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GROUNDWATER TABLE AND HYDROCHEMISTRY OF KAKINADA COASTAL AQUIFER, A.P. DURING THE YEAR 1996

DELTAIC REGIONAL CENTRE
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ABSTRACT

As a part of monitoring of groundwater levels and its quality in and around Kakinada town, the analysis of groundwater levels and its quality during the year 1996 is presented in the report. The flow of groundwater is controlled by the drainage of the area and subdued replica of surface topography. The influence of sea water was clearly observed on TDS, Cl, Na and HCO_3 contents in the observation wells. According to hardness classification the study area falls under hard to very hard zone. Change in major anions and cations in the observation wells indicates mixing of shallow groundwater in the study area. Groundwater samples have been classified according to Stiff, Piper's and U S Salinity laboratory classification. The hydrochemical ratios of Mg/Cl, Cl/HCO_3 and Mg/Ca for each sample have been calculated. The SAR and %Na in each well indicated that the study area falls under medium hazard of sodium in the study area. The TDS, HCO_3 and NO_3 contents were exceeded the maximum desirable limits of ISI (1983) drinking water standards. Detailed investigations are to be initiated to find the sources of Nitrate pollution in the study area.

1. 0 INTRODUCTION

1.1 General

The need to understand the fundamental concepts of describing groundwater flow is becoming increasingly important as groundwater resources become more and more threatened by contamination and overuse. This understanding involves an appreciation of several fields of Science and Engineering. Groundwater flow through porous material occurs the influence of energy, flowing from regions of high energy to regions of low energy. As such, it is similar to the flow of heat and flow of electricity. The amount of energy a particle of water possess at any position within a flow system is the sum of three forms of potential energy i.e. elevation energy, pressure energy and velocity energy. A particle of water has elevation energy by virtue of its position in the flow system relative to some standard measurement plane i.e. sea level or MSL. A schematic diagram showing hydrogeologic conditions for an unconfined aquifer and a confined aquifer is shown in Fig.1. If several wells are constructed in the same aquifer and a set of water-level measurements are made at the same time, the resulting contour map represents the potentiometric surface of the aquifer. The combined study of water table fluctuations and its quality variations in a regional scale will provide more useful information than an individual study of groundwater levels or its quality.

One of the concerns of those involved in water management is the maintenance of water quality, the avoidance of degradation that may be hazardous to health. The primary threats to health come from the chemical loading of surface and subsurface water reservoirs derived from a multitude of sources. These chemical loads are in transit to a variety of sinks from which they are removed, long or short-term, from the surface-subsurface water system. The main concern is not only with the immediately apprehended effects on the humans who drink the water, but on the foods we eat, related to geologic and agriculture amplification of toxic effects. Water quality is also important because of its influence on the operating efficiency and life of equipment including pumps and wells. In recent decades, the growth of populations in the developed countries and their rise in living standards have demanded the rapid expansion of water supplies. Engineering hydrologists

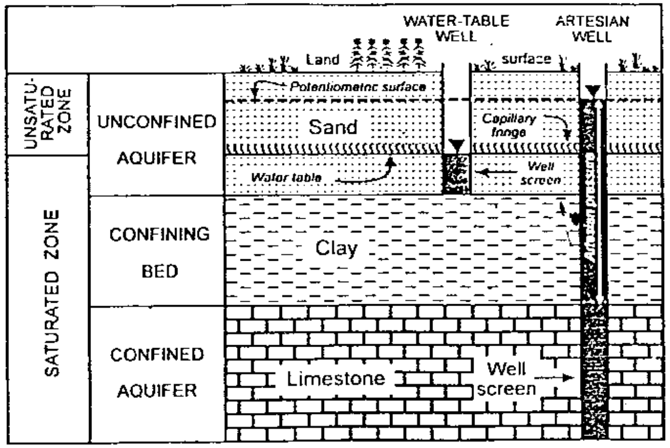


Figure 1 Diagram showing hydrogeologic conditions for an unconfined aquifer and a confined aquifer (modified from Heath, 1983).

have fully occupied in the assessment and development of increasing quantities of water for domestic and industrial use. While natural water resources may be plentiful, especially in advanced countries, the need for larger storage's and for greater water transference to the main centers of consumption has led to increased concern for the quality of the water. The groundwater quality process includes many chemical reactions due to:

I. Dissolution of lime stone

ii. Oxidation reduction process

iii. Ion exchange processes

iv. Decomposition of aquifer rocks

v. Transport of various leachates

vi. Industrial and municipal waste products

vii. Mining wastes and

viii. Salt water intrusion and storm water runoff.

Keeping in view of the rapid urbanization in Kakinada town the demand for freshwater has been increasing. The detailed water level fluctuation investigations and assessment of groundwater quality have carried out in the unconfined coastal aquifer of Kakinada town.

1.2 Review

Study of the factors affecting groundwater quality may enable the prediction of its future quality as compared with its present quality. Groundwater-quality determinations may be important for reasons other than its suitability for certain uses. For example, Kunkle (1965) computed the groundwater runoff in a stream from measurements of the total dissolved solids (TDS) or ionic concentrations of the groundwater and the total surface runoff of the stream.

