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Paleo Channel Flow Dynamics in Central Godavari Delta, East Godavari District A.P.

National Institute of Hydrology
Deltaic Regional Centre
Kakinada

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Preface

The ever-growing demand for fresh water for human consumption has become a worldwide cause for concern. Nowadays, groundwater reserves are exposed to intensive exploitation, which may create serious problems in coastal area where some hydraulic connection exists between the water reservoirs and seawater. Hydraulic gradients following intensive withdrawal of freshwater in this type of aquifer can favor salt water intrusion, which in extreme situation can strongly affect the pumping wells. Increases in the sea level along the coast of India as result of climate change might become a serious problem with dramatic consequences projected for the next century, such as the retreat of shorelines, loss of wetlands and intrusion of salt water into aquifers and estuaries. The effect of higher mean sea level on the hydrology of coastal areas, apart from the effects of increased flooding is also important in coastal areas.

Along coastal areas and deltas, the seawater intrusion phenomena can be better understood by going through the time series of some typical parameters of chemistry of ground water and supported by stable isotopic characteristics. Seawater encroachment inland is the most common observation that causes increase in salinity. Several other sources that can affect groundwater quality along coasts are fossil seawater in un-flushed parts of the aquifer following invasion of seawater during relatively high sea levels; displacement of old saline groundwater from underlying or adjacent aquifers or aquitards; pollution from various sources including sewage effluents, marine water; etc,.

In collaboration with AP State Groundwater Department scientific investigations were undertaken in a typical; deltaic paleo channel aquifer in the Godavari delta to understand the sea water intrusion process and to evaluate groundwater budget to understand the threat of seawater intrusion, while utilizing the full groundwater potential of the aquifer. The study was part of work plan of Deltac Regional Centre, National Institute of Hydrology, Kakinada. The study was undertaken at Deltaic Regional Centre, National Institute of Hydrology, Kakinada by Shri. SV Vijaya Kumar, Scientist E1 with support of Dr. Bhishm Kumar, Scientist F, Dr. YR Satyaji Rao, Scientist E2, Dr. PC Nayak, Scientist C, Shri. B Krishna, Scientist C, Shri. T Vijaya, SRA and Shri. PR Rao, RA.

Abstract

Demand for fresh water for agriculture as well as drinking purposes in deltas is increasing day by day. In such situation conjunctive use studies to identify fresh water pockets in the deltas and to arrive at different strategies for better utilization of surface and groundwater are gaining importance. One such major Paleo channel of Gautami Godavari in the central delta of East Godavari District has been identified by AP State Ground Water Department (APGWD). The objective of the study is to characterize groundwater of Paleo channel in Godavari delta; evaluation of groundwater quality and isotope characterization of groundwater of the paleo channel; quantification of Paleo channel flow etc.

There is striking contrast in chemistry of oceanic water and continental fresh ground water and help in noticing initiation of seawater intrusion. The chemical analysis data indicated that there is no significant seasonal change in groundwater quality in paleo channel and most of the samples belong to calcium-bicarbonate type. In the upstream side of paleo channel groundwater quality is similar at most places. This scenario is mainly due to influent characteristics of river branches at the head of the delta and due to the three major canals of the delta system. However, the groundwater towards down stream is deteriorating from the aspect of major cations and anions. The stable isotope plots for δO^{18} and δD also indicates that the significance of rainfall recharge is not much and most of the recharge is from river, canal waters.

Groundwater levels at Kundalapalli, Machavaram, Modekurru, Vyagreswaram and Naranedra puram indicate an average rise of 1.6 to 1.9 m and a fall of 1.75 to 2.2 m from up stream to down stream in and around paleo channel. In the study area, about 3500 Ha i.e., 18% of the cropland under the Palivela lock (Amalapuram main canal) is irrigated from the Ambajipeta channel i.e accounting to 20 MCM per season. Whereas the actual requirement is about 35 MCM, the balance of 15 MCM is the draft from Groundwater of the paleo channel. From the groundwater balance of the study area, the net groundwater flow into the system is about 3.5 MCM for monsoon season. Thus draft of non-monsoon season is estimated about 40 MCM. The study can be duplicated for other such aquifers facing threat of seawater intrusion and help in undertaking distributed groundwater modelling of the interface.

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INTRODUCTION

The ever-growing demand for fresh water for human consumption has become a worldwide cause for concern. Nowadays, groundwater reserves are exposed to intensive exploitation, which may create serious problems in coastal area where some hydraulic connection exists between the groundwater reservoirs and seawater. Hydraulic gradients following intensive withdrawal of freshwater in this type of aquifer can favor salt water intrusion, which in extreme situation can strongly affect the pumping wells. Increases in the sea level along the coast of India as result of climate change might become a serious problem with dramatic consequences projected for the next century, such as the retreat of shorelines, loss of wetlands and intrusion of salt water into aquifers and estuaries. The effect of higher mean sea level on the hydrology of coastal areas, apart from the effects of increased flooding is also important in coastal areas.

Demand for fresh water for agriculture as well as drinking purposes in deltas is increasing day by day. In such situation conjunctive use studies to identify fresh water pockets in the deltas and to arrive at different strategies for better utilization of surface end groundwater are gaining importance. An inhomogeneous material composed of different textures is equivalent to its overall behavior to an homogeneous anisotropic porous medium (Bear, 1972), provided the thickness of individual layers is much smaller than the lengths of interest within the porous medium domain. The resistance of the layers governs the flow in vertical direction (recharge) (Bear and Verruijt, 1992). We know that paleo channels contain and yield fresh water in significant quantities if they have hydraulic connection from the original river course, where they get recharged. One such major Paleo channel of Gautami Godavari in the central delta of East Godavari District has been identified by AP State Ground Water Department (APSGWD). From areal photographs and other remote sensing methods and ground truth surveys the course of the paleo channel has been identified by the APSGWD. Now, efforts are being made to compute the groundwater potential of this paleo channels.

The objective of the study is to characterize groundwater of Paleo channel in Godavari delta; quantification of Paleo channel flow; evaluation of groundwater quality and isotope characterization to investigate seawater intrusion, if any. The brief methodology adopted was to conceptualization of the study area and its boundaries;

monitoring of quality and fluctuations of groundwater; chemical and isotopic characterization of rainwater, canal water and groundwater; to evaluate the groundwater balance in the study area.

Stable isotope investigation

The concept that the hydrological cycle system can be viewed as a global distillation column of waters fed by evaporation from the ocean as moisture which condenses as a result of cooling of air masses as it rises to higher levels. The degree of depletion of heavy isotopic water species of hydrogen and oxygen is correlated in the residual waters, provided there exists equilibrium between the condensed phases and the vapors at all times. For stable isotopes, their differences in isotopic species in water play an important role in the variation that is observed in the atmospheric water cycle by promoting fractionation effects during vapor/liquid and vapor/solid phase changes. Thus, isotope fractionation occurs at each phase change except sublimation and melting of compact ice.

Stable isotopes are the atoms of an element, which are satisfied with the current arrangement of proton, neutron and electron. According to Clark and Fritz (1997), stable isotopes such as D and ^{18}O can be used as conservative groundwater tracers since their values remain constant as long as there is no phase change or fractionation along flow path.

Dansgaard (1964) described in detail the process of formation of stable isotopes in Precipitation. Munnich (1968) has studied the moisture movement and recharge using isotope techniques and prepared guidelines for IAEA. Bhandari et. al. (1986) conducted hydrogeological investigations in Sabarmati and Mahi basins and Coastal Saurashtra using radioisotope and chemical tracers.

Geo-chemical investigations

Along coastal areas and deltas, the seawater intrusion phenomena can be better understood by going through the time series of some typical parameters of chemistry of ground water. This is due to the contrast in chemistry of oceanic water and continental fresh ground water. Sea water in general has uniform chemistry with predominance of Cl^- and Na^+ with a molar ratio of 0.86; an excess of Cl^- over the alkali ions, Na and K; and Mg greatly in excess of Ca^{2+} with Mg/Ca ranging from 4.5 to 5.2. In contrast, fresh groundwater is characterized by highly variable chemical composition with dominance of HCO_3^-, SO_4^{2-} and Cl^-. Ca^{2+} and Mg^{2+} are fundamental cations of a natural groundwater followed by alkali ions of Na and K.

Seawater encroachment inland is the most common observation that causes increase in salinity. Several other sources that can affect groundwater quality along coasts are such as fossil seawater in un-flushed parts of the aquifer following invasion of seawater during relatively high sea levels; displacement of old saline groundwater from underlying or adjacent aquifers or aquitards; pollution from various sources including sewage effluents, marine water; etc,.

2.0 METHODOLOGY

Govt. of Andhra Pradesh, Ground Water Department referred this study to DRC, NIH, Kakinada. The objective of the study is to characterize Paleo channel in Godavari delta; quantification of Paleo channel flow; evaluation of groundwater quality; The brief methodology adopted was to conceptualization of the study area and its boundaries; monitoring of quality and fluctuations of groundwater; chemical and isotopic characterization of rainwater, canal water and groundwater; groundwater balance.

Stable isotope characterization

Isotopes are supplementary tools for hydrological investigations and should be employed as an integral part of studies. It is understood that all hydrogeologic, hydrochemical, hydrodynamic and isotopic interpretations have to be space and time related. So, it is necessary that one should consider all the related aspects of water sampling for isotopes and prevailing hydrogeologic conditions in a study area.

Elements that contain atoms with required number of protons but different numbers of neutrons are called isotopes. Isotopes can be classified in two important categories, (i) stable isotopes and (ii) unstable isotopes. Stable isotopes are the atoms of an element, which are satisfied with the present arrangement of proton, neutron and electron. The atoms of an element which do not decay with time or take infinite time to decay are called stable isotopes of that element. On the other hand, unstable isotopes are the atoms of an element which do not satisfy with the present arrangement of atomic particles and disintegrate by giving out alpha (α), beta (β) particles and/or gamma (γ) radiation etc. and transform into an another type of atom. This process continued till the stable nuclide (element) is formed. Because of disintegration or the property of giving out radiation, the unstable isotopes are also called radioactive isotopes. For example, ^{1}H and ^{2}H are stable isotopes while ^{3}H is unstable. Similarly ^{12}C and ^{13}C are stable isotopes while ^{14}C is unstable. On the other hand, isotopes of oxygen (^{16}O, ^{17}O and ^{18}O) are stable. Over 2000 isotopes of 92 naturally occurring elements have been identified out of which several hundred are stable isotopes. But for hydrological investigations, we talk much about hydrogen and oxygen stable isotopes.

The δD and δ^{18}O analyses help in understanding the contribution of different recharge sources and also to pinpoint the most important recharge source. Dansgaard (1964) conducted one of the earliest studies of the δ^{18}O in precipitation. The δ value is the most common way to express the difference in isotopic composition between a sample and a reference with a ratio of R-value, which is a reference standard for the substance.

Measurements of stable isotopes are done in terms of abundance ratios i.e. atomic mass of heavy atom to the atomic mass of light atom. However, the absolute abundance ratio of isotopes is not usually measured in natural waters and in other components. Only the relative difference in the ratio of the heavy isotopes to the more abundant light isotope of the sample with respect to a reference is determined. The difference is designated by a Greek letter δ and is defined as follows:

$$\delta = (R_{sample} - R_{reference}) / R_{reference} \qquad (1)$$

where, R's are the ratios of the $^{18}O/^{16}O$ and D/H isotopes in case of water. The difference between samples and references are usually quite small, δ values are therefore, expressed in per mille differences (‰) i.e. per thousand, δ (‰) = δ x 1000. It is called as 'del'.

$$\delta (‰) = [(R_s - R_r) / R_r] \times 10^3 \qquad = [(R_s / R_r) - 1] \times 10^3 \qquad (2)$$

If the δ value is positive, it refers to the enrichment of the sample in the heavy-isotope species with respect to the reference and negative value corresponds to the sample depleted in the heavy-isotope species.

The reference standards normally considered are SMOW (Standard Mean Oceanic Water) and VSMOW (Vienna Standard Mean Ocean Water). VSMOW has the same ^{18}O content as defined in SMOW but its D-content is 0.2 ‰ lower. Over the period of use, the old standards have been consumed. Therefore, other reference standards have been developed in due course of time. These are SLAP (Standard light Antarctic Precipitation), NBS-1 and NBS-1A (National Bureau of Standard) and GISP (Greenland Ice Sheet Precipitation).

The relation between δD and δ^{18}O that has been observed in global precipitation is expressed mathematically by the equation known as Global Meteoric Water Line (GMWL)

$$\delta D‰ = 8\,\delta^{18}D + 10 \qquad (3)$$

The relation between δD and $\delta^{18}O$ can be written in a standard form as a linear equation

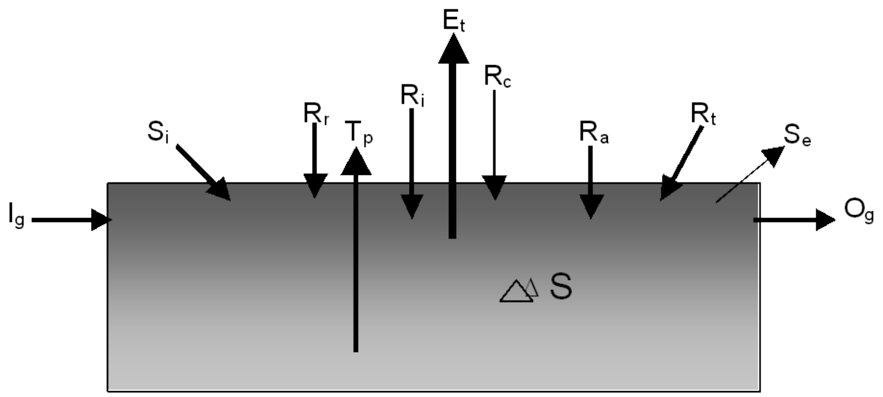
$$\delta D‰ = A\ \delta^{18}O + d \qquad (4)$$

Where A is the 'slope' and d is the 'intercept' of δD vs. $\delta^{18}O$ line of fresh global meteoric waters. One can develop regional and local meteoric water lines on the pattern of standard relationship between δD and $\delta^{18}O$ valid on regional or local levels. The 'slope' of the line corresponding to $\delta^{18}O$ versus δD of water undergoing evaporation decreases as humidity decreases. That is the slope of standard meteoric line of 8 can range between 8 and 3 in the case of evaporation depending on the relative humidity. The result of this is that residual liquid water that has undergone evaporation plots to the right of the meteoric water line following a slope of 3 to 8. Waters that have experienced the greatest evaporation factor are farthest from the meteoric line. The slope of this divergent line indicates that relative humidity during the evaporation process. Waters of Closed Basins must have undergone evaporative fractionation.

Groundwater balance

The principle of water balance or water budget states that, with in any system difference of all the supply components and use components should balance the change in storage of the system. Depending on the water resources development of the system, water balance should be conducted area wise for canal water, groundwater and rainwater. In deltas and coastal areas, where rainfed and public lift irrigation schemes are hardly found, components of rainwater balance and groundwater balance are of less importance compared to water balance components of canal water. Once conjunctive use practice of surface water and ground water commences the components of groundwater balance becomes important in areas where exclusive extraction of groundwater is expected to occur. Canal water balance should be taken up when canal water is the main source of supply supplemented by groundwater from private wells. Richard et. al (1980) prepared a manual for preparation of water balance which describe in detail the selection of parameters, boundaries, time period, and level of detail for different applications. The groundwater estimation committee of union ministry of water resources (MOWR, 1983, 1997), after making a review of various aspects has made certain recomondations for evaluating the groundwater potential of any region.

