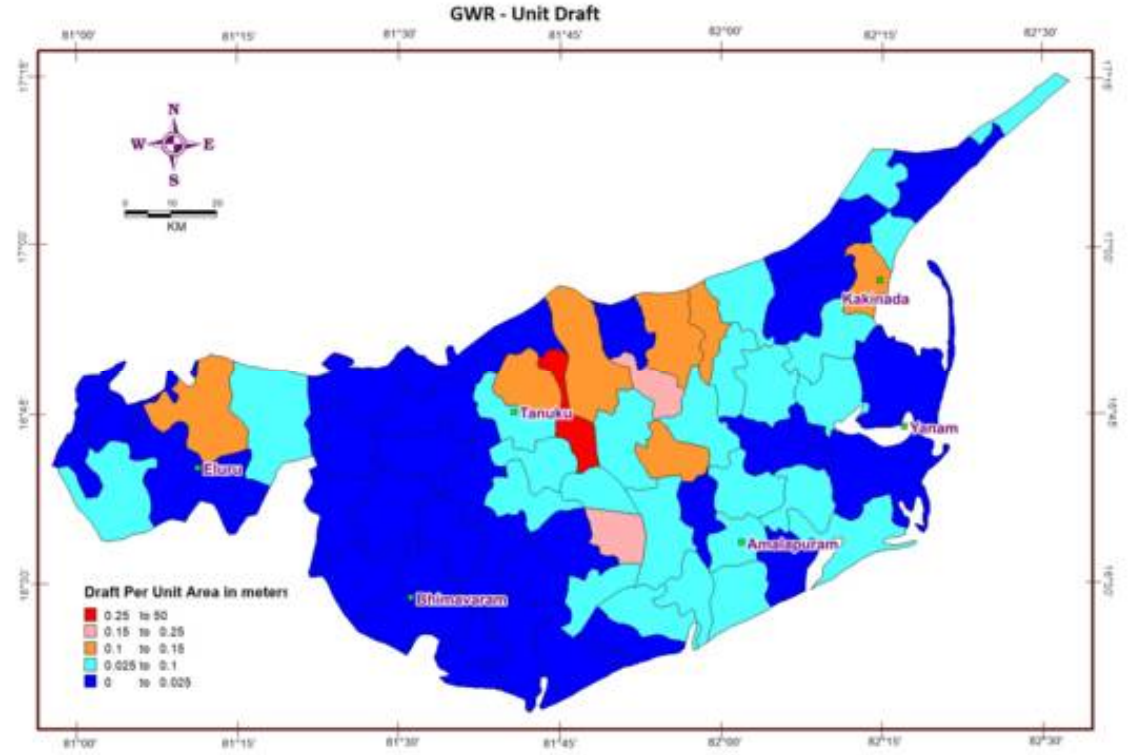


Fig. 34 Ground Water Resources – Unit Draft of the Area

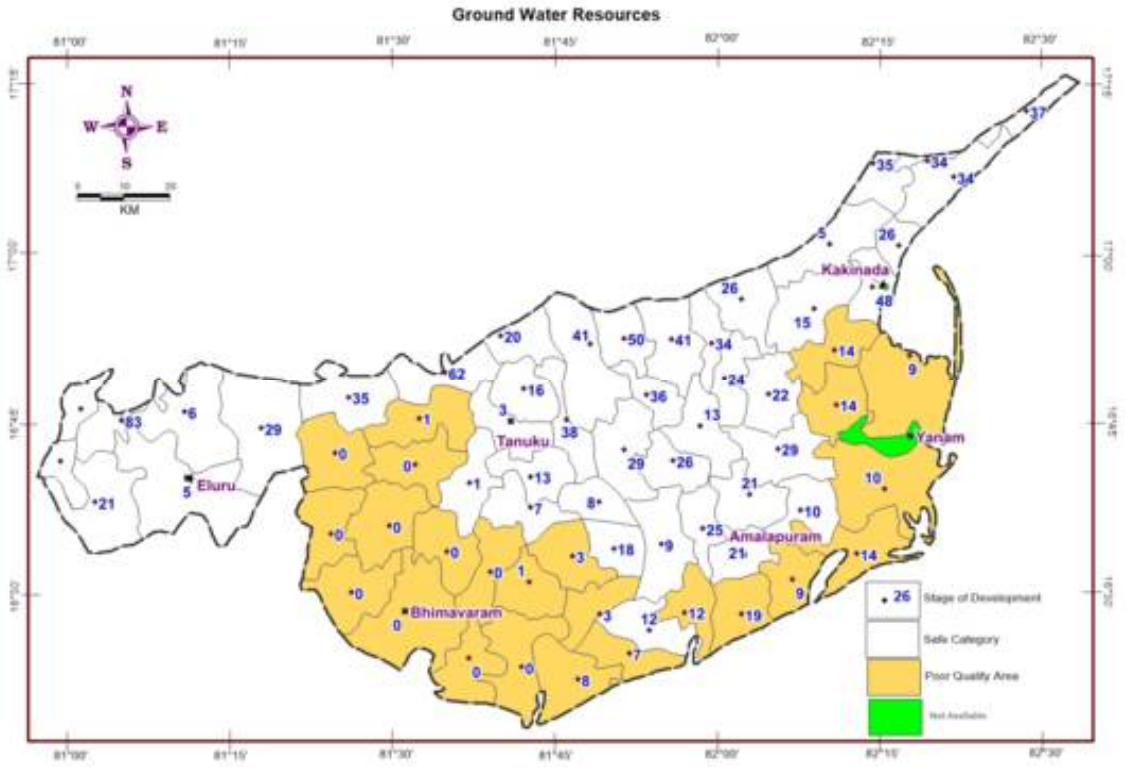


Fig. 35 Ground Water Resources of the Area

Table-6 Ground Water Resources - Mandalwise

S.No	District	Mandal/ Block	Net annual ground water availa-bility (MCM)	Existing gross ground water draft for all uses (MCM)	Provision for domestic and industrial requirement supply to 2025	Net ground water availability for future irrigation develop-ment(MCM)	Stage of ground water develop-ment (%)	Cate-gory	Re-marks
1	East Godavari	Aalamuru	3032	1102	177	1930	36	Safe	
2	East Godavari	Ainavilli	3600	757	202	2843	21	Safe	
3	East Godavari	Amalapuram	2446	522	291	1925	21	Safe	
4	East Godavari	Ambajipet	1904	485	131	1350	25	Safe	
5	East Godavari	Anaparthi	2160	730	151	1538	34	Safe	
6	East Godavari	Atreya-puram	3828	1575	168	2153	41	Safe	
7	East Godavari	Biccavole	3702	842	195	2714	23	Safe	
8	East Godavari	Kadiam	3588	1780	230	1638	50	Safe	
9	East Godavari	Kakinada(U)	420	789	375	506	48	Safe	
10	East Godavari	Kakinada (R)	1647	107	1357	0	26	Safe	