Study of the chemical constituents of water and their changes may also be useful in locating the source or source of recharge, the direction of groundwater flow, the presence of the aquifer boundaries(Hem, 1970; Walton, 1970; Todd, 1980) and the configuration of flow systems in the aquifers(Henningson, 1962; Mifflin, M.D, 1968).

Changes in groundwater quality are due to the varying quality of the infiltrated precipitation, the reaction of groundwater to its environment, the length of the flow path, the residence time of water in a certain location, vegetation types, and human-determined features. In magnetic water, the quality also changes as a result of the absorption of gases (Abdel, 1986)

Venkateswara Rao, B and Yadiah, Y (1996) collected groundwater samples of 45 wells and three surface water samples from the Hyderabad city for hydrochemical analysis and identified the polluted areas. They concluded that the major pollution is due to Chloride, Calcium and Sulfate from effluents of SIRIS pharmaceutical factory.

Abhay Kumar Singh et al (1996) carried out hydrochemical analysis of groundwater samples collected from 19 open wells in different parts of the Varanasi city and concluded that the high concentrations of Na^+, Cl^-, TDS, NO^-_3 and PO^{-3}_4 are due to the domestic and municipal sewage in the city.

Satyaji Rao, Y.R et al (1995) evaluated the groundwater quality in and around Kakinada town and concluded that the main source of high Chloride content in the shallow wells is mainly due to the salt creek which passes across the city.

1.3 Scope and objectives of the study

Stress on groundwater, both in terms of quality and quantity, are growing rapidly due to increasing trend of demands, significant changes in land use pattern, domestic effluent and Industrialization, thus, influence the local hydrological cycle. Therefore, there is a need especially in developing towns for complete understanding of groundwater contamination phenomena. With the advent of advanced technology, considerable use is now being made of models which allow the prediction of groundwater flow path and contaminated migration pathways. Development of a model is an exercise in conceptualizing the true nature of the groundwater regime from the available data. In this connection the DRC of NIH, Roorkee had started monitoring the groundwater levels and its quality in and around Kakinada since 1994. The present report deals with preliminary analysis of groundwater levels and quality data pertaining to the year 1996.

Objectives:

1. Field survey for connecting all observation wells to the Mean Sea Level (MSL)

2. Analysis of groundwater levels and demarcation of groundwater flow directions

3. Analysis of groundwater samples (116 No.) for physical and chemical parameters and its variation from sea coast

4. Shallow groundwater hydrochemistry in and around Kakinada town

   * Stiff classification
   * Piper's trilinear classification
   * U S Salinity Laboratory classification
   * Hydrochemical ratios (Mg/Cl, Cl/HCO_3, Mg/Ca) and its variations from sea coast
   * SAR and %Na variations

5. Comparison of Groundwater quality parameters with WHO(1984) and ISI(1983) drinking water standards.

2.0 STUDY AREA

Kakinada is the headquarters of East Godavari District in Andhra Pradesh and it is situated on the East coast of India. Kakinada town is located between 82^0 N to 82^0 20' N latitude and 16^0 45' E to 17^0 5' E longitude. The area of the town is around 31 Sq. Km. The location of the study area is shown in Fig. 2. Kakinada Port commands good natural facilities for large export and import trade as it has all kinds of communication facilities-land, sea, rail and two delta navigation canal thus making it a class I town and commercial centre. The port being upgraded as a major port on the east coast of Coringa Bay, is aiding in accelerating the industrialization. Availability of natural gas in abundance at distance of 60-70 Km in Krishna - Godavari basin is also one of the factors which is fuelling the rapid industilisation thus makes more stress on natural resources.

2.1 Hydrogeology

The area is covered with coastal alluvium of recent origins, consists of fine to medium grain sands with clay and beach sands. Few medium and minor drains in the city are draining the waste water into Bay of Bengal through salt creek. The depth of groundwater level varies between 0.6 m to 3.5 m with respect to the ground level. The main recharge of groundwater is of monsoon rainfall during July to October. High tides in Bay of Bengal resisted by Hope island and it results low tides reaching part of Kakinada coast. High tides were observed at Vakalapudi area, north-east of Kakinada town. The general groundwater quality in Kakinada varies portable to saline. The hydrochemistry of shallow groundwater in East Godavari District is shown in Fig.3

2.2 Drainage

Major drains in Kakinada, namely, Upputeru (Saltwater creek), Gaderu, Cheedila pora and Yeleru drains are draining the waste water and storm water into the Bay of Bengal through salt water creek (Fig. 4). The salt water creek at Jagannadhapuram is acting as main cargo handling of the ships. Due to mild slope of sea coast so far there is no planned drainage network in the city. Most of the residential buildings allowing sewage