The hydrologic water balancing for an area is undertaken by estimating or calculating individual supply components and abstraction or use components properly and understanding the change in storage. Precipitation or rainfall; stream flows; storage in tanks and reservoirs; groundwater pumpages; changes in groundwater storage; groundwater inflows; imported water; return flows are some of the supply components. Agricultural water for irrigation; municipal and commercial uses for drinking and industry; compensation releases; water rights and legal entitlements for drawing water; natural depletions through evaporation, evapotranspiration, groundwater outflows and seepage are some of the use components. Standard techniques and methods of estimating most of the components are discussed in brief here. Some of the supply components and components are being continuously monitored by various State and Central Government organizations, whereas difficulties are being faced in estimating those components which require detailed experiments. Because of this when each experimental information is not available, a



R_i = Recharge from field irrigation; R_c = Recharge from canal seepage; R_r = Recharge from rainfall
R_a = Recharge due to water conservation structures (Artificial Recharge); S_i = Recharge from influent seepage from river;
I_g = Recharge from groundwater inflow; R_t = Recharge from tanks; E_t = Evapotranspiration from deep rooted trees and water-logged areas; T_p = Draft from groundwater; S_e = Discharge due to effluent seepage to drain;
O_g = Discharge due to groundwater outflow; ΔS = Change in groundwater storage

suitable empirical relation should be sought in estimating such parameters.

Fig. 1.Water Balance Components of Groundwater System

The budget

The basic concept of water balance, as mentioned earlier, is

$$\sum I - \sum O = \Delta S \qquad \text{--------- 1}$$

where I is input or supply components of the system, O is output or use components of the system and ΔS is change in storage of the system. The detailed input and output components for groundwater balancing are listed below and the methodologies for assessment are described.

I. Supply components:

A) Natural recharge:

1) Rainfall recharge

2) Recharge from river

3) Recharge from other basins

B. Artificial recharge:

1) Induced recharge from rivers

2) Recharge from Canals and fields

3) Recharge by injection and spreading

II. Use components:

A. Natural

1) Evapotranspiration

2) Regeneration in rivers

3) Outflow to other basins

B. Artificial

1) Groundwater draft through public and private openwells, filter points and tubewells. Some times legal aspects need to be consdidered.

Consdering various inflow and outflow components, the ground water balance can be formulated as

$$(R_i + R_c + R_r + R_a + S_i + I_g + R_t) - (E_t + T_p + S_e + O_g) = \Delta S \qquad \text{----- 2}$$

where,

R_i = Recharge from field irrigation

R_c = Recharge from canal seepage

R_r = Recharge from rainfall

R_a = Recharge due to water conservation structures (Artificial Recharge)

S_i = Recharge from influent seepage from river

I_g = Recharge from groundwater inflow

R_t = Recharge from tanks

E_t = Evapotranspiration from deep rooted trees and water-logged areas

T_p = Draft from groundwater

S_e = Discharge due to effluent seepage to drain

O_g = Disharge due to groundwater outflow

ΔS = Change in groundwater storage

Recharge from canal seepage

Seepage refers to the process of water movement from a canal into and through the bottom and the sides. It constitutes a significant part of total recharge to aquifer system. This is more so in case of newly developed command areas compared to old systems. So one should be very careful while estimating this component. The investigations carried out in different parts by a number of organizations suggest the following ways and means of assessing seepage losses. The canal seepage losses can be estimated by direct methods(Doorenbos, 1963; Klaatz, 1971).

For areas, where water table is not shallow, the Groundwater Estimation Committee, GEC, 1997 has recommended canal seepage of 1.8 to 2.5 cumecs per million square meters of wetted area for normal soils with some clay alongwith sands. It is 3 to 3.5 cumecs per million square meters of wetted area for sandy soils with some silt for unlined canals. It may be taken as 20% of the above values in case of lined canals and canals in hard rock areas as shown in Table 1.

Table 1. Table showing recharge due to seepage from canals

Sl. No	Canal type & soil type	Recommended value / million sq.m of wetted area
A	Unlined in normal soils with some clay content along with sand	1.8 to 2.5 m3/s (or) 15 to 20-Ha-m/day
B	Unlined in sandy soils with some silt content	3.0 to 3.5 m3/s (or) 25 to 30 Ha-m/day
C	Lined canals and canals in hard rock	20% of that of unlined canals
Note 1: For water logged and shallow areas it has to be suitably reduced		
Note 2: If specific results are available, those should be preferred.		

Empirically, the seepage losses can be computed as

$$\text{Losses in cumecs/ km} = C/200 * (B+D)^{2/3} \qquad \text{----- 3}$$

Where B and D are the bed width and canal depth in metres being with C=1.0 for intermittent running channels and 0.75 for constant running channels.

The canal seepage losses can be estimated by direct methods. The general accepted method of measuring the quantities of seepage is by methods like (a) Inflow - outflow method (b) Ponding method (c) Seepage meter measurement and (d) special methods like tracers, electrical resistivity logging, piezometric surveys and nuclear techniques. The various guidelines for estimating seepage losses are at best approximate unless confirmed directly.

Recharge from tanks

Studies have indicated that seepage from tanks varies from 9% to 20% of their live storage. Since records of data on live storage capacity of tanks is rarely maintained, the recharge from tanks may be taken as 44 to 60 cm per year over the total water spread, taking into account the hydro-climatic conditions in the area as per GEC 1984. **GEC, 1997** modified this to 1.4 mm/day over the period of availability on the average water spread area. In case the information on this is not available 60% of the maximum water spread can be considered.

The seepage from percolation tanks is higher and may be taken as 50% of its gross storage. In case of seepage from ponds and lakes, the norms suggested as above for tanks by Groundwater estimations committee may be taken.

Influent and effluent seepage

The stream - aquifer interaction in the study area is to be evaluated in the study area by estimating the influent and effluent seepage components, which are very important components of the groundwater balance equation. The effluent and influent seepage changes from reach to reach along the stream and from season to season during the study period. After understanding the stream - aquifer interaction, the groundwater contribution component, i.e., influent or effluent seepage is to be arrived at from accounting the stream water budget relationship, which considers discharges at upstream and downstream of reach; discharges of tributaries, flows diverted, evaporation from stream surface and flood plain; and change in bank storage. It can be observed that this requires lot of observed data that will be scarcely available. The component can be distributed to either bank depending on the gradient of water table and transmissivity of the formations of either bank. As per GEC, 1997, this component may be ignored if gauge- discharge data is not available.

Groundwater inflow or outflow

To estimate subsurface inflow or outflow of groundwater the hydraulic gradient of water table in the area and permeability of the formation and depth of formation are to be investigated in detail. The recharge and discharge boundaries in the study area are to be delineated. If one wants to use isophreatic lines to arrive at the gradient the observation well network should be a well distributed one. The depth to water table of OB wells of concurrent observations is only to be used. Here comes the importance of the detailed analysis of the groundwater level data. Once satisfactory gradients are established, the inflow outflow can be determined from the following relationship

$$Q = \sum^{L} TI\Delta L \qquad \text{--------- 4}$$

where T is the transmissivity, I is the hydraulic gradient averaged over a length ΔL and L is the length of the recharge or discharge boundary. GEC 1997 nullified this component of net groundwater flow when watershed as a whole is considered. In command areas this has to be estimated from groundwater table slope and distance through which inflow and outflow occur.

Evapotranspiration from groundwater reservoir

Evapotranspiration, ET, is the quantity of water lost to atmosphere by evaporation and that transpired through plants for their sustenance. When the evapotranspiration is from an area where water table is close to the ground surface or say up to 2 m from ground, the evaporation from soil and transpiration from plants can be at maximum possible rate or at potential rate. During well inventory, investigations should be specifically oriented towards accurately delineating water table depth at intervals of 0.3 m for depth less than 1.0 m. From lakes and marshes evaporation takes place at potential rate, i.e., at pan-evaporation multiplied by pan coefficient. For forested areas, fully-grown orchards, evapotranspiration can be considered at potential rate because such trees are deep-rooted and therefore have better access to groundwater. Certain plants have very deep roots and take up water by transpiration even from a deep water table, say 15-20 m. Actual ET is less than or at the most equal to potential ET. The later is affected mainly by meteorological factors and the former depends on plant and soil conditions.

Penham method, Thornthwaite formula and Blaney- Criddle formula for determining the potential evapotranspiration when water supply is not a limiting factor are better known methods. For determining the actual ET, moisture flux method and water balance method based on lysimeter studies, water level fluctuations or soil moisture balances are suitable. As per GEC 1997, hilly areas are deleted from the assessment unit and thus this component is considered as small during the monsoon season. It is recommended that 5% to 10% of the total annual groundwater potential may be assigned to account for natural discharges in the non-monsoon season.

Draft from groundwater

Draft or pumpage is the amount of water lifted from the aquifer by means of various means and methods. The withdrawal for agriculture can be from public tube wells, private tubewells, filter points, dugwells by means of pumps fitted with electric motors or oil engines. Draft from individual well vary widely, depending on the yield, type of well, well design, depth to water table and method of lift, crops grown, land holding, climate, the original source of irrigation and soil-water management practices adopted. Inventories of wells and sample survey of groundwater draft from various types of wells are pre-requisites for computation of draft rate. Where wells are energized, power consumption data give adequate information to account draft. The GEC, 1997 has suggested the following draft estimates for Andhra Pradesh for different structures as shown in Table 2.

Table 2. Table of Average gross unit draft (Ha-m) for different structures in Andhra Pradesh

Sl.No	Type of structure	Average gross unit draft (Ha-m)
1	Dugwell with Mohot	0.35
2	Dugwell with pumpset	0.65
3	Borewell with pumpset	1.3
4	Shallow tubewell	2.05
5	Medium tubewell	4.1
6	Deep tubewell	5.85

Where wells are used for irrigation, agricultural statistics can be used for computation of groundwater draft for irrigation. The basic information required for this purpose is crop-wise area irrigated by wells, water requirements of crops, cropping seasons, soil-moisture conditions and sources of water. The water requirement is the total amount of water required at the field head to mature a crop and includes the amount of water required to meet evapotranspiration needs, application losses and other special needs like leaching, puddling, pre-planting irrigation etc.,. The methodology suggested by Ministry of Agriculture (1971), Govt. of India for estimating the monthly crop water requirement, using pan-evaporation and crop coefficient is also considered most suitable. The total cropped area available from village level statistical data can be substantiated using remotely sensed satellite information, if feasible.

In a regional water balance, one is often interested only in the total withdrawal by pumpage during the period of balance. In a detailed forecasting problem, the areal distribution of pumpage is important.

Change in groundwater storage

The change in groundwater storage is an indicator of the long-term availability of groundwater. The change in groundwater storage between beginning and end of the non monsoon season indicates that the total quantity of water withdrawn from groundwater storage and similarly, the change between the beginning and end of the monsoon season indicates the amount of water gone into the reservoir. Since the accumulated storage of monsoon season is utilized subsequently during non-monsoon season one should be very cautious while assessing the storage. This storage plays a very important role while formulating the conjunctive practice in the study area.

To assess the change in groundwater storage, the water levels are to be observed through a network of observation wells evenly and well spread all over and around the study area. The water levels are highest immediately after monsoon and lowest before monsoon season. In peculiar circumstances, like untimely storms along the coastal areas because of cyclones or some other specific weather phenomena this may vary and is to be duly noted while analyzing the water level data. The change in storage can be computed from the following equation

$$\Delta S = \sum h\,A\,S_y \qquad \text{--------- 5}$$

where, ΔS is change in storage; h is change in water level; S_y is specific yield; A is area of influence.

The specific yield may be computed from pumping test. In case if there is no pumping test data available for the area, the guidelines as suggested by the groundwater estimation committee, 1997 for specific yield of different types of geological formations are shown in Table 3.

Table 3. Norms for Specific yield@ in different formations (%)

Geology	Formation	Recommended	Minimum	Maximum
Alluvium	Sandy	16	12	20
	Silty	10	8	12
	Clayey	6	4	2
Hard Rock	Weathered granite,gneiss,Schist (low clay)	3	2	4
	Other Weathered granite,gneiss,Schist	1.5	1	2
	Weathered, vesicular, jointed basalt	2	1	3
	Laterite	2.5	2	3
	Sandstone	3	1	5
	Quartzite	1.5	1	2
	Limestone	2	1	3
	Karstified limestone	8	5	15
	Phyllites, Shales	1.5	1	2
	Massive poorly fractured rock	.3	.2	.5

@ The recommeded value should be used unless data based on field study is available to justify minimum, maximum or any intermediate value.

3.0 STUDY AREA

The Godavari Delta is located on the east coast of India and lies between sea and the 12 m contour. Godavari is the largest river, draining Peninsular India that has made an extensive delta on the east coast of India protruding 35 kilometers from adjoining coast into the Bay of Bengal. The present day delta is the third largest delta of India after those of Ganges and Mahanadi. Significant discharges from Godavari commence from June and reach a maximum in August. August and September are the months of peak discharge. The mean discharge is 3600 Cumecs. The region exhibits a hot tropical climate characterized by a range of oppressively low daily temperatures in summer, high humidity and a moderate annual rainfall. The temperature continuously increases from the end of February to the hottest month (May) between 35 ^{o}C and over 40 ^{o}C in the interior. In the coldest month (January) 22 ^{o}C is recorded in the coastal region and 19-20 ^{o}C in the interior. The normal annual rainfall of the district is 1075 mm. The normal annual rainfall is about 1227.9 mm at Amalapuram; 1296.7 mm at Mummidivaram; 1193.3 mm at Razole and 1145.5 mm at Kothapeta. The Study area map is shown in Fig 2.

Agriculture

The Godavari Delta Irrigation is one of the oldest and most important irrigation system in the state of Andhra Pradesh playing a vital role in the rice economy of India over a century. From Agriculture point of view, the alluvial soils are considered to be the most fertile lands and paddy being the major crop of the godavari delta system, it is known as rice bowl of A.P. A large number coconut trees also grow in the study area and coconut for about 15 % of the total area. There is no forest area in the delta system. The Kharif season commences from 1st June when irrigation water released through the canal system, which extends upto November. The Rabi season is from December to April of the succeeding year. The major crops and source of irrigation of important administrative regions of the delta is shown in Fig.3.