11	East Godavari	Kapileswarapur	3997	514	134	3250	13	Safe	
12	East Godavari	Kothapet	3324	877	322	2347	26	Safe	
13	East Godavari	Mandapet	4168	1501	271	2436	36	Safe	
14	East Godavari	Mummidivaram	4144	407	342	3437	10	Safe	
15	East Godavari	P.Gannavaram	3744	352	185	3292	9	Safe	
16	East Godavari	Pedapudi	3738	569	211	3212	15	Safe	
17	East Godavari	Pithapuram	1470	511	242	800	35	Safe	
18	East Godavari	Ramachandrapu	4599	1028	432	3571	22	Safe	
19	East Godavari	Ravulapalem	3719	1094	236	2615	29	Safe	
20	East Godavari	Rayavaram	2927	704	136	2213	24	Safe	
21	East Godavari	Razole	2557	295	267	2262	12	Safe	
22	East Godavari	Samalkota	2563	130	460	1995	5	Safe	
23	East Godavari	Thondangi	855	319	87	459	37	Safe	
24	East Godavari	U.Kothapalli	2288	772	254	1464	34	Safe	
25	West Godavari	Achanta	6517	1161	245	5111	18	Safe	
26	West Godavari	Attili	6250	67	132	6096	1	Safe	
27	West Godavari	Bhimadole	3962	1146	271	2564	29	Safe	
28	West Godavari	Denduluru	3095	1794	307	1170	58	Safe	
29	West Godavari	Eluru	3566	164	1470	2072	5	Safe	
30	West Godavari	Pedapadu	3790	794	235	3102	21	Safe	
31	West Godavari	Iragavaram	4907	661	128	4173	13	Safe	
32	West Godavari	Nidadavolu	1687	52	32	1635	3	Safe	
33	West Godavari	Pedavegi	40	0	0	40	0	Safe	
34	West Godavari	Penugonda	6712	557	266	5889	8	Safe	
35	West Godavari	Penumantra	7084	520	241	6394	7	Safe	
36	West Godavari	Peravali	6632	2509	134	4085	38	Safe	
37	West Godavari	Tadepalligudem	1304	188	28	1101	14	Safe	
38	West Godavari	Tanuku	5995	205	254	5586	3	Safe	
39	West Godavari	Undrajavaram	6728	1045	144	5589	16	Safe	
40	West Godavari	Unguturu	2073	30	4	2043	1	Safe	
41	East Godavari	Allavaram	3042	583	561	2459	19	Safe	PQ
42	East Godavari	I.Polavaram	4167	402	383	3766	10	Safe	PQ
43	East Godavari	Kajuluru	4427	609	531	3818	14	Safe	PQ
44	East Godavari	Karapa	3574	502	449	3072	14	Safe	PQ
45	East Godavari	Katernikona	3936	544	544	3392	14	Safe	PQ
46	East Godavari	Malkipuram	2589	185	179	2404	7	Safe	PQ
47	East Godavari	Mamidikuduru	2522	294	266	2228	12	Safe	PQ
48	East Godavari	Sakhinetipalli	3025	245	239	2781	8	Safe	PQ
49	East Godavari	Tallarevu	4267	404	379	3864	9	Safe	PQ
50	East Godavari	Uppala guptam	3882	367	360	3515	9	Safe	PQ
51	West Godavari	Akiveedu	14824	0	0	14824	0	Safe	PQ
52	West Godavari	Bhimavaram	8872	0	0	8872	0	Safe	PQ
53	West Godavari	Ganapavaram	7490	0	0	7490	0	Safe	PQ
54	West Godavari	Kalla	8132	0	0	8132	0	Safe	PQ
55	West Godavari	Mogalturu	5366	7	0	5359	0	Safe	PQ
56	West Godavari	Narasapuram	9902	0	0	9902	0	Safe	PQ
57	West Godavari	Nidamarru	6288	12	0	6276	0	Safe	PQ
58	West Godavari	Palakoderu	6971	0	0	6971	0	Safe	PQ

59	West Godavari	Palakollu	7211	70	0	7141	1	Safe	PQ
60	West Godavari	Pentapadu	10589	158	0	10431	1	Safe	PQ
61	West Godavari	Poduru	8105	209	0	7896	3	Safe	PQ
62	West Godavari	Undi	12035	0	0	12035	0	Safe	PQ
63	West Godavari	Veeravasaram	21663	0	0	21663	0	Safe	PQ
64	West Godavari	Yelamanchili	7969	239	0	7730	3	Safe	PQ
		Total	3116	335	146	2726	11	Safe	

5. GROUND WATER RELATED ISSUES

The Delta system has emerged due to the depositional cycles of the River Godavari, debouching the inland sediments into the Bay of Bengal. On the eastern and southern sides 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 Godavari 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, 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 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 Godavari delta are :

- Water Logging
- Ground Water Salinity
- Aqua Culture

Water Logging :

Water logging is a common feature in irrigation commands of surface water projects. Godavari deltaic area is not an exceptional one. The DTW maps reveal that an area of 2,500 km^2 (36%) is under water logged condition during premonsoon period, whereas during postmonsoon period it is extended to 4,400 km^2 (63%) (Fig. 15 & 16). The area prone to water logging during premonsoon and postmonsoon periods is 2,250 km^2 (32 %) and 1,870 km^2 (27 %) 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 Godavari 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 area can be due to the following three reasons viz., palaeo salinity, due to leakage from the bottom aquifer, due to sea water intrusion caused by human activity. Based on the studies carriedout by CGWB, the origin of salinity in the unconfined aquifer is discussed in the following paragraphs.