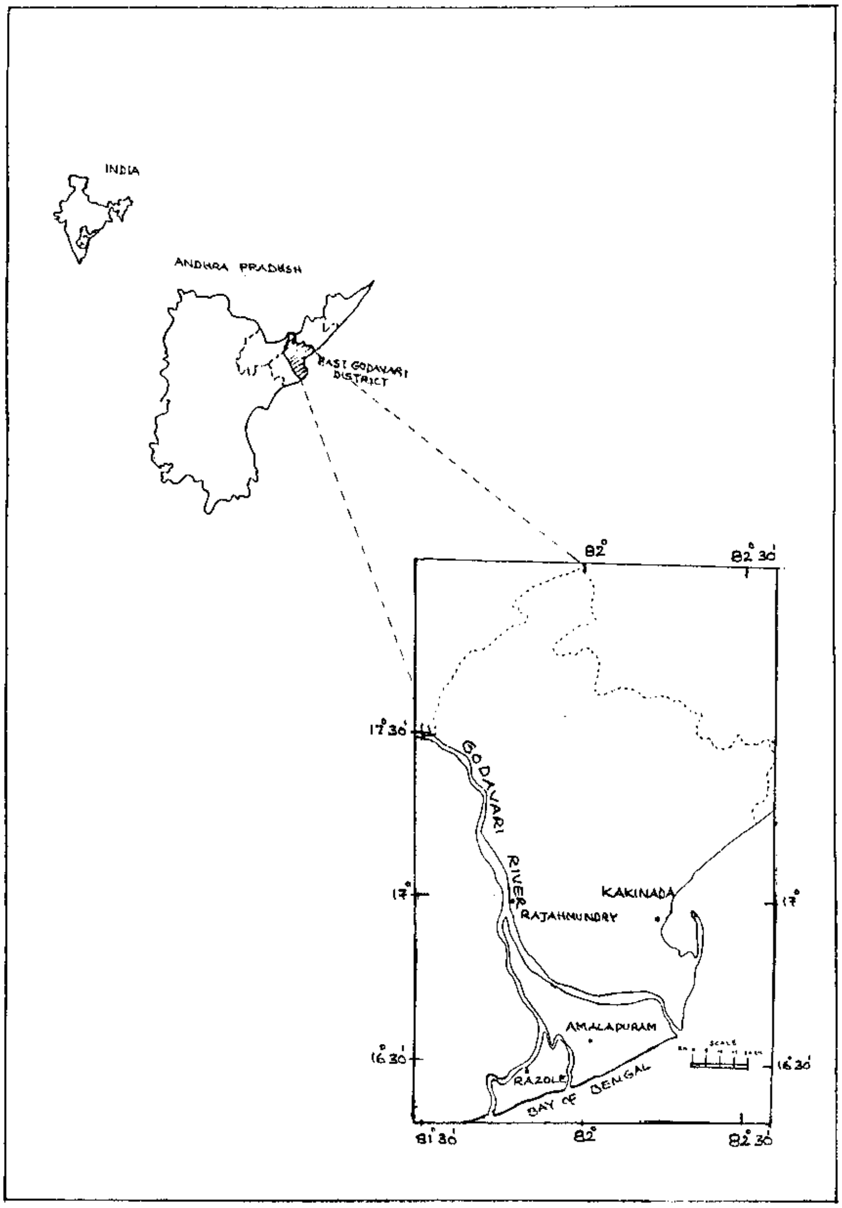
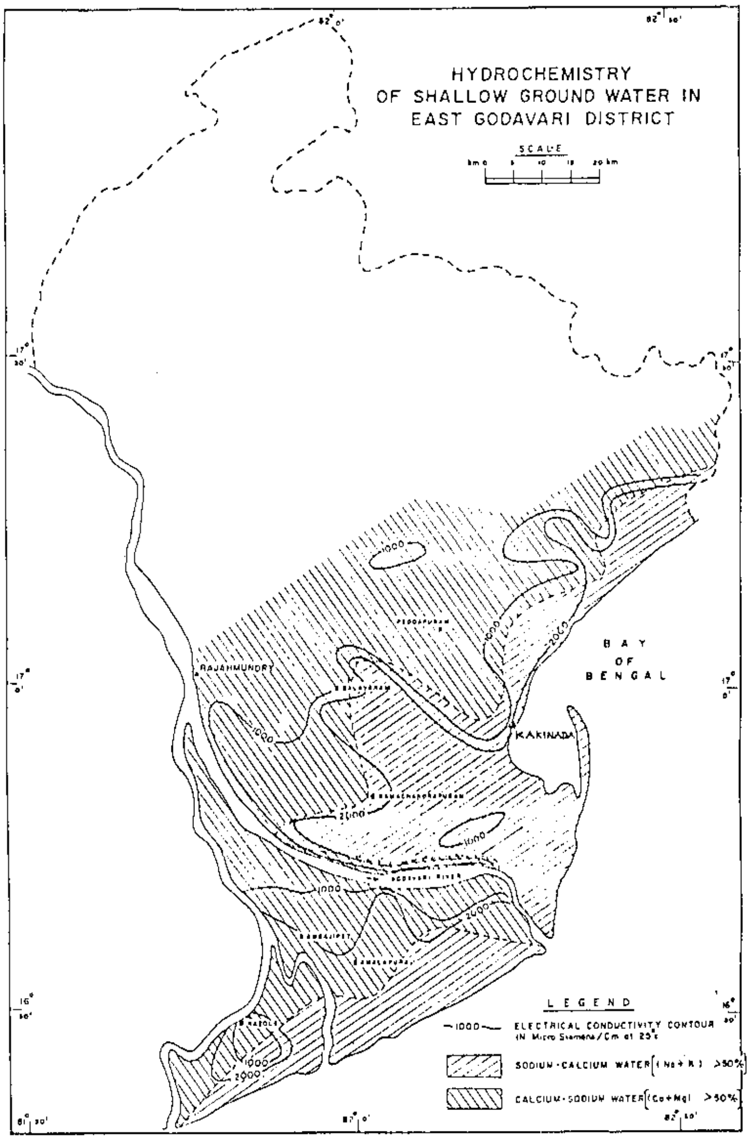