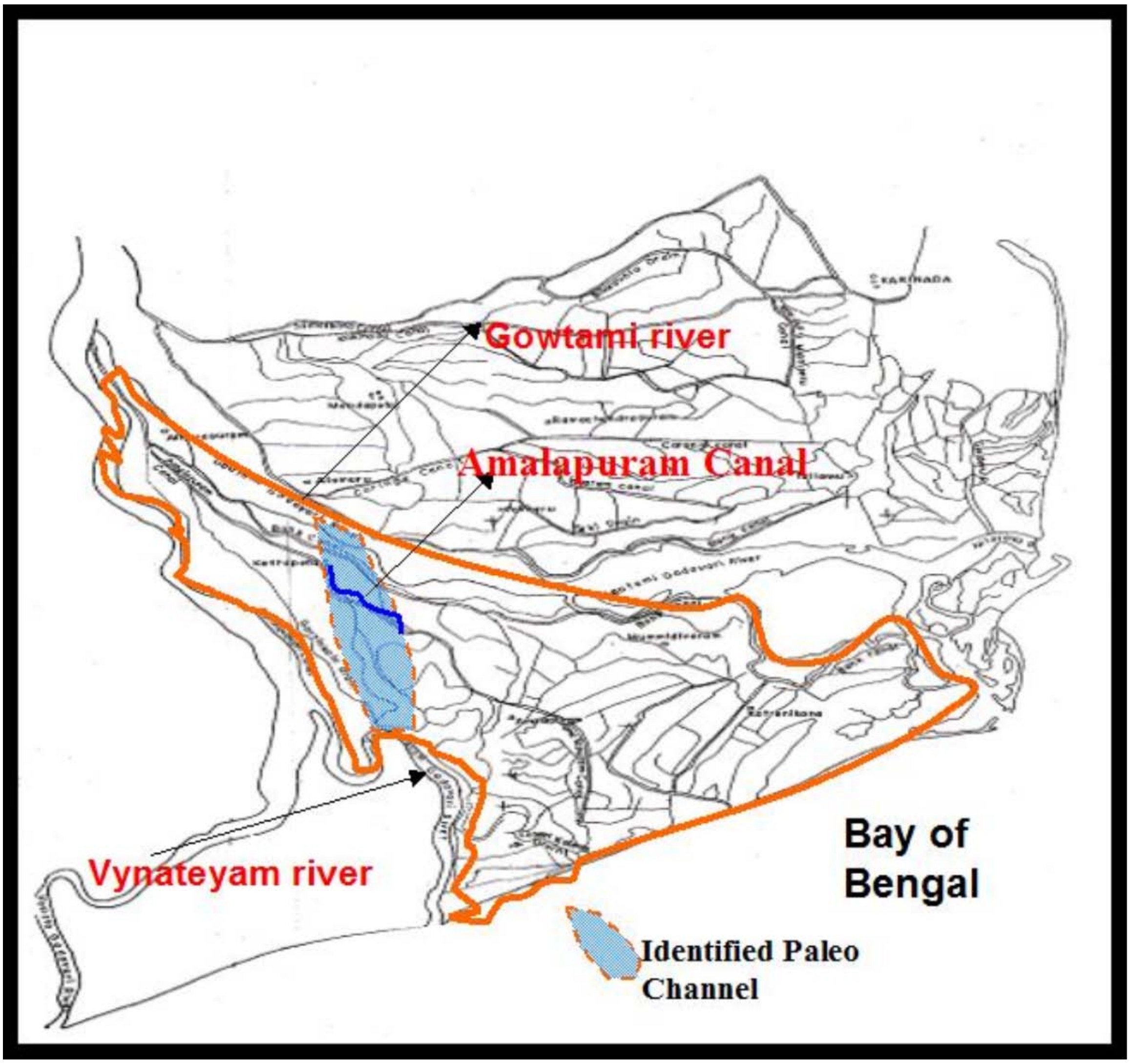


Fig. 2. Canal Network of Central Godavari Delta along with Paleo Channel

Irrigation Canal Network

The Irrigation system of the Godavari Central Deltal comprises of central delta main canal taking off from the S A C Barrage at Dowlaiswaram. The central delta is served by number of major, medium and minor drains to remove the surplus water from the fields that gets accumulated especially during southwest monsoon when the area is subjected to incidence of heavy and widespread rainfall. Three branch canals namely Gannavram canal, Amalapuram canal and Bank canal,all taking off at Ryalli at main canal. One distributory, ie., Benda Canal taking off from Amalapuran canal and a number of channels taking off from these branch canals. The paleo channel under study is along the main canal from Mandapalli and the Ambajipeta channel that takes off from Palivela lock. The canal system remains operational for nearly 11 months with a closure period of one month during April and May in summer. The map showing the network of canals is shown in Fig. 2

Irrigated Area under different sources for different mandals

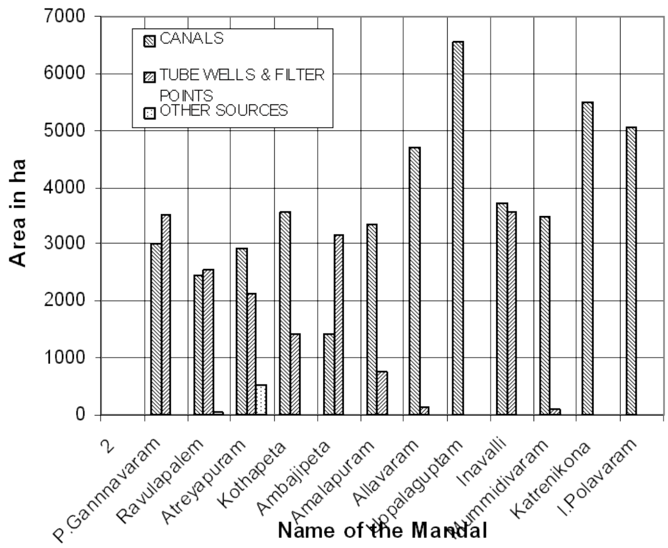


Fig. 3. Irrigated Area under different sources for different Mandals

Hydro-geology

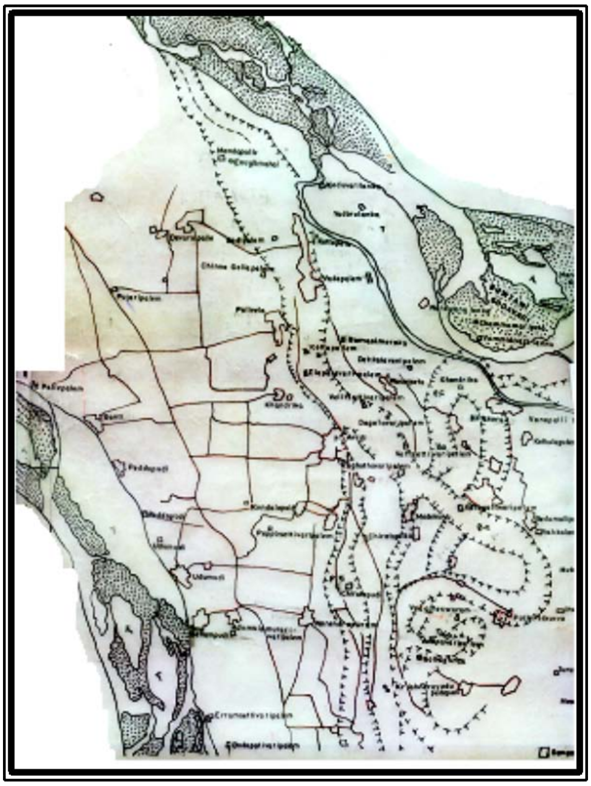
The rock types of the Godavari basin and its tributaries represent nearly a complete cross-section of the geology of peninsular India. More than half of the drainage basin of the Godavari consists of the Deccan Trap of late cretaceous Eocene age. It is essentially doleritic or basaltic in composition and is constituted of abundant labradorite and enstatie augite (pigonite) with intestinal glassy matter altered to plagonite anchlorophaeite. The alluvial cover is relatively shallow, underlain by crystalline basement, mostly Khondalites. This delta also lies toward southeastern end of PermoCarbonierous Gondwana trough but the limits of the delta are markedly beyond the limits of this ancient rift valley. The occurrence of marine coastal territories in the region of the delta head near Rajahmundry points to the fact that in the geologically recent past the area occupied by the deltaic alluvium was under the sea.

The alluvium consists of clayey soils with sands. Silts and gravel beds are mixed with clay in varying proportions. The thickness of alluvium varies from a few meters to more than 300 m and it overlies Rajahmundry sand stones. The thickness of granular zones in the alluvium ranges form 18 to 258 m within the explored depths. Groundwater in the deltaic alluvium occurs under both water table and confined conditions. In the alluvium of East Godavari district, dug wells range in depth from 2 to 11 m below ground level (BGL) and tap groundwater mostly for domestic purposes. The depth of the water table ranges from 0.2 to 8.5 m bgl and generally is within 2 m bgl tap confined aquifers and yield as much as 4000 cu. M /day. The wells yield between 700 and 22000 cu. M /day. The pumping water levels in these wells are generally with 14 m bgl. The freshwater is limited to shallow depths locally. This fresh water pockets are developed by dug wells and filter point well. At favorable places the filter pint wells yield up to 11000 cu. M /day. In the major portion of the alluvial area the entire alluvium explored down to 300 m depth contains saline water. The quality of groundwater in the alluvium varies widely both horizontally and vertically. The quality is generally good near the positive hydrological boundary to the Godavari down to depth of 300 m but the freshwater zone tapers gradually towards the coast, the freshwater saline interface sloping inland.

Identified Paleo Channel

The geographical distribution of the Paleo channel is of about 100 sq. m comprising of an unconfined single aquifer. The paleo channel emerges in the North, just above Mandapalli village on the right bank of Gautami Godavari and disappears in the South near Tondavaram on the left bank of Vainateyam river branch of Vasista Godavari river of the Godavari river delta system The delineated map of paleo channel is shown in Figure 4 .

Fig. 4. Demarcated Paleo Channel from Aerial Photographs study Area by GWD



Geophysical traverses have been conducted to establish the assistance and boundaries of this paleo channel as shown in Fig 5. Groundwater utilization is by means of filter point wells down to 10 to 15 meters. It is found that in the southern part of the paleo channel where it merges into the Vainateyam river groundwater extraction is considerably high and the quality is also poor. The paleo-channel under investigation is sloping towards the Vynateyam branch with the head located near Mandapalli near Gautami branch of the Godavari river.

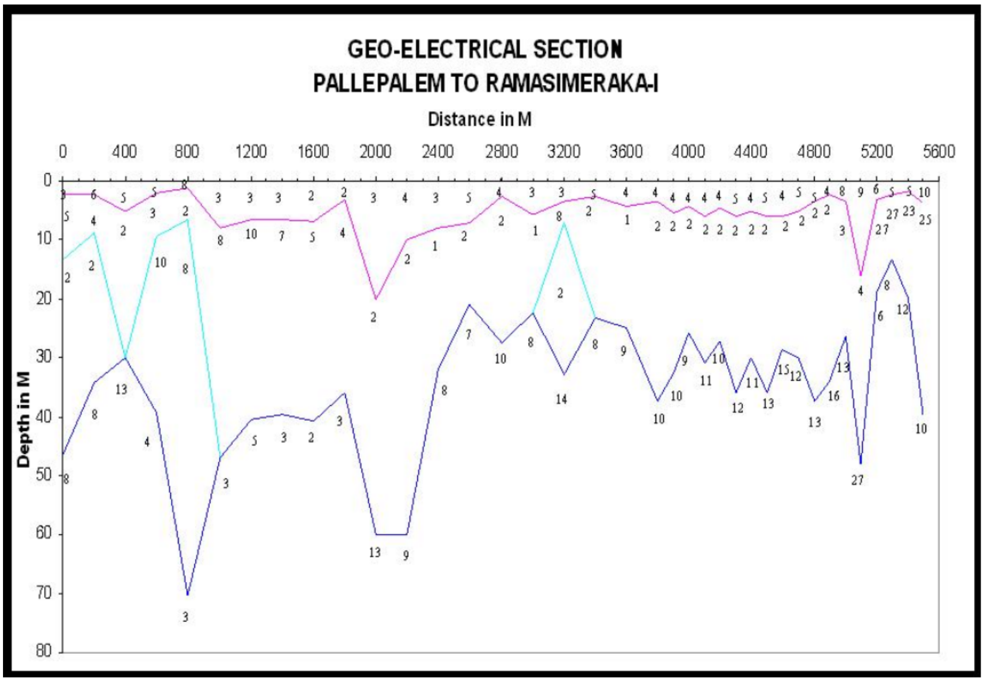


Fig. 5. Geo Electrical Section (Pallepalem to Ramasimerakha -I)

The delta is crossed by many a paleo-channels which are common in such deltaic morphological conditions, especially in highly fluvial dominant river deltas like the Godavari. Moreover, almost the entire paleo channel is geographically distributed in the area under Ambajipeta channel of Amalapuram Canal system. Therefore this will become ideal to develop conjunctive use strategies for this particular Amalapuram Canal System. The variation of electrical conductivity (EC) of groundwater in the delta is shown in Fig. 6. The typical photos of the Amalapuram canal, Ambajipeta channel taking off from Palivela lock, the groundwater extraction adjacent to canal using electric and oil motors and a view of paddy and coconut fields is shown from Fig. 7, Fig. 8, Fig. 9 and Fig. 10 respectively.