Palaeo Salinity : By palaeo 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 Godavari delta, it can be understood that most of the delta is under sea in the geological past. If the ground water in Godavari delta is palaeo 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 Godavari Delta is not of palaeo salinity.

Leakage from Bottom Aquifer : The Godavari Delta has five aquifers upto a depth of 300 m bgl and the top one is upto maximum of 34 m bmsl and is unconfined in nature and has fresh water. The other four aquifers are saline in nature. The second aquifer which exists in between 22 m and 60 m bmsl 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. Even 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 Godavari Delta, the fresh water discharges into sea were computed as 907365 m^3/day and 1419894 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 tip of the interface also starts moving towards the land. This type of situation is not present in Godavari 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 indicators also indicate there is small area near the coast which is influenced by saline water.

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. The unconfined aquifer in the delta is maximum to a depth of 34m bmsl and the ground water in this aquifer is fresh excepting small pockets. The field EC

measured during the time of monthly monitoring of water levels indicate the increase in the vicinity of Dinda, N.Kothapalli, Kandikuppa, S.Yanam, Gollapalli , Narsapur and Mogalturu during the water stress months indicates the rise of transition zone of fresh water – saline water interface due to abstraction of ground water in this area for the purpose of Irrigation.

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 the saline water occurs at a depth of 40 - 480 m during post monsoon season saline water occurs at deeper level compare to premonsoon season. The aquifer has an extension upto 34m 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 studies, and 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 upto 750m from the coast during pre monsoon season and 500m from the coast during post monsoon season. One of the sections (in the eastern most part of the delta) is presented as Fig. 36. Whereas in the vicinity of Upputeru area (Mallvaki Lanka to Kodurupadu) the figure 37 indicates that at most the toe of the interface is effective upto 24 Km from the coast during pre monsoon season and 4 km from the coast during post monsoon season.

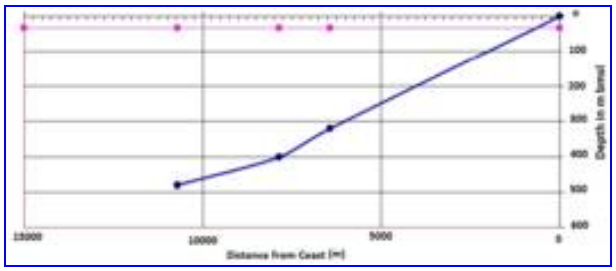


Fig. 36a Location of the Toe of Fresh Water – Saline Water Interface During Premonsoon

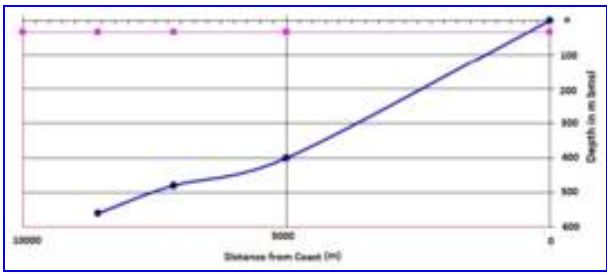


Fig. 36b Location of the Toe of Fresh Water – Saline Water Interface During Postmonsoon

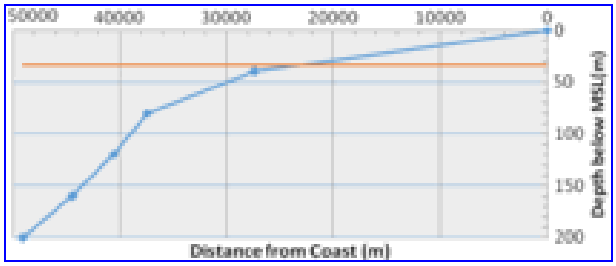


Fig. 37a Location of the Toe of Fresh Water – Saline Water Interface During Premonsoon