Fig. 2 Location of the study area



REPRODUCED FROM CGWB REPORT (1995)

Fig. 3 Shallow groundwater Hydrochemistry of East Godavari district

disposal on land and making obstruction to the natural drainage by forming the new roads and colonies.

2.3 Climate

Kakinada coast is under tropical climate and frequently effected by cyclonic storms and depressions in Bay of Bengal. Sometimes thunderstorms also bring rainfall to Kakinada during the summer season. The city is very warm in April to June with a maximum temperature of 40^0 C and winter months are December to January having minimum temperature 20^0 C. High percentage of humidity upto 75% to 80% observed during the summer months. The average evaporation rate varies from 2.5 to 9 mm/day. The average monthly minimum and maximum temperature, evaporation and humidity measured at Hydrometeorology Observatory of Deltaic Regional Centre, NIH, Kakinada for the year 1996 are presented in the following Table No. 1.

Table No.1 Climate data in the study area for the year 1996

Months	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Average Max. Temp(^{0}C)	29	30	35	36	39	34	32	32	34	31	30	28
Average Min. Temp(^{0}C)	19	20	22	25	27	27	26	26	25	25	21	19
Average Evaporation (mm/day)	3	4	6	6	7	5	4	4	4	3	4	3
Average Relative Humidity (%)	90	85	86	82	83	86	94	94	93	91	84	85
Total Rainfall (mm)	1.1	0	0	5	15	370	242	224	187	302	195	26

3.0 METHODOLOGY

3.1 Groundwater Table

Variation of groundwater table reflects primary the mass balance between recharge and discharge, and secondary the influence of local transitivity and storativity (or more appropriately hydraulic conductivity, specific storage and aquifer volume). Here, first present the temporal variation of water levels at several representative wells to qualitatively describe the hydrologic conditions in the study area. Total 29 dug wells are chosen to monitor the groundwater level in each well during the month of March 96, June 96, Sept. 96 and Dec. 96. The location of observation wells are shown in Fig. 4. The measuring point of each observation well was connected to the Mean Sea Level by check level survey. The reduced groundwater levels during the study period are given in Table 2. The groundwater table slope and topography of the study area are compared. The rainfall pattern and groundwater table fluctuation in the study area are plotted. Due to the high groundwater table variation among observation wells, two groups of wells have formed i.e. wells parallel to the salt water creek (well no. 15 to 28) and rest of the area (well no. 1 to 16 and 29).

Among four sets of ground water level observations, June 96 and Dec. 96 have considered as pre and post monsoon periods.The pre-monsoon and post-monsoon ground water table contours have plotted for identifying the ground water flow directions in the study area.

3.2 Groundwater quality parameters

Chemical hydrogeology is the study of Chemical energy of the hydrologic system and can be defined simply as a study of geologic and hydrologic controls on the chemical character of ground water. The objectives of chemical hydrogeologic investigations are to determine groundwater circulation and its velocity and the sources, concentration, behavior, and fate of chemical constitutions. Water quality, one of several aspects within the discipline of chemical hydrogeology, is concerned with the chemical description of

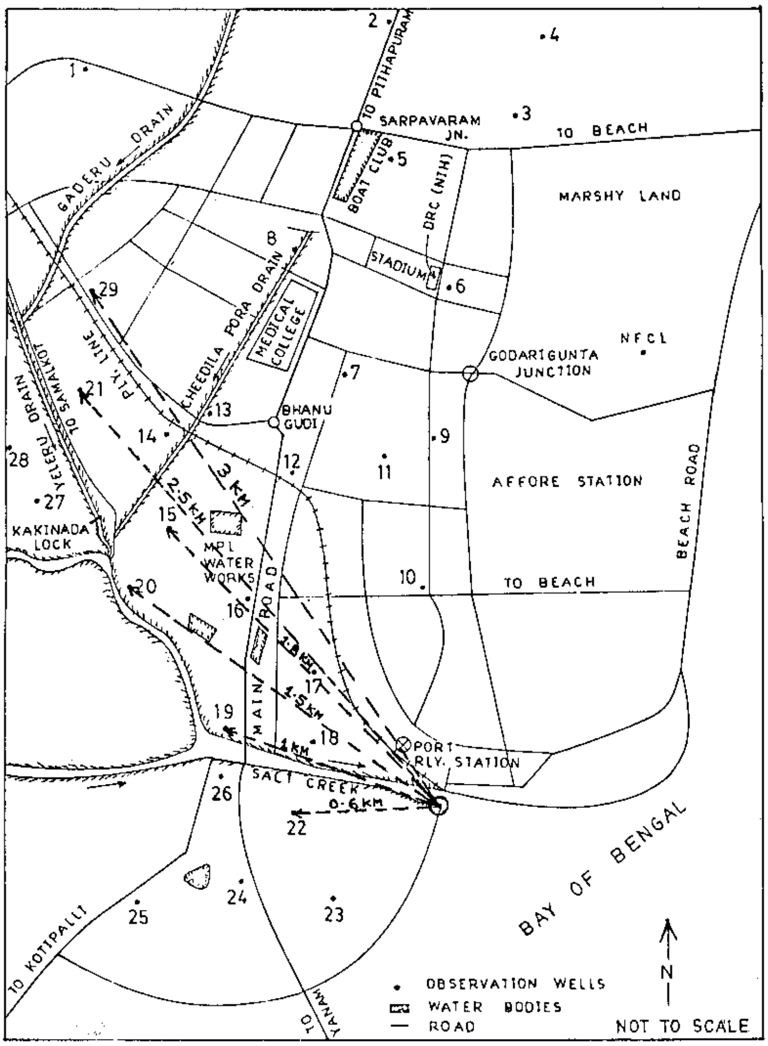


Fig. 4 Location of observation wells in the study area

water, geographic distribution of various constituents, and specific usability of water for manufacturing, agriculture, and municipal and domestic supplies.

3.2.1 Groundwater sampling

Groundwater sampling is one of the most important step for representing the various groundwater systems. To obtain the groundwater hydrochemistry of Kakinada town, four sampling surveys were conducted in the month of March 96, June 96, Sep. 96 and Dec. 96. In each survey 29 samples (Total 116 nos.) were collected by lowering the sampler in the dug wells at various places in the town. Physical parameters i.e. pH, Temperature and Electrical Conductivity values were measured with portable water quality kit at the time of sample collection in the field. For other chemical analysis samples were collected in clean polyethylene bottle fitted with screw caps and brought to the DRC laboratory. Further appropriate reagent is added to preserve the samples till the analysis is completed. The procedure for physico - chemical analysis of samples is adopted from Manual on 'Physico-chemical analysis of water and waste water' (NIH Report UM-26).

3.2.2 Physical Parameters

pH value represents the concentration of hydrogen ions in water and is a measure of acidity and alkalinity of water. pH value below 7.0 indicates acidic character while pH greater than 7.0 is indicative of alkaline character of water.

Electrical conductivity is a measure of waters capacity for conveying electrical current and is directly related to the concentration of ionized substances in the water. Conductivity measurement is commonly used to determine the purity of demineralised water and total dissolved solids in irrigation and domestic waters. The EC values (μ moh/cm) of all samples were measured at 25^0C. The temperature of the each sample is measured with digital thermometer.

3.2.3 Sources of chemical parameters and its measurements

(a) Carbonate and Bicarbonate (Alkalinity)

Sources of carbonate and bicarbonate includes CO_2 from the atmosphere, CO_2 produced by the biota of the soil or by the activity of sulfate reducers and other bacteria in deeper formations, and the various carbonate rocks and minerals of sodium carbonate can accumulate as evaporate in closed basins, causing high carbonate levels in groundwater that has been in contact with it. Bicarbonate concentrations of more than 2000 mg/l are not uncommon in groundwater and higher concentrations can occur where CO_2 is produced within the aquifer. Carbonate concentrations in groundwater are usually less than 10 mg/l. The carbonate and bicarbonate contents in the samples are calculated by standard titrimetric methods using phenolphthalein and methylorange as indicators. Alkalinity is the capacity of the water to neutralize the acid. Since practically all alkalinity of natural water is produced by carbonate and bicarbonate ions, titrated alkalinity is expressed as the equivalent concentration of $CaCO_3$ obtained by adding the equivalents of CO^{2-}_3 and HCO^-_3 and expressing the sum as mg/l of $CaCO_3$.

(b) Calcium and Magnesium

Sources of calcium are igneous rock minerals like silicates, pyroxenes, amphiboles, feldspars, and silicate minerals produced in metamorphism. Since the solubility of these minerals is low, water from igneous or metamorphic rock tends to be low in calcium as well as in TDS.

In sedimentary rock, magnesium occurs as magnesite and other carbonates, sometimes mixed with calcium carbonate. Dolamite contains calcium and magnesium in equal amounts. Most of groundwater contains relatively small amounts of magnesium, except where they have been in contact with dolamite. Calcium and magnesium contents in the samples are determined using titrimetric methods.

(c) Hardness

Hardness of water relates to its reaction with soap and to the scale and incrustations accumulating in containers or conduits where the water is heated or transported. Since soap is precipitated primarily by Ca and Mg ions, hardness is defined as the sum of the concentrations of these ions expressed as mg/l of $CaCO_3$. Total hardness and calcium hardness were determined by EDTA titrimetric method.

Total Hardness = 2.497 Ca + 4. 115 Mg

where

Ca and Mg contents are in ppm.

<u>Hardness classification</u>

Soft	0 - 60 ppm
Moderately hard	61-120
Hard	121-80
Very hard	> 180

Water for domestic use should not contain more than 80 mg/l total hardness. Hardness of groundwater can be increased if contaminated by acid leachate from mine spoils, garbage disposal areas or other sources. Such acid waters can mobilize Ca in underground materials. In recent years, health aspects are receiving increasing interest because of findings that point to greater incidence of coronary heart disease in areas with soft water than with hardwater (Crawford, 1972).

(d) Sodium - Potassium

Sodium is primarily derived from feldspars in igneous rock and its weathering products (clay minerals) in other material. Shale and clay layers often yield water with a relatively high sodium content. Other sources of sodium are leachate and deep percolation water from the upper soil layers, and contamination of groundwater by salty connate water or water of marine origin. Ratio of sodium to total cations is important in agriculture and human pathology.

Potassium is less common than sodium in igneous rock, but more abundant in sedimentary rock as potassium feldspars. These minerals, however, are very soluble so that potassium levels in groundwater normally are much lower than sodium concentrations.

Sodium and potassium contents of the sample are determined by Flame emission method using Flame Photometer.

(e) Chloride

Primary sources of chloride in groundwater are evaporates, salty connate water and marine water. Groundwater containing significant amounts of chloride also tend to have high amounts of sodium, indicating the possibility of contact with water of marine origin. Leaching of chlorides that have accumulated in upper soil layers may be a significant chloride source in dry climates. Chloride content in the sample is measured by silver nitrate method.

(f) Sulphate

The most important sulphate deposits are found in evaporate sediments (gypsum, anhydrite, sodium sulphate). In arid regions, leaching of sulphate from the upper soil layers may also be significant, causing sulphate to be the principal anion of the underlying groundwater. Sulphate content in the sample is measured by gravimetric method.

(g) Nitrate

Major natural sources of nitrate are from atmosphere, legumes, plant debris and animal excrement. Water containing large amounts of Nitrate (more than 100 mg/l) is bitter tasting and may cause physiological distress. Water from shallow wells containing more than 45 mg/l has been reported to cause methemoglobinemia infants. The Nitrate - Nitrogen of the sample is measured by UV-Absorbance Spectrophotometer.

(h) Phosphate

A common phosphorus-containing mineral is apatite, which has a very low solubility. Thus, phosphorus concentrations in most natural groundwaters are less than 0.1 mg/l (Herman Bovwer, 1978).

3.2.4 Variation of groundwater quality parameters from the sea coast

After completing the chemical analysis of ground water samples the Ion Balance error has been calculated for all samples (116 nos.) collected in and around Kakinada. Well Nos. 22, 19, 20, 15, 21 and 29 are choosen at approximate distances of 0.6, 1, 1.5, 1.8, 2.5 and 3 kms respectively from the sea coast as shown in Fig.4. These wells are considered to be free from other sources of pollutions. Chemical constituents of TDS, Sodium, Chloride, Bicarbonate, Calcium, Magnesium, Sulphate and Nitrate in ppm are plotted against the distance from the sea coast. Thus, the groundwater quality variation could be studied.

3.3 Shallow groundwater chemistry

3.3.1 Stiff Classification

The Stiff classification (Stiff, 1951) is to define the type of water based on the presence of dominant cations and dominant anions. The original Stiff plot connects the points on the diagram and produces pattern which, when compared to another analysis, is useful in making comparisons of waters. However a classification table has been prepared for the samples collected during the study period and compared for the changes in water types.

3.3.2 Piper's Trilinear Classification

Piper (1953) developed a form of Trilinear diagram which is an effective tool in segregating analysis data. The chemical analysis of samples collected during the month of March 96, June 96, Sept. 96 and Dec. 96 are plotted on Piper trilinear diagrams. Then the hydrochemical facies of each well at differed time periods are obtained. The changes in hydrochemical facies are studied with respect to time and space in the study area.

3.3.3 U S Salinity Laboratory Classification

The suitability of groundwater for irrigation has been studied for each well by plotting their values of SAR and Electrical Conductivity(μmoh/cm) on WILCOX diagrams and obtained the classification.

3.3.4 Hydrochemical ratios

The Mg/Cl ratio is more than one in shallow groundwater of high chloride content indicating mixing up of fresh water with saline water in deltaic region.

The high Mg/Ca ratio in ground water which is commonly used as diagnostic characteristics for geochemical environment of the groundwater body. In normal ground water the magnesium - calcium ratio commonly ranges from as low as 0.05, ocean water the Mg/Ca ratio is 5.2.

A high Cl/HCO_3 ratio as chloride being a major component of sea water in large quantity.

The variations of above ratios in the study area are plotted. Further, it is also studied the variations of the ratios at different distances from the sea coast.

3.3.5 Sodium Adsorption Ratio (SAR) and %Na

The percentage of Sodium and SAR values have been calculated in each well during the study period. The variation in % Na and SAR in each wells has been studied in the study area. The following equations are being used to calculate % Na and SAR.

$$\% Na = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} * 100$$

$$SAR = \frac{Na^+}{((Ca^+ + Mg^+)/2)^{0.5}}$$

where all ionic concentrations are expressed in milliequalent per litre. Calculation of SAR for a given water sample provides a useful index of the Sodium hazard of that water for soils and crops.

3.4 Potability of groundwater

The suitability of ground water for drinking purposes is examined based on the quality standards recommended by WHO (1984) and ISI (1983). Further the wells exceeded the Maximum permissible limits of ISI (1983) are identified.

4.0 RESULTS AND DISCUSSIONS

4.1 Groundwater table

Groundwater levels have been measured in 29 observation wells in the study area during the month of March 96, June 96, Sept. 96 and Dec. 96. These water levels were connected to the Mean Sea Level and the same are given in Table 2.

The comparison of RL of ground and groundwater level in all observation wells are shown in Fig. 5. From the Fig.5 it is observed that the groundwater level in few wells (Nos. 23, 25 and 27) was not followed the surface gradient. It may be due to the stage of back water in the salt creek. The average groundwater table (above MSL) in the study area during the month of March 96, June 96, Sep.96 and Dec. 96 are 1.92, 1.464, 2.982 and 2.825 Mts. respectively. The analysis of groundwater levels in observation wells shows that the groundwater level nearby salt creek and Kakinada lock are different from the rest of the area. Hence, the observation wells were grouped into two classes. They are (I) well nos. 1 to 14 and 29 and (II) well nos. 15 to 28. The average ground water level in these two classes are compared with the corresponding monthly rainfall in the study area. The variation of average groundwater level between class I and class II is clearly observed in the Fig. 6. The rainfall data and groundwater level data for the year 1995 were taken from NIH - CS (AR)- 195 report. The spatial distribution of Reduced groundwater levels in pre and post-monsoon periods are shown in Fig.7 and 8 respectively. From these ground water table contour maps the ground water flow direction has been demarcated.The groundwater flow direction is similar in both the seasons. The overall shallow groundwater flow is perpendicular to the sea coast. The slope of groundwater table has followed the topographical gradient of the study area. However, the groundwater divide line was observed at well Nos. 5, 8 and 29. The tank at boat club situated near by well No.5 may be acting as recharge source in the study area(Fig. 4). More observation wells are necessary to understand this phenomena in the study area. The groundwater flow direction in the area of wells (Nos. 22, 23, 24, 25 and 26) was not clear. The ground water flow direction may be dominated by the quantity of seepage from salt creek. More observations are necessary on stage measurements in salt creek in order to understand the actual phenomena.

Table No. 2

Reduced groundwater levels in observation wells during the year 1996

Well No.	Location	R.L of Ground	March 96	June 96	September 96	December 96
1	Sarpavaram	4.63	2.75	1.85	3.84	3.75
2	Balaji nagar	6.09	3.78	3.18	4.83	4.81
3	Vlasapakalu	4.34	2.08	1.58	3.45	3.36
4	Vakalapudi	3.91	1.91	1.31	3.36	3.22
5	Ramanayyapeta	5.34	3.22	2.82	4.34	4.16
6	R.R Nagar	4.73	2.49	1.99	3.62	3.60
7	Madav Nagar	4.06	2.41	1.71	3.71	3.52
8	Nagamallithota	5.21	3.38	2.88	4.83	4.54
9	Godarigunta	4.27	2.44	1.99	3.69	3.35
10	Sambamuthynagar	3.72	1.94	1.39	3.29	3.05
11	Shantinagar	3.79	2.81	2.61	3.54	3.32
12	Perraju peta	3.65	1.94	1.44	2.84	2.64
13	Kondayya palem	4.53	2.53	2.33	3.27	3.22
14	Gandhi Nagar	4.03	2.12	1.82	3.21	2.99
15	Rama Rao peta	3.87	1.71	1.21	2.49	2.39
16	Surya Rao peta	3.73	1.39	0.54	2.87	2.82
17	Suryanarayanapuram	2.93	1.70	1.10	2.40	2.30
18	Budam peta	3.81	1.23	0.63	2.42	2.38
19	Temple street	2.56	1.03	0.63	2.31	2.24
20	Frazer peta	3.61	1.87	1.17	2.33	2.26
21	Pratap nagar	3.57	1.81	1.41	2.85	2.76
22	Revenue colony	2.75	1.26	1.26	2.03	2.04
23	Godanayyapeta	2.04	1.29	1.49	1.61	1.65
24	M S N Charities	3.02	1.03	0.48	1.89	1.88
25	Turangi	2.73	0.51	0.01	1.47	1.41
26	Paradesamma Peta	2.37	0.63	0.18	1.07	1.50
27	Indra palem	2.51	-0.01	0.39	1.20	1.35
28	Chidiga	3.05	0.82	0.07	0.87	1.35
29	Madura nagar	5.12	3.44	2.94	4.48	3.99

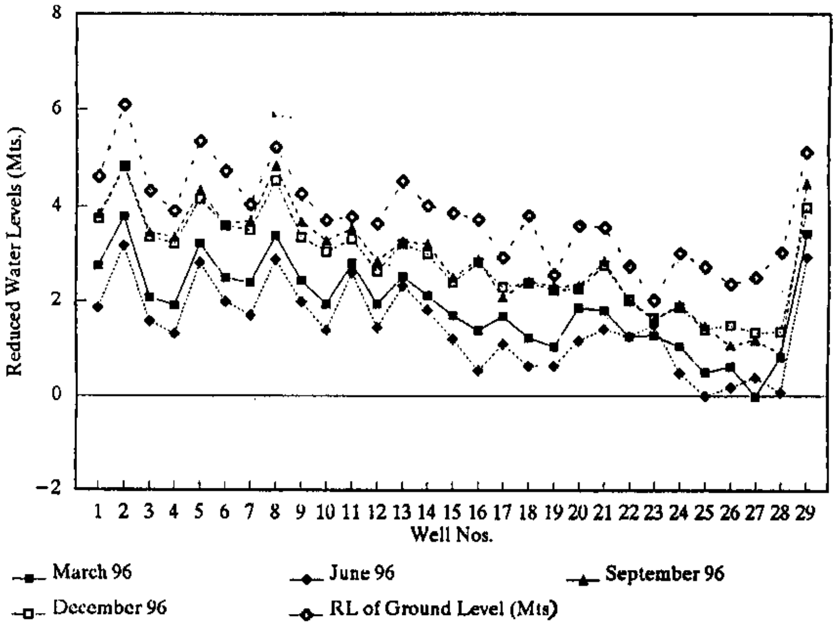


Fig. 5 R.L of ground and groundwater levels in the observation wells

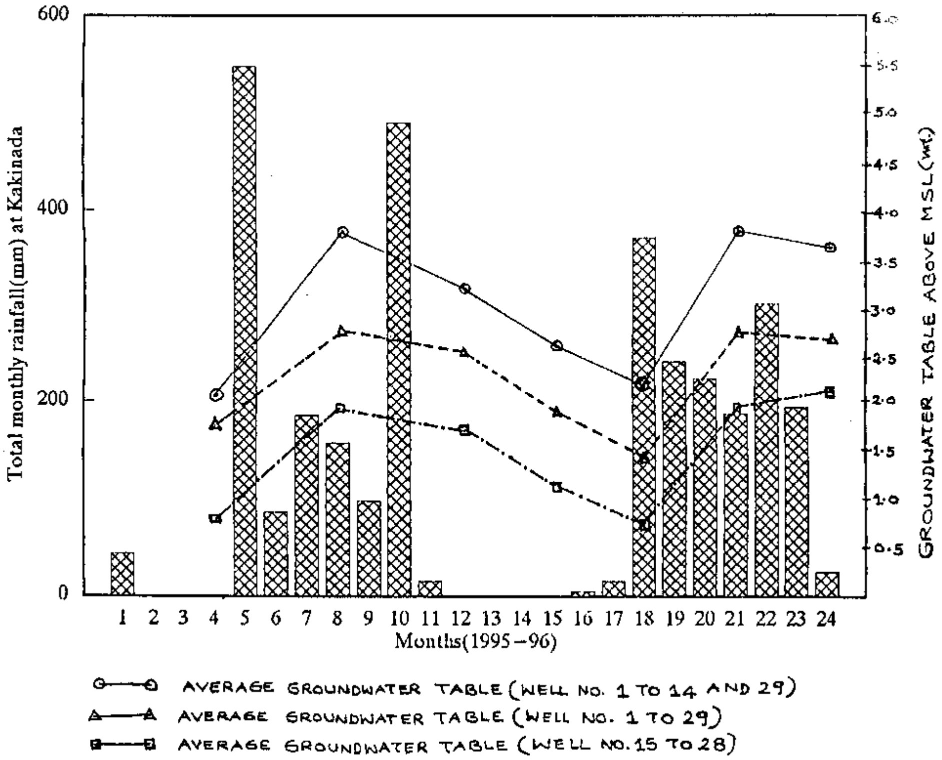


FIGURE 6 COMPARISON BETWEEN RAINFALL AND AVERAGE GROUNDWATER TABLE