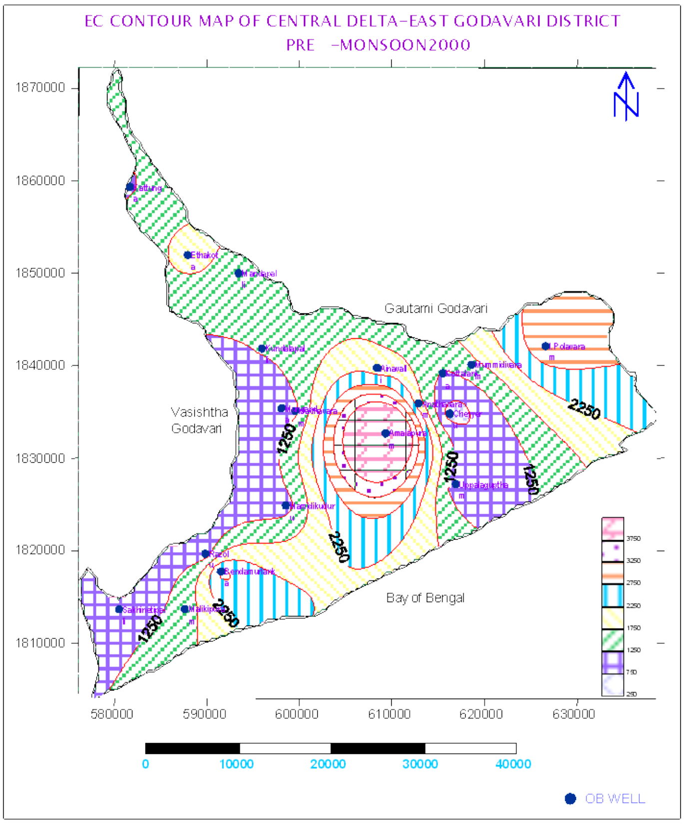


Fig. 6. EC Contour Map of Central Delta East Godavari District Premonsoon 2000

Fig. 7. Amalapuram Canal at Rice Mill Kothapeta

Fig. 8. Well with Oil Motor between Kothapeta and Palivela

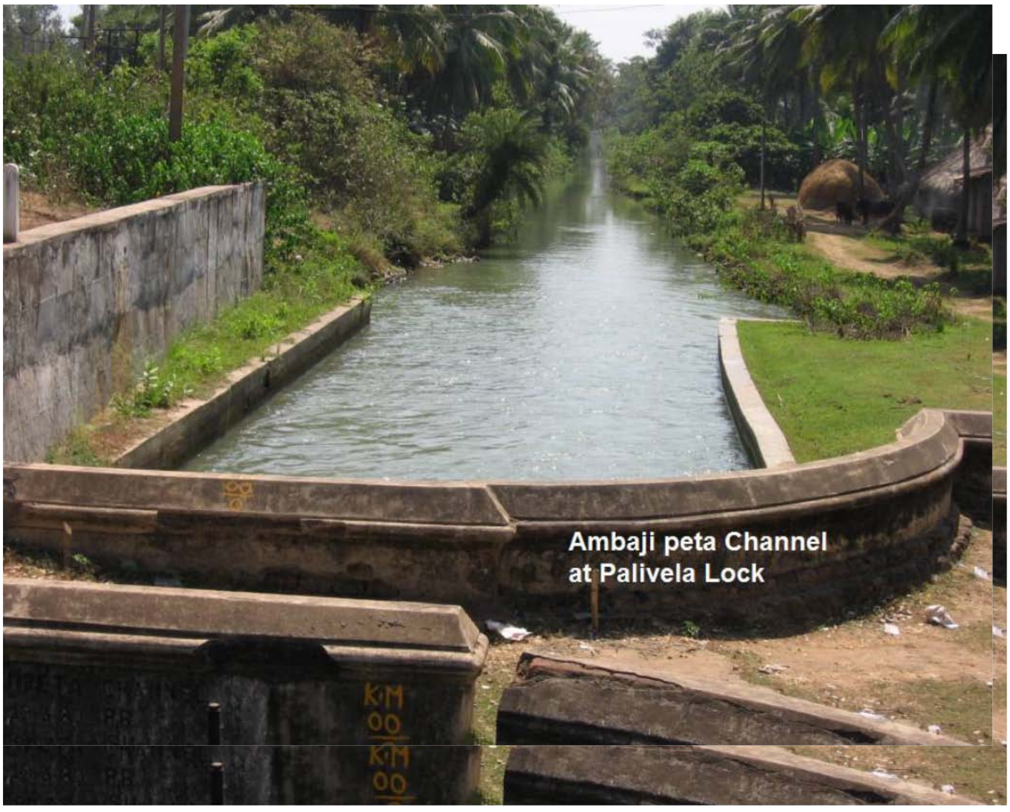


Fig. 9. Ambajipeta Channel at Palivela Lock

Fig. 10. Well adjacent to Ambajipeta Canal at Palivela Lock

Fig. 11. A view of Paddy and Coconut in the Area at Chirutapudi

4.0 SAMPLING & ANALYSIS

A network of tube wells and deep dug wells is established for collection of water samples. The field investigations like geo-hydrological studies, sampling for quality and isotope analysis of pre and post monsoon Groundwater samples, monitoring for depth to groundwater levels were undertaken during the years 2005 to 2007. Rain, river, canal, drain and groundwater in the study area are being collected monthly. The samples are being analyzed for chemical as well as stable isotope composition also. Monthly rainwater samples were collected from the Agricultural Research Station, Ambajipet for isotope characterization. The monthly rainfall is shown in Fig 12. Water samples were collected in February 06, March 06, June 06, July 06, September 06 and November 06 from shallow and tube wells for the pre-monsoon and post monsoon period. Hydrological investigations were conducted to monitor water samples from about 15 locations. The samples of precipitation, canal water, river water, drain water and groundwater were collected for chemical and isotope analysis. Efforts were made to avoid any contamination, evaporation and effect of exchange with atmosphere.

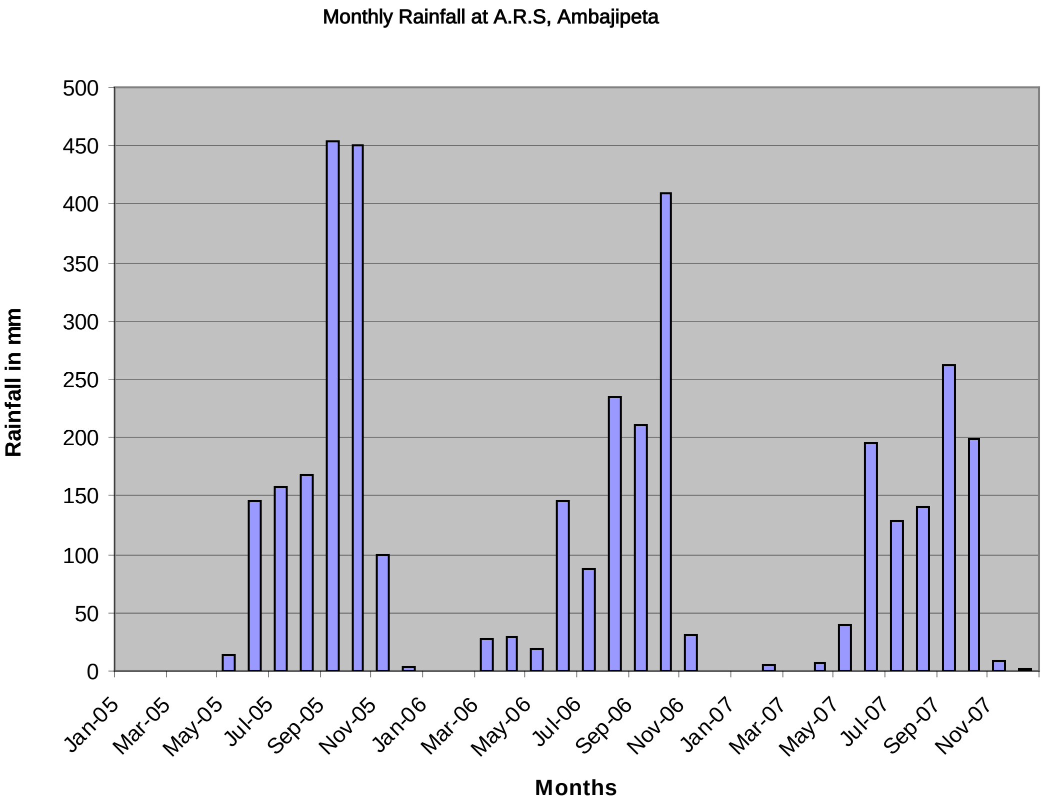


Fig.12. Monthly Rainfall at ARS, Ambajipeta, East Godavari District

Chemical Characterization

Hydrochemistry of water samples collected in and around paleo channel in Central Godavari Delta is evaluated and chemical characterization of groundwater of paleochannl and surrounding is discussed here.

Water sampling surveys were collected in the months of February 06, March 06, June 06, July 06, September 06 and November 06 to collect water samples from shallow wells/filter points, canal water, river water and drain water in and around major paleo channel in the Central Godavari Delta. The electrical conductivity values of the groundwater, canal water and river water are shown in Fig. 13. The location of major paleo channel is shown in Fig. 4.

In order to characterize water quality and its seasonal variations only March 2006, July 2006 and September 2006 samplings were only considered for present analysis and these months may be considered as representative seasons of pre monsoon, monsoon and post monsoon respectively in the study area. All the samples collected were analyzed at Water Quality Laboratory of Deltaic Regional Centre of NIH, Kakinada for physical and chemical parameters by following the standard procedures. The computed Ion balance error is within $\pm$ 10%. The chemical analysis indicated that, the EC of groundwater in the paleo channel is around 650 to 750 Micro mhos/cm and is clearly distinct from the groundwater in the neighborhood (EC values ranges from 2000 to 5000 Micro mhos/cm). Towards the Vynateyam river end, EC is going up to 2690 Micro mhos/cm (back water effect). The average chemical concentrations of each sample collected from shallow wells, canal water, drain water and river water are shown Table 4.

The variation of chloride and bicarbonate ions of groundwater sampled from the paleochannel during March, June and September 2006 is shown in Fig. 14 to 16. In the figures, from left to right the observation well locations are shown from upstream to downstream along the paleo channel. Results indicate that there is no major contaminant type in the shallow groundwater of the study area except Tondavaram area (nearby Vinathayam river). This salinity is mainly due to back water effect in the river. The chemical data of all groundwater samples **(Table 4 no.s)** are classified with Pipers diagrams to infer water types and its seasonal changes. The Pipers classification of groundwater samples collected in the paleo channel, North side of paleo channel and downward of paleo channel in the months of March 2006, June 2006 and September 2006 are shown in Fig.17, Fig. 18 and Fig. 19 respectively.

Fig. 13 Electrical Conductivity of water samples of 12 and 14 th March 2006

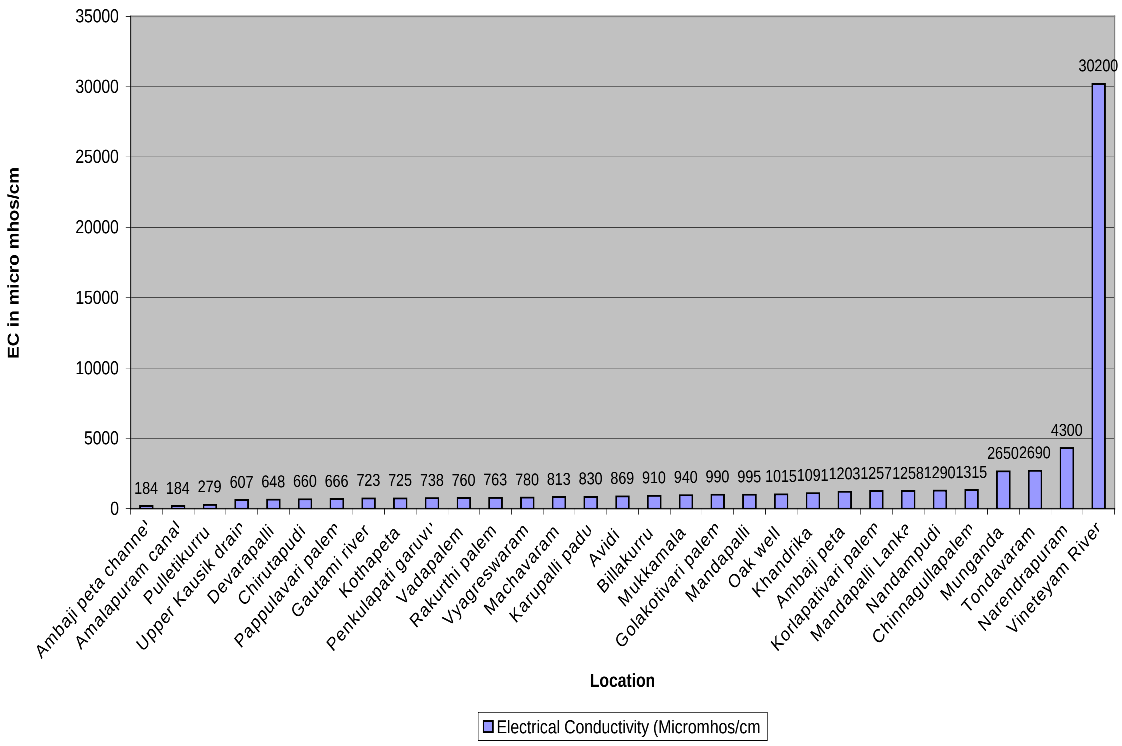
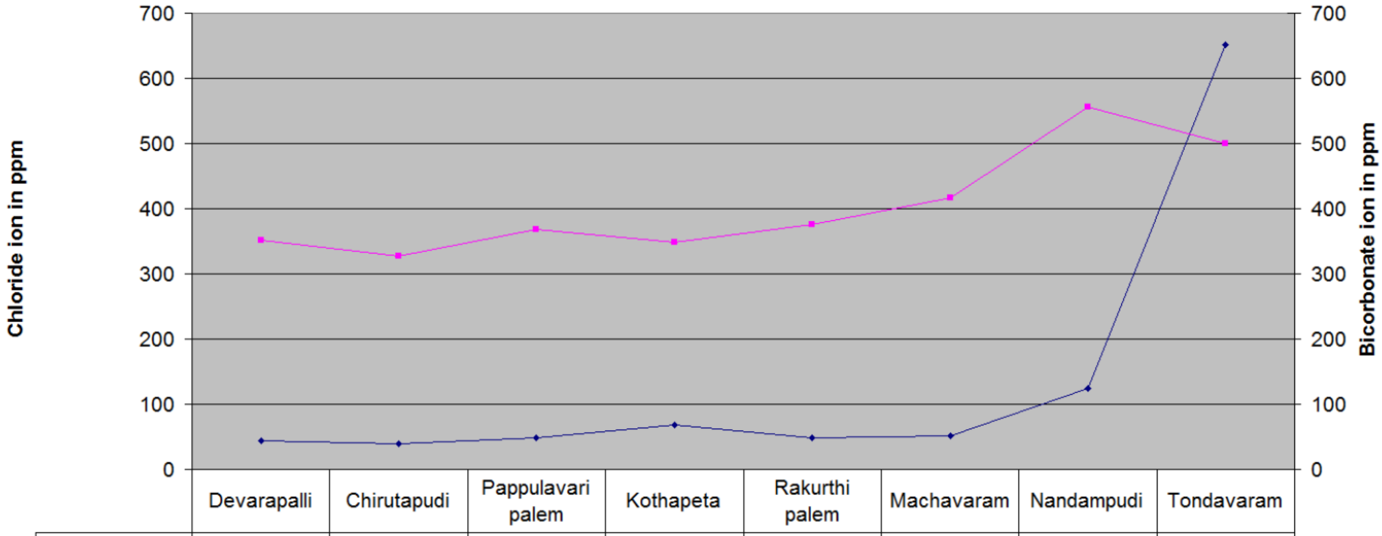


Fig. 14 Chloride and Bicorbonates in Groundwater along paleo channel during March 2006

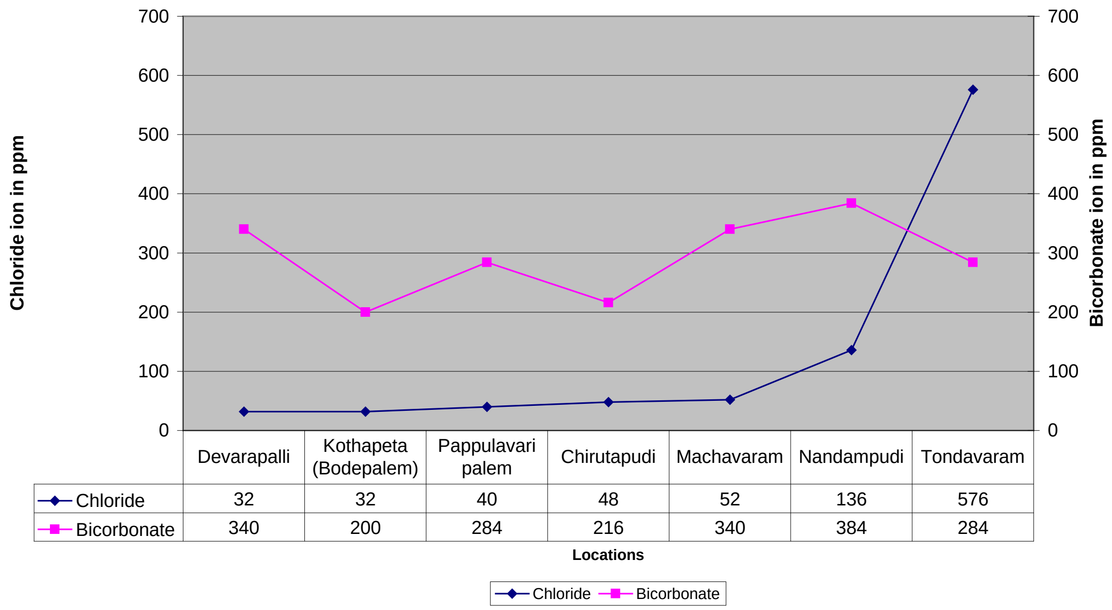


	Devarapalli	Chirutapudi	Pappulavari palem	Kothapeta	Rakurthi palem	Machavaram	Nandampudi	Tondavaram
Chloride	44	40	48	68	48	52	124	652
Bicorbonate	352	328	368	348	376	416	556	500

Locations

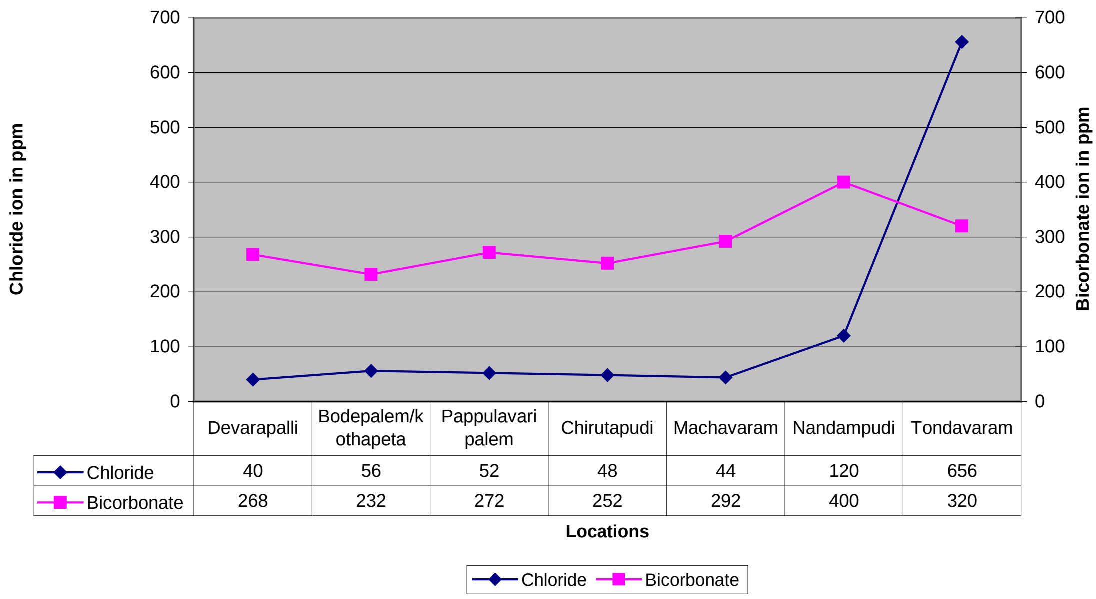
Chloride Bicorbonate

Fig. 15 **Chloride and Bicorbonates in Groundwater along paleo channel during June 2006**



	Devarapalli	Kothapeta (Bodepalem)	Pappulavari palem	Chirutapudi	Machavaram	Nandampudi	Tondavaram
Chloride	32	32	40	48	52	136	576
Bicorbonate	340	200	284	216	340	384	284

Fig. 16 **Chloride and Bicorbonates in Groundwater along paleo channel during September 2006**



	Devarapalli	Bodepalem/kothapeta	Pappulavari palem	Chirutapudi	Machavaram	Nandampudi	Tondavaram
Chloride	40	56	52	48	44	120	656
Bicorbonate	268	232	272	252	292	400	320

There is no significant seasonal change in groundwater quality in paleo channel, nothside and downside of paleo channel except wells located at Vinatheyam river. The water quality of Vinatheyam river sample, canal water and drain water are given in **Table 4.** Most of the groundwater samples belongs to calcium-bicarbonate type in the paleo channel. However, the groundwater towards down stream is deteriorating from the aspect of major cations and anions. This scenario is mainly due to influent characteristics of river branches at the head of the delta and the canals of the delta system. The characterization of groundwater quality of the system is of immense importance in optimum utilization of water resources in the paleo channel. Further the Pipers classification all water samples quality data is shown in Fig. 20. This classification clearly indicates the chemistry of river water is different from other sources of water. However, few samples in the paleo channel near to Vynaetheyam river which are influenced by backwater effect may also be seen very clearly. Rest of the water shows similar water chemistry in the study area.

Stable isotope characterization

The procedure of sampling water for deuterium and oxygen-18 analyses is very simple. A very small amount of sample is enough. But to be on safer side and for repeated measurements a minimum of 20 ml sample is collected in a HDPE bottle. While collecting samples, groundwater from tube wells and hand pumps water was left for sufficient time so that the sample represents groundwater of the aquifer understudy. The sample bottles were sealed with wax and transported to laboratory for isotopic analysis. The physical properties of water are measured in-situ. The samples were analyzed for δD and $\delta^{18}O$ stable isotopes using Continuous flow isotope ratio mass spectrometer and Dual inlet isotope ratio mass spectrometer available at NIH, Roorkee. The measured error in estimates is $\pm$ 0.1 $\%_0$ in $\delta^{18}O$ and is $\pm$ 1.0 $\%_0$ in δD. The rainfall is collected at Kakinada, which is about 50 Km from the study area. The same is considered as representative of local precipitation of the study area.

The δD and $\delta^{18}O$ relatioship help in understanding the contribution of different recharge sources and also to pinpoint the most important recharge source. From the analysis, it is observed that the stable $\delta^{18}O_{16}$ and δD i.e, Deuterium isotopes have strong correlation in the groundwater samples of paleo channel. $\delta^{18}O_{16}$ ratio is around 2.5 to 3.5 per mil and is a strong characteristic in paleo channel groundwater compared to groundwater of surrounding formations. It is observed that $\delta^{18}O_{16}$ ratio can be used as an index to identify paleo channel groundwater. The Recharge to the paleo channel is mainly due to recharge from Amalapuram canal system.

Table 4. Average chemical parameters of shallow wells, Canal water, River water, Drain water

Name of the Village	EC	Ph	TDS	Ca	Mg	Na	K	Cl	HCO3	SO4	NO3
Shallow wells											
Devarapalli	683	7.21	437	50	27	54	3	39	320	44	10
Chirutapudi	766	7.11	490	38	26	36	1	45	265	35	2
Machavaram	851	7.16	544	44	35	40	4	49	349	44	0
Pappulavari palem	710	7.13	454	67	21	31	2	47	308	26	0
Penkulapati garuvu	635	7.15	406	68	13	18	1	44	288	20	59
Vadapalem	727	7.31	465	49	18	18	2	57	257	17	13
Mandapalli	679	7.15	435	65	17	22	1	48	287	21	80
Avidi	855	7.0	547	10	8	208	3	75	349	68	8
Kothapeta	647	7.0	414	35	19	28	2	52	260	20	7
Rakurthi palem	954	7.0	611	57	39	49	1	52	344	75	11
Nandampudi	1510	7.3	966	45	47	109	6	127	447	89	1
Tondavaram	3007	7.2	1924	98	83	398	4	628	368	88	6
Karupalli padu	930	7.1	595	37	34	82	12	52	404	53	0
Mukkamala	1016	7.3	650	50	44	69	4	72	407	84	5
Vyagreswaram	944	7.2	604	31	33	58	5	72	341	46	0
Canal water	184	8.1	118	14	9	17	2	26	84	13	1
Gowtami River Water	723	7.57	463	27	37	78	5	68	312	65	20
Vinataeyam River Water	30200	6.85	19328	802	462	4500	250	12100	184	910	3
Drain water sample	607	8.12	388	26	19	45	3	6.0	304	41	2

EC in micro mho/cm, all other units are in ppm

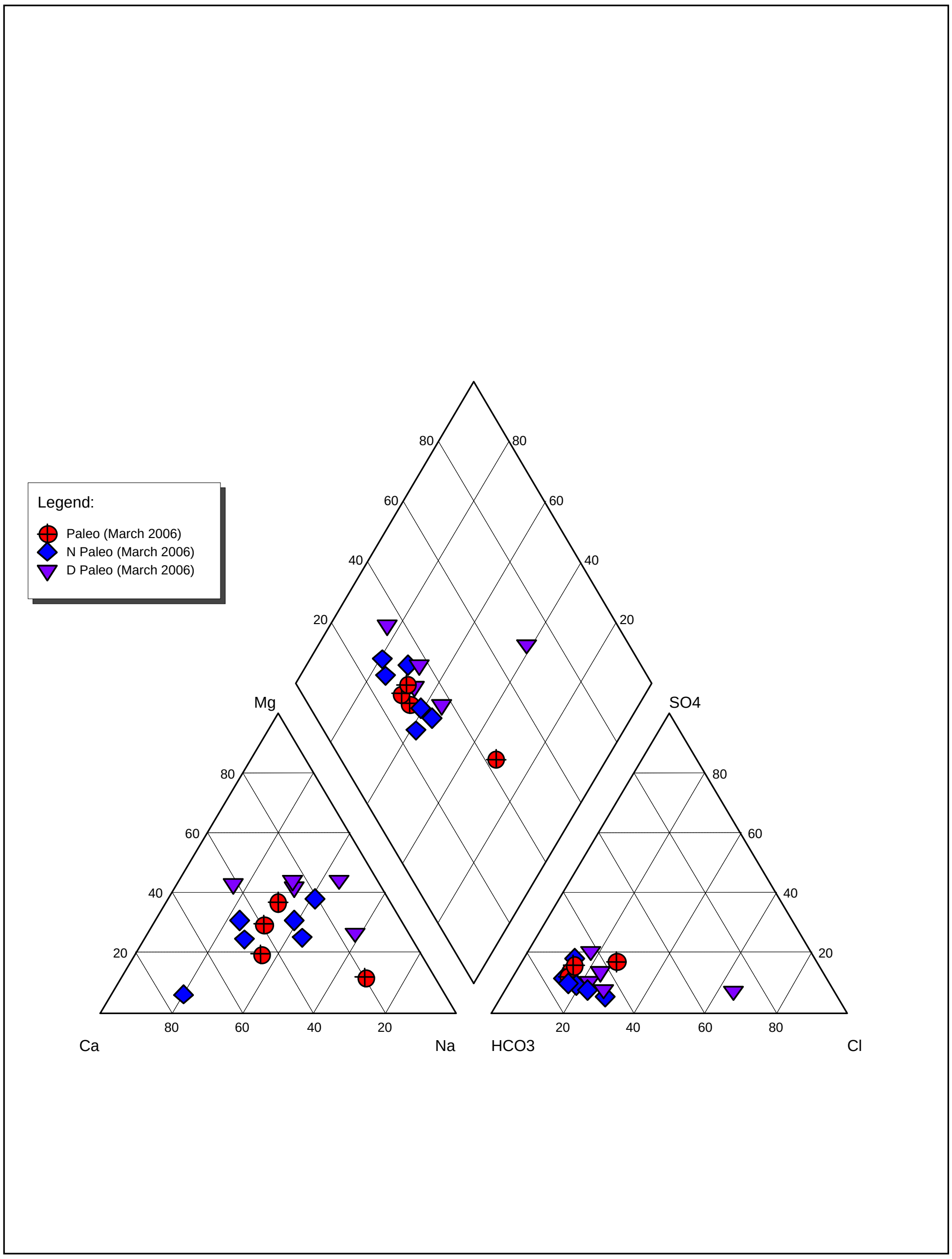


Fig. 17. Piper's tri-linear classification plots of groundwater samples with in palio channel, northside palio channel and downward palio channel during March 2006

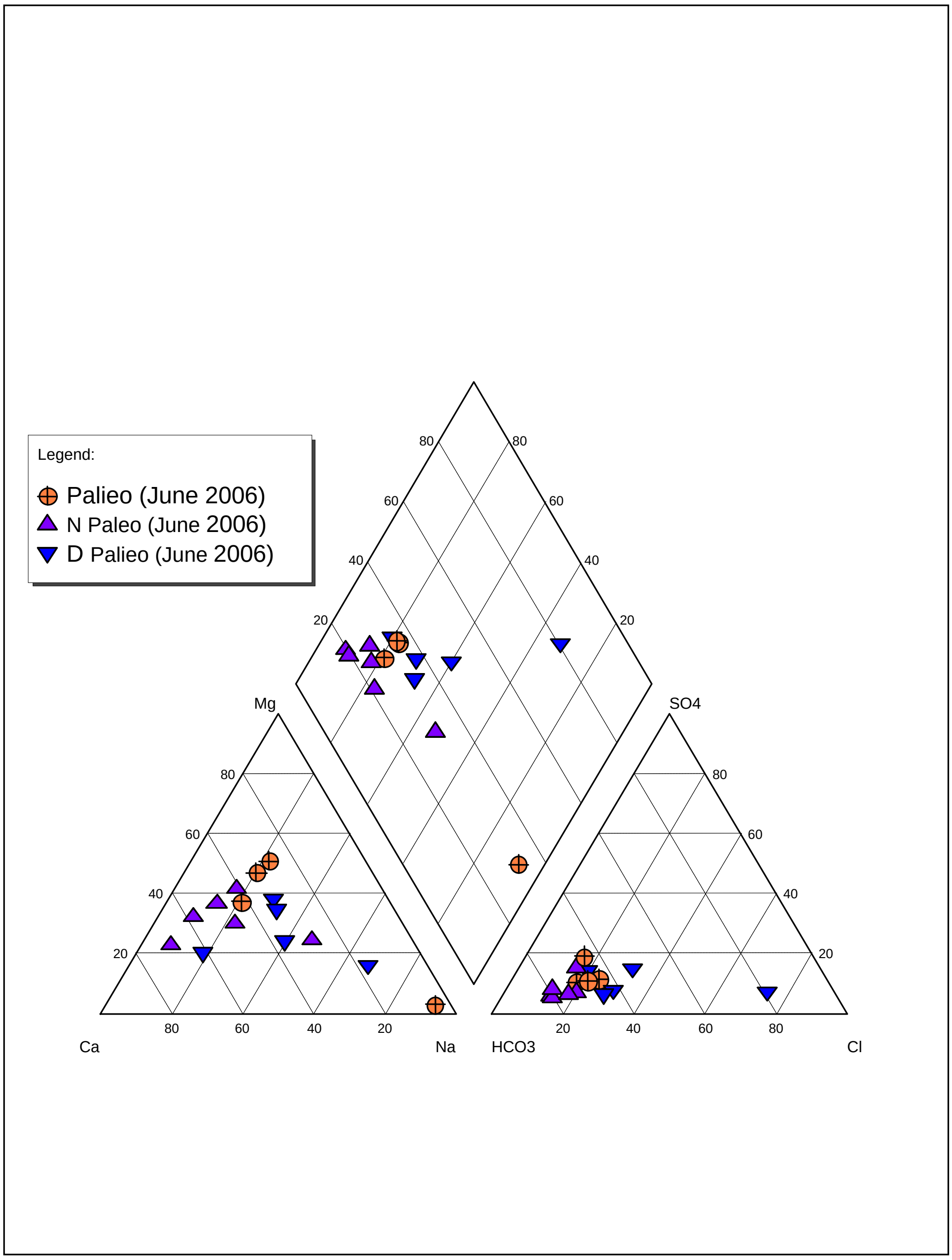


Fig. 18. Piper's tri-linear classification plots of groundwater samples with in palio channel, north side palio channel and downward palio channel during June 2006

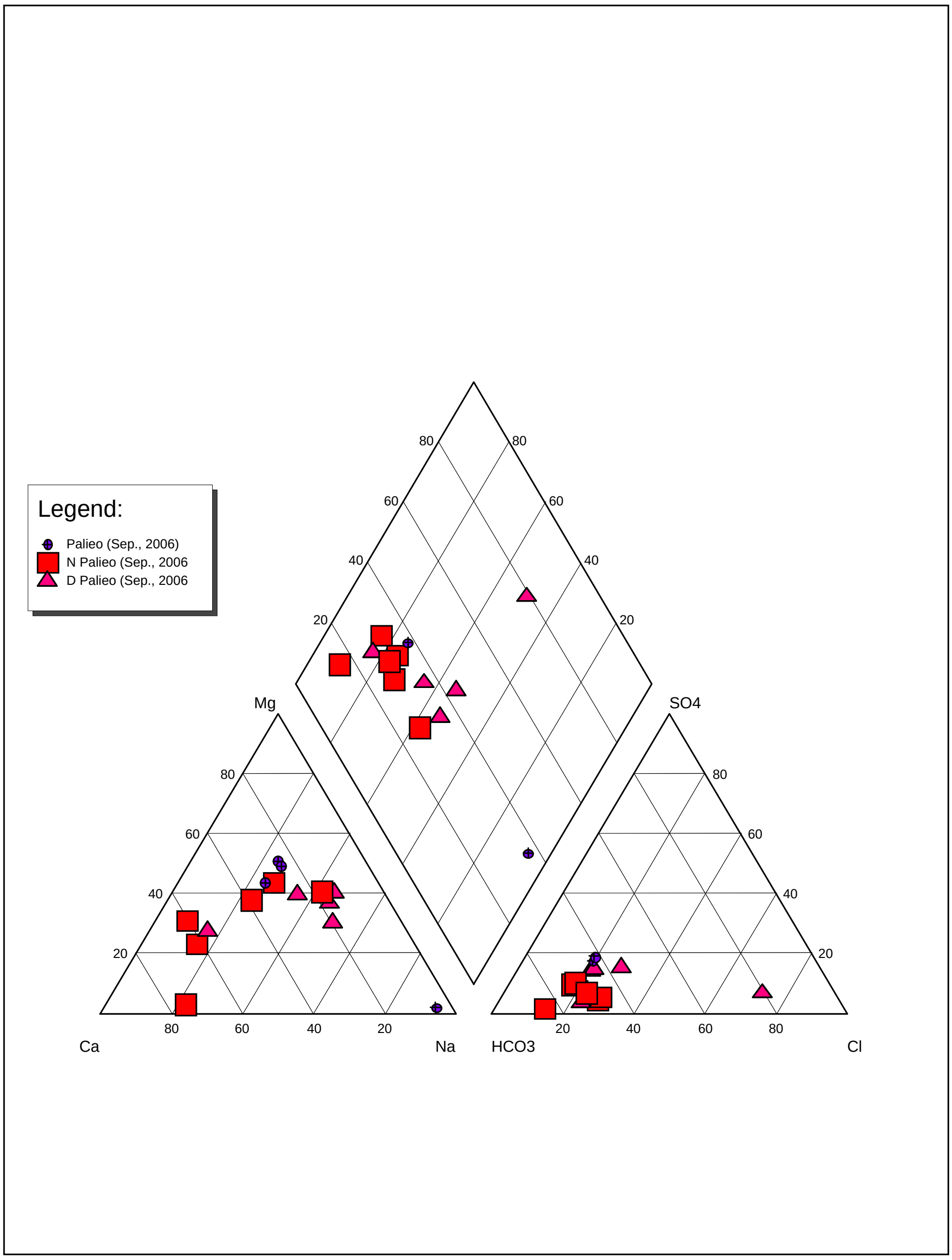


Fig. 19. Piper's tri-linear classification plots of groundwater samples with in palio channel, north side palio channel and downward palio channel during September 2006

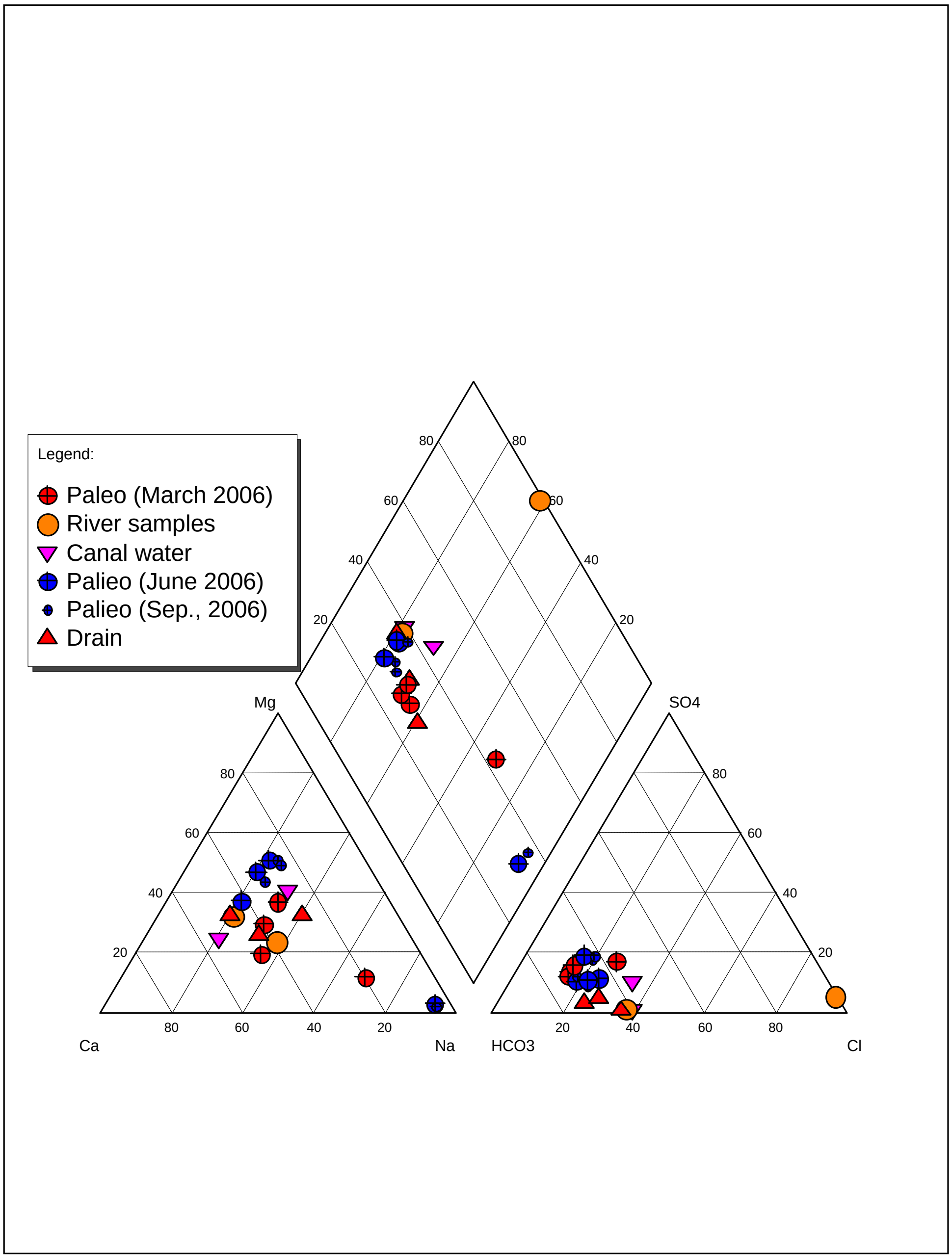


Fig. 20. Piper's tri-linear classification plots of groundwater samples with in palio channel, river samples, canal water and drain water

From the analysis, it is observed that the stable $\delta^{18}O_{16}$ and Deuterium isotopes have strong correlation in the groundwater samples of paleo channel and further it was inferred that recharge to the paleo channel was mainly due to canal water. The linear equation of local precipitation occurred at Kakinada, LMWL i.e, local meteoric water line during the study period is plotted for $\delta^{18}O$ vs δD. The equation (4) as explained previously is found to be

$$\delta D‰ = 8.2516\ \delta^{18}O + 11.541 \quad (5)$$

The slope of the line corresponding to $\delta^{18}O$ versus δD of water undergoing evaporation decreases as humidity decreases. That is the slope of standard meteoric line of 8 can range between 8 and 3 in the case of evaporation depending on the relative humidity. The result of this is that residual liquid water that has undergone evaporation plots to the right of the meteoric water line following a slope of 3 to 8. Waters that have experienced the greatest evaporation factor are farthest from the meteoric line. The slope of this divergent line indicates that relative humidity during the evaporation process. Waters of Closed Basins must have undergone evaporative fractionation.

Groundwater balance

Groundwater levels at Kundalapalli, Machavaram, Modekurru, Vyagreswaram and Naranedra puram villages are collected and analyzed to understand the fluctuations in the study area from 2005 to 2007. From the observation well network of water table, the groundwater table in the study area during May 2007 is about 3.5 to 4.5 m below ground level. It is about 1 to 2 m below ground level by November 2007.

The depth of the paleo channel is about 10 to 15 m. In general, the water table may go down up to 4m below ground level in the upstream side and up to 2.5 m below ground level in the down stream side during summer. It may be about 2 m and 1 m below ground level respectively at U/S side and D/S side by the end of monsoon season. The spatial plot of rise and fall of groundwater table indicates an average rise of 1.6 to 1.9 m and a fall of 1.75 to 2.2 from up stream to down stream in and around paleo channel.

From the groundwater balance of the study area, the net groundwater flow into the system is about 3.5 MCM for monsoon season (Figure 1). Using the same the groundwater draft for the system that consists of volume pumped for crops and natural evapo-transpiration needs for non-monsoon season is about 40MCM

In the study area, about 3500 Ha i.e., 18% of the crop land under the Palivela lock of Amalapuram main canal is irrigated from the Ambajipeta channel with only 10% of water that is released into it accounting to 20 MCM per season. Where as the actual requirement is about 35 MCM, the balance of 15 MCM is the draft from Groundwater of the paleo channel. The detailed water balance components during monsoon (Three years represented in three circles) and non-monsoon (Two years represented in two circles) are shown in Figures.

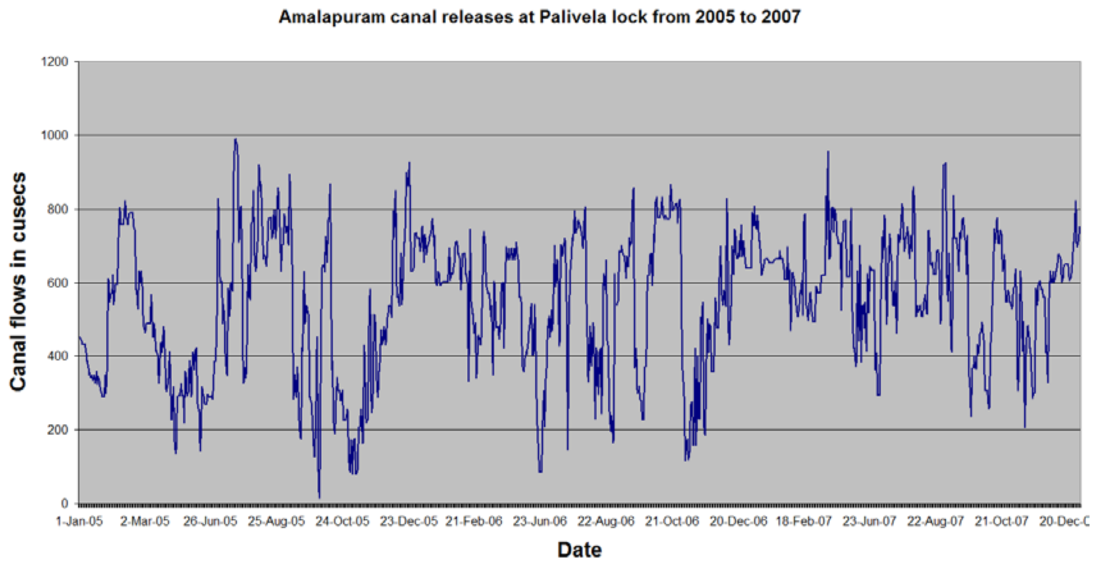


Figure 21 Amalapuram Canal Releases at Palivela Lock from 2005 to 2007

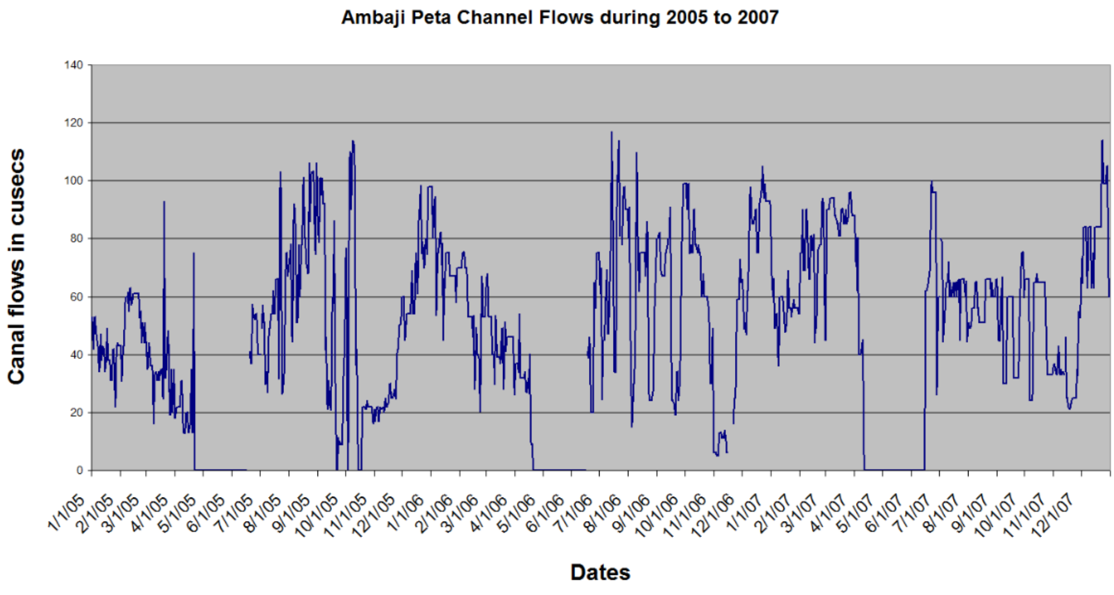


Figure 22 Ambajipeta Channel Flows during 2005 to 2007

Fig. 23 **Seasonal change in groundwater table from 2005 to 2007 in the study area**

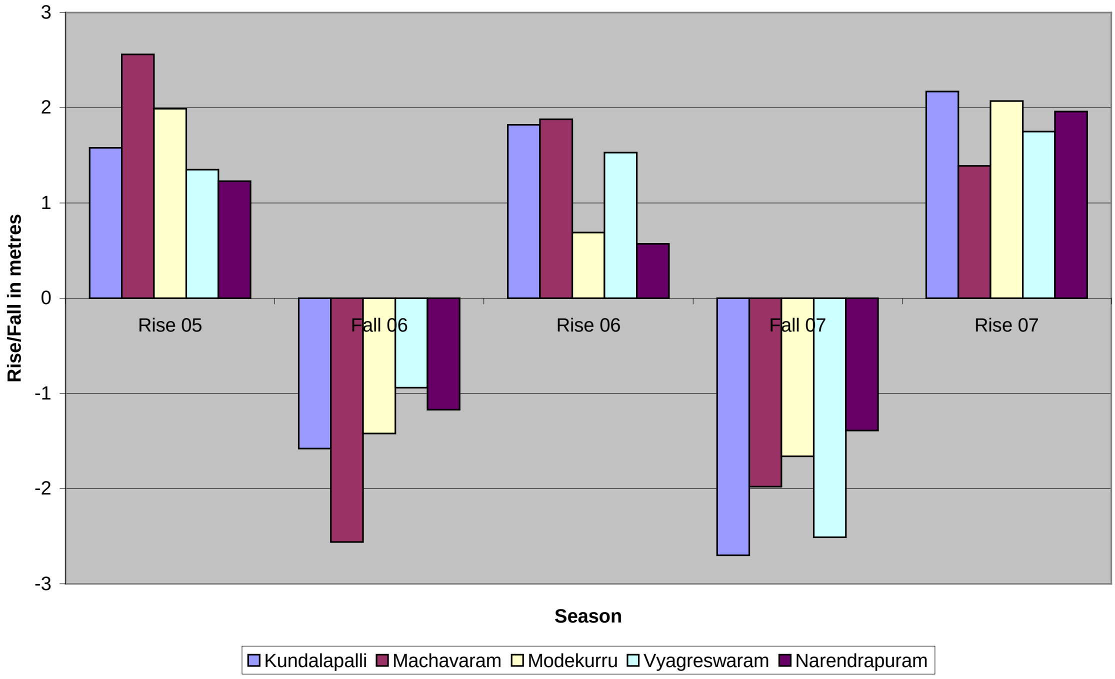
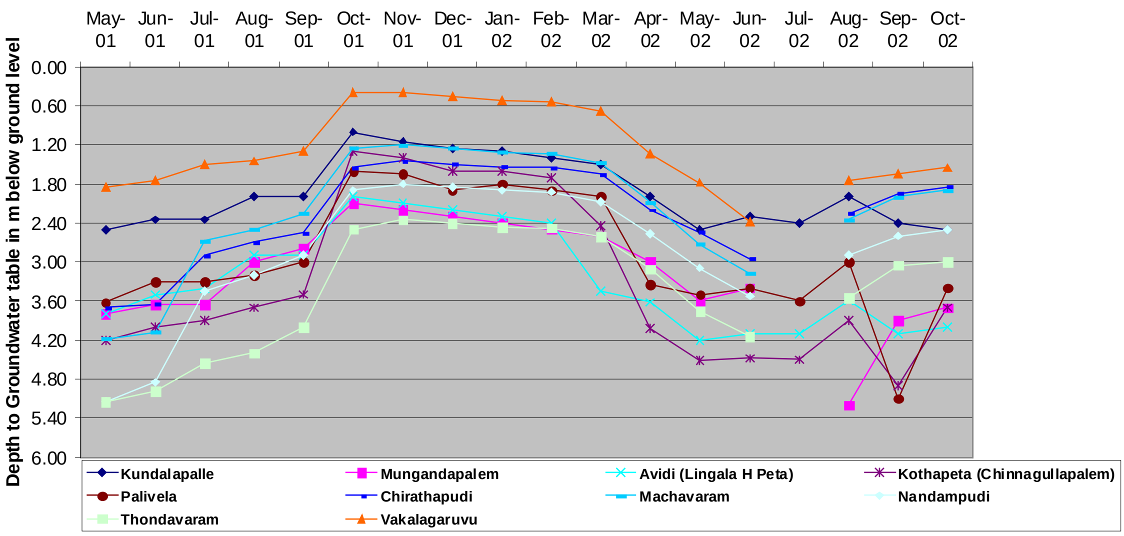


Fig. 24 Depth to Groundwater table at some villages in the paelo channel in study area



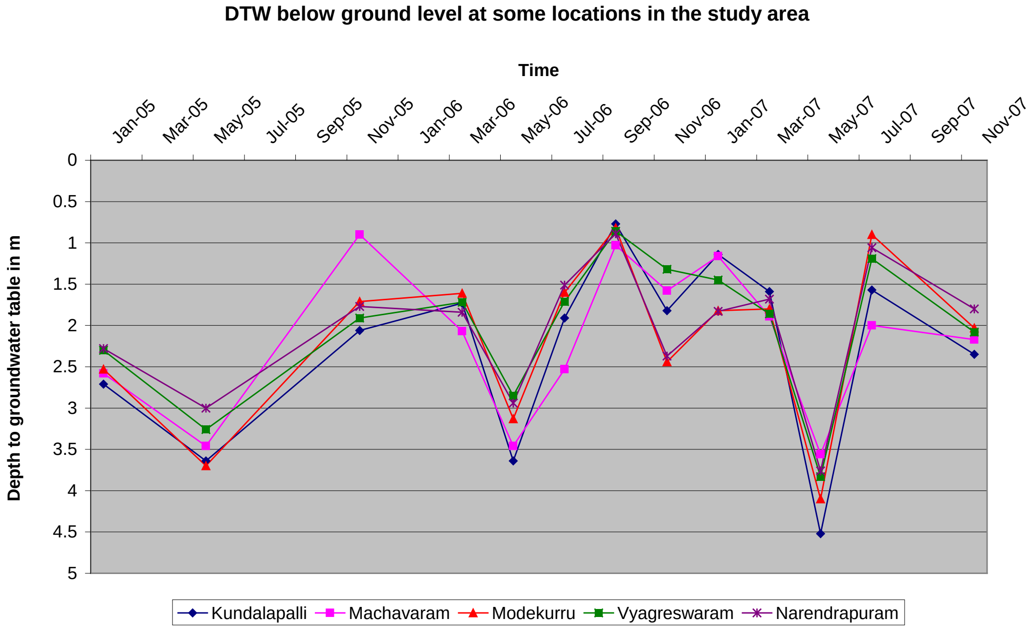


Fig. 25 DTW below ground level in the study area

Fig. 26
Depth to Groundwater table during post monsoon of 2005
(Blue lines indicate paleo channel)

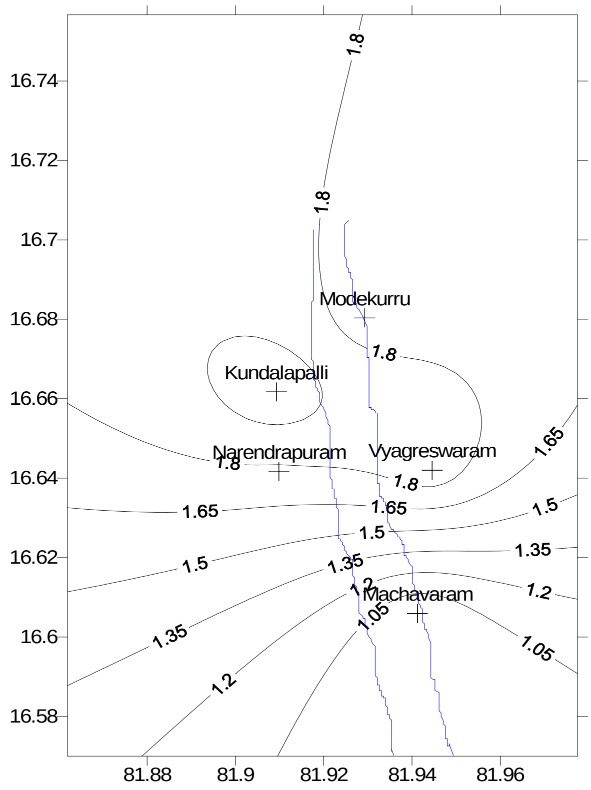


Fig. 27

Rise of groundwater table during monsoon of 2007
(Blue lines indicate paleo channel)

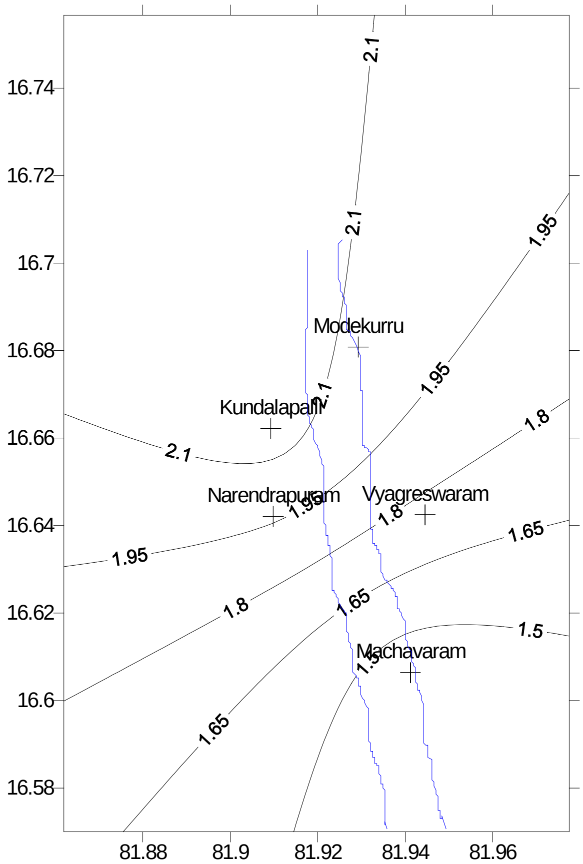


Fig. 28 **dDvs d18O of Precipitation, Groundwater, Canal and drain water and river in the study area**

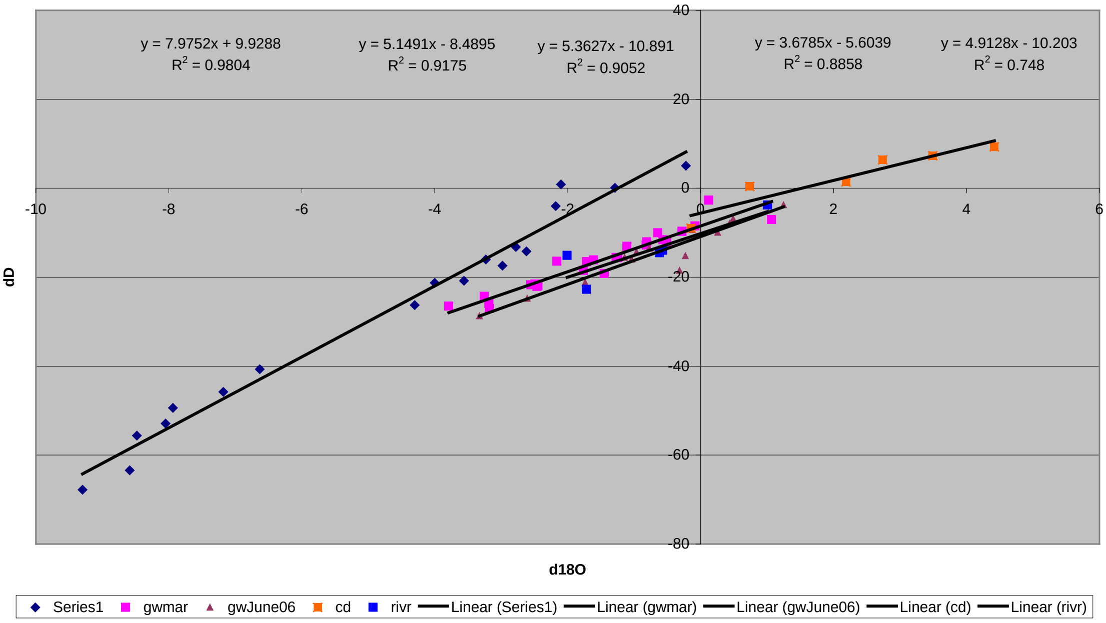


Fig. 29 Variation of EC and del O18 in the groundwater of paleochannel in June, July, November 2006

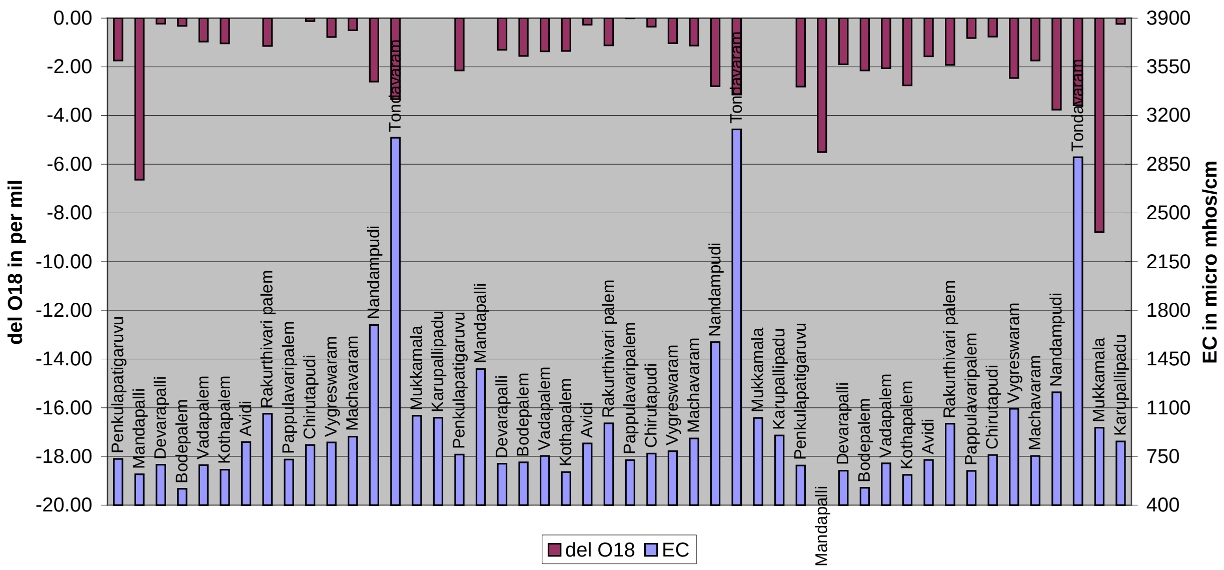


Fig. 30 Variation of delO18 with EC in the study area

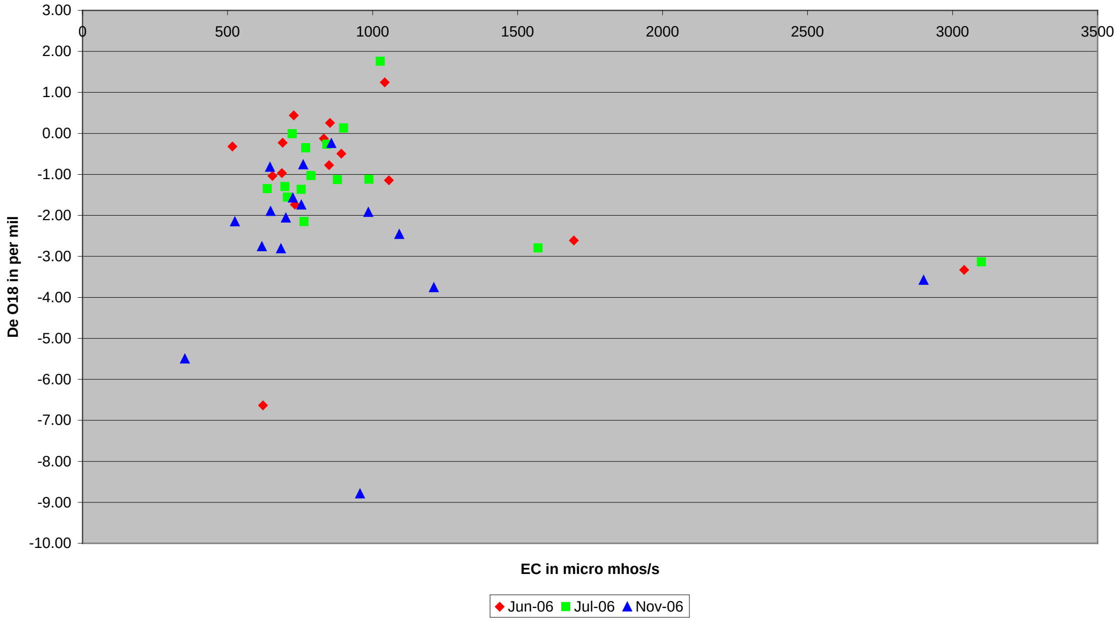


Fig. 31 Variation of del O18 in the study area during Pre and post monsoon 2006

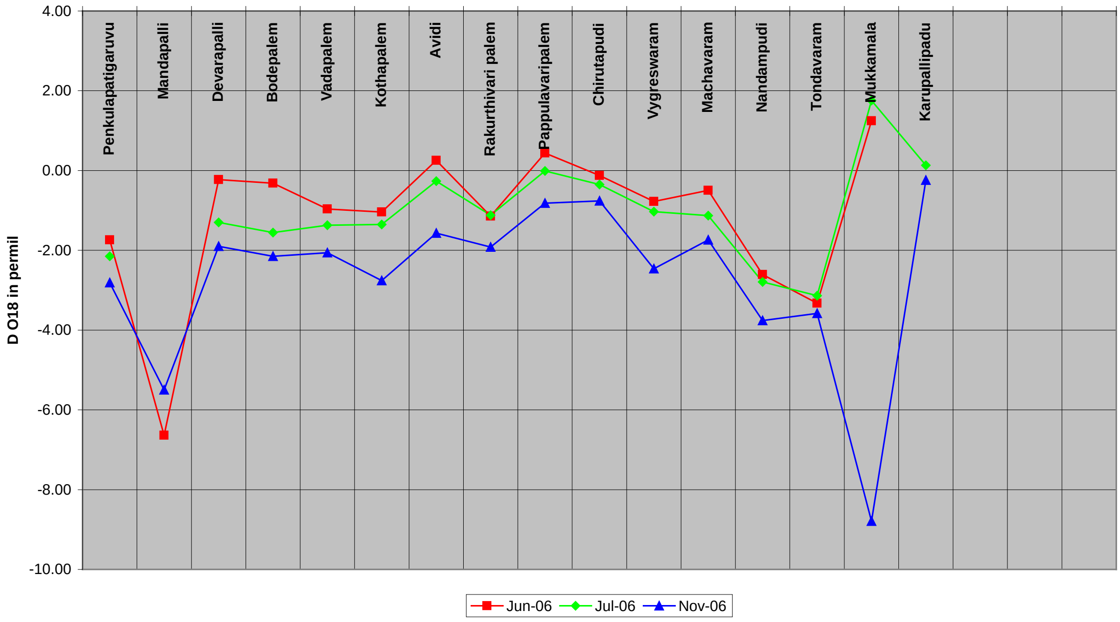


Table 5. Groundwater Balance of monsoon season in the study area of paleo channel (in MCM)

	2005-06	2006-07	2007-08
Change in Storage	14.16	9.84	12.504
Recharge from canals	4.8	4.8	4.8
Recharge from SW	7.528	8.846	8.358
Draft	15	15	15
Recharge from GW	3.75	3.75	3.75
Rainfall recharge @15%	9.5123	6.403	6.789
Net groundwater flow Estimated	3.570	1.041	3.807

Table 6 Groundwater Balance of non monsoon season in the study area of paleo channel (in MCM)

	2005-06	2006-07
Change in Storage	-11.808	-14.76
Recharge from canals	5.6	5.6
Recharge from SW	7.346	9.44
Draft	37.672	44.400
Recharge from GW	9.418	11.100
Rainfall recharge @15%	0	0
Net groundwater flow	3.500	3.500
Net Draft	28.254	33.300

Fig. 32 Groundwater Balance for Monsoon season of 2005 (Inner most) to 2007 (Outer most) in MCM in the study area of Paleo channel in Central Godavari delta

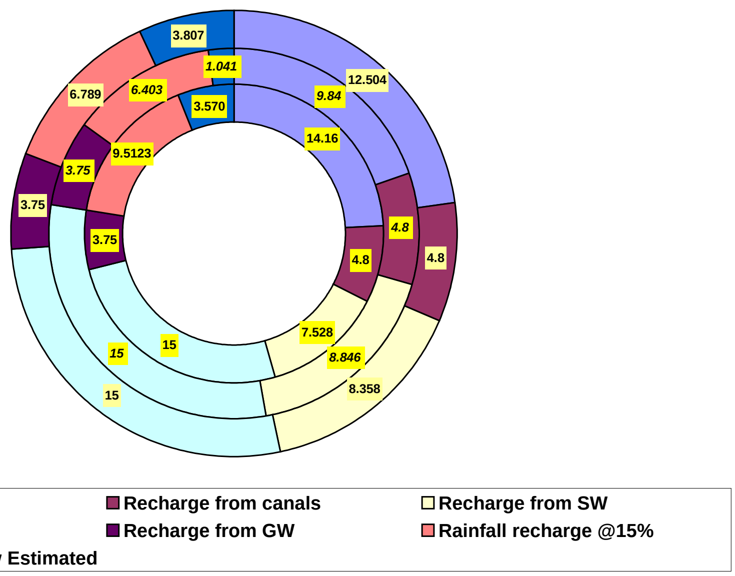
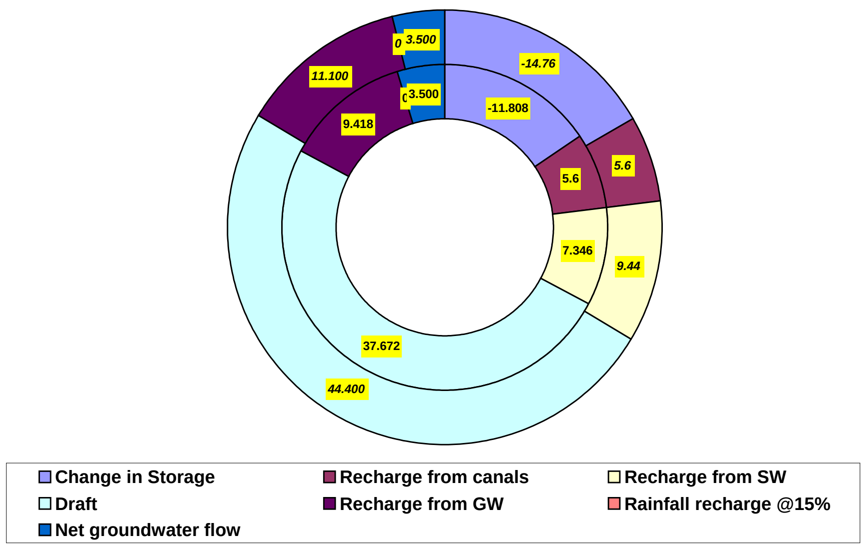


Fig. 33 Groundwater Balance for Non-monsoon season of 2005-06 (Inner most) to 2006-07 (Outer most) in MCM in the study area of Paleo channel in Central Godavari delta



5.0 CONCLUSIONS

The chemical analysis data indicated that there is no significant seasonal change in groundwater quality in paleo channel and most of the samples belong to calcium-bicarbonate type. In the upstream side of paleo channel groundwater quality is similar at most places. This scenario is mainly due to influent characteristics of river branches at the head of the delta and due to the three major canals of the delta system. However, the groundwater towards down stream is deteriorating from the aspect of major cations and anions. The stable isotope plots for δO^{18} and δD also indicates that the significance of rainfall recharge is not much and most of the recharge is from river, canal waters.

Groundwater levels at Kundalapalli, Machavaram, Modekurru, Vyagreswaram and Naranedra puram villages are collected and analyzed to understand the fluctuations in the study area from 2005 to 2007. From the observation well network of water table, the groundwater table in the study area during May 2007 is about 3.5 to 4.5 m below ground level. It is about 1 to 2 m below ground level by November 2007. In the study area, about 3500 Ha i.e., 18% of the crop land under the Palivela lock of Amalapuram main canal is irrigated from the Ambajipeta channel with only 10% of water that is released into it accounting to 20 MCM per season. Where as the actual requirement is about 35 MCM, the balance of 15 MCM is the draft from Groundwater of the paleo channel. The depth of the paleo channel is about 10 to 15 m. In general, the water table may go down up to 4m below ground level in the upstream side and up to 2.5 m below ground level in the down stream side during summer. It may be about 2 m and 1 m below ground level respectively at U/S side and D/S side by the end of monsoon season. The spatial plot of rise and fall of groundwater table indicates an average rise of 1.6 to 1.9 m and a fall of 1.75 to 2.2 from up stream to down stream in and around paleo channel. From the groundwater balance of the study area, the net groundwater flow into the system is about 3.5 MCM for monsoon season. Using the same the groundwater draft for the system that consists of volume pumped for crops and natural evapo-transpiration needs for non-monsoon season is about 40MCM.

Annexure I

Paleo channel studies in Central Godavari Delta : River, Canal and groundwater samples of 16th Feb 2006

Sl. No	Location	Electrical conductivity (EC)
1	Gautami at Mandapalli	864
2	Oakwell intake	1180
3	Hand pump Mandapalli	1430
4	Kothapeta_ramaraopeta	550
5	Kottapalem	700
6	Chiratapudi	738
7	Avidi	920
8	Machavaram	877
9	Thondavaram	3200

Annexure II

PALE0 CHANNEL STUDIES: WATER SAMPLES COLLECTED DURING 14th and 16th MARCH-2006

W.NO	Name of the Village	Electrical Conductivity (Micromhos/cm)
CGS-1	Ambaji peta	1203
CGS-2	Devarapalli	648
CGS-3	Chinnagullapalem	1315
CGS-4	Chirutapudi	660
CGS-5	Korlapativari palem	1257
CGS-6	Khandrika	1091
CGS-7	Munganda	2650
CGS-8	Machavaram	813
CGS-9	Pappulavari palem	666
CGS-10	Penkulapati garuvu	738
CGS-11	Vadapalem	760
CGS-12	Billakurru	910
CGS-13	Mandapalli Lanka	1258
CGS-14	Mandapalli	995
CGS-15	Avidi	869
CGS-16	Kothapeta	725
CGS-17	Rakurthi palem	763
CGS-18	Nandampudi	1290
CGS-19	Tondavaram	2690
CGS-20	Pulletikurru	279
CGS-21	Narendrapuram	4300
CGS-22	Karupalli padu	830
CGS-23	Golakotivari palem	990
CGS-24	Mukkamala	940
CGS-25	Vyagreswaram	780
CGS-26	Ambaji peta channel	184
CGS-27	Gautami river	723
CGS-28	Amalapuram canal	184
CGS-29	Vineteyam River	30200
CGS-30	Upper Kausik drain	607
CGS-31	Oak well	1015

Annexure III

Paleo channel studies in Central Godavari Delta :Canal and Drain samples of 26th May 2006

S.No.	Location	EC(µs/cm)
CD1	Ralli Arm at Dowalaiswaram (At barrage)	212
CD2	Mandapalli (Bank canal)	265
CD3	Rice mill at China Gollapalem (Amalapuram canal)	251
CD4	Devarapalli Lock (Amalapuram canal)	201
CD5	Sankya Drain (Near Munganda)	673
CD6	Lower Kaushik Drain (Near Ambajipet)	492
CD7	Mukkamala Lock (Amalapuram canal)	200

Annexure IV

Samples collected on 8th,12th June-2006 from Central Godavari Delta

W.No.	Name of the Village	Electrical Conductivity Micro mhos/cm 8th and 12th 2006	Electrical Conductivity Micro mhos/cm 17th and 18th July 2006
CGS1	Mandapalli	622	1378
CGS2	Penkulapatigaruvu	732	764
CGS3	Bodepalem	517	707
CGS4	Devarapalli	690	698
CGS7	Vadapalem	687	754
CGS9	Kothapalem	655	637
CGS10	Avidi	853	843
CGS11	Pappulavaripalem	728	723
CGS12	Chirutapudi	832	770
CGS15	Machavaram	892	879
CGS16	Mukkamala	1042	1027
CGS18	Vygreswaram	850	788
CGS20	Kausik drain	931	456
CGS21	Karupallipadu	1028	901
CGS22	Tondavaram	3040	3100
CGS23	Nandampudi	1694	1571
CGS24	Rakurthivari palem	1056	988
CGS25	Vynateyam River	16690	392
CGS26	Amalapuram canal	No sample	181

Dug wells:

1. Pedagulapalem 2. Ravanuthi meraka 3. Chiratha pudi
4. Isuka pudi 5. Mukkamala 6. Pulletikurru

Bore wells:

1. Mandapalli 2. Penkulapati Garuvu 3. Kothapeta
4. Devarapalli 5. Kammi reddi palem 6. Vadapalem
7. Kothapalem 8. Avidi 9. Pappulavari palem
10. Chiratha pudi 11. Machavaram. 12. Mukkamala
13. Vyagreswaram

Drain:

Upper Kaushik drain

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STUDY TEAM

Shri. S V Vijaya Kumar, Scientist E1

Dr. Bhishm Kumar, Scientist F

Dr.Y R Satyaji Rao, Scientist E2

Dr. P C Nayak, Scientist C

Shri. B Krishna, Scientist C

Shri. T Vijaya, SRA

Shri. P R Rao, RA

Head

Dr. Y R Satyaji Rao, Scientist E2

Coordinator

Dr. Bhishm Kumar, Scientist F

Director

Shri. R D Singh