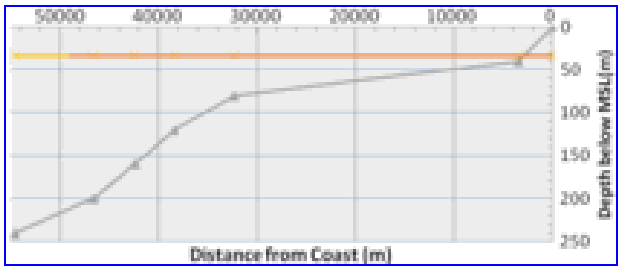


Fig. 37b Location of the Toe of Fresh Water – Saline Water Interface During Postmonsoon

The area covered by poor quality ground water in the Godavari delta is estimated to be 930 km^2 during premonsoon period in the area along coast and some patches in inland, whereas during postmonsoon period it is limited to 475 km^2. It is evident from this that as soon as water released into canals for irrigation and after rainfall the temporarly accumulated inferior water is flushed out or being diluted and the area is getting reclaimed naturally to some extent.

In this scenario the problem of salinity if at all exists 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 western part of the delta mainly due to the direct recharge of saline water through Upputeru and some contribution may be from the aquaculture activities.

It is reported that there is no reduction in crop yields and other problems due to water logging and salinity in the area. As the command area is in operation since 1852, 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.

Aqua Culture :

In coastal tracts and in the vicinity of the Kolleru lake, 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 mudflats 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 is applied, this causing the pollution of shallow aquifers.

6. MANAGEMENT PLAN

The Problems in the Godavari 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, people 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,

The available fresh ground water may be encouraged to extract through conjunctive use. 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.

Management Plan for the areas where quality deterioration due to sea water intrusion is taking place:

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. There should be strict Implementation of Ban on Pumping in the areas which are less than 2kms from the sea and also pumping from the first two aquifers for the purpose of Aquaculture.

Artificial Recharges Measures should be practised in upper reaches such that the ground water head is always 2m 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 2kms from the coast and also strict Implementation of 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 2kms from the coast by maintaining the flows in the creek either from direct river water or drain water from the irrigation canals. Aqua Culture Should not be encouraged beyond 2kms from the coast.

This problem can 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 it should not arise a need for pumping in the tail end areas especially areas less than 2kms from the coast. Strict Implementation of Ban on Pumping in the areas which are less than 2kms from the sea. Artificial Recharges Measures should be encouraged to be practised in upper reaches such that the ground water head is always 2m 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. Pumping the ground water through a net work 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.

7. SUM UP

- Godavari deltaic area is covering an area of 6,950 km^2.
- Topographically the area is gently undulating to near flat.
- The normal rainfall of the area is 1146 mm.
- The area depict 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.
- Paddy is the main crop and the surface water is main source of irrigation.
- The area is underlined by alluvium followed by sandstones. The thickness of alluvium varies from less than 40 m to more than 400 m.
- Alluvium is the principal aquifer. Five aquifers exist upto a depth of 300 m. The shallow aquifer is under unconfined condition and the deeper aquifers are in confined conditions.
- The ground water development is low in the area. Shallow aquifer is being tapped by dug wells and by filter points/ shallow tube wells in the area as and when need arises and the depth of the wells generally ranges from 3 to 12 m.
- In general ground water levels are < 6 m and < 4 m during premonsoon and postmonsoon seasons respectively. No significant changes exist in the long term water level trend.
- The quality of ground water in shallow aquifers is fresh except the area near coast, where as the deeper aquifers are saline.
- Net ground water availability is 3,116 MCM and the stage of development is 11%.
- The hydraulic gradient is towards sea and the fresh water discharges into sea were computed as 907365 m^3/day and 1419894 m^3/day during the pre and post monsoon seasons respectively.
- An area of 2,500 km^2 (36 %) and 4,400 km^2 (63%) under water logged condition during premonsoon and postmonsoon periods respectively.
- Ground water salinity problem 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.

To overcome the problems in the area the following measures may be implemented :

- ✓ 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.
- ✓ Existing regulations must be adhered strictly to avoid ecological imbalances and environmental problems arise due to aquaculture.

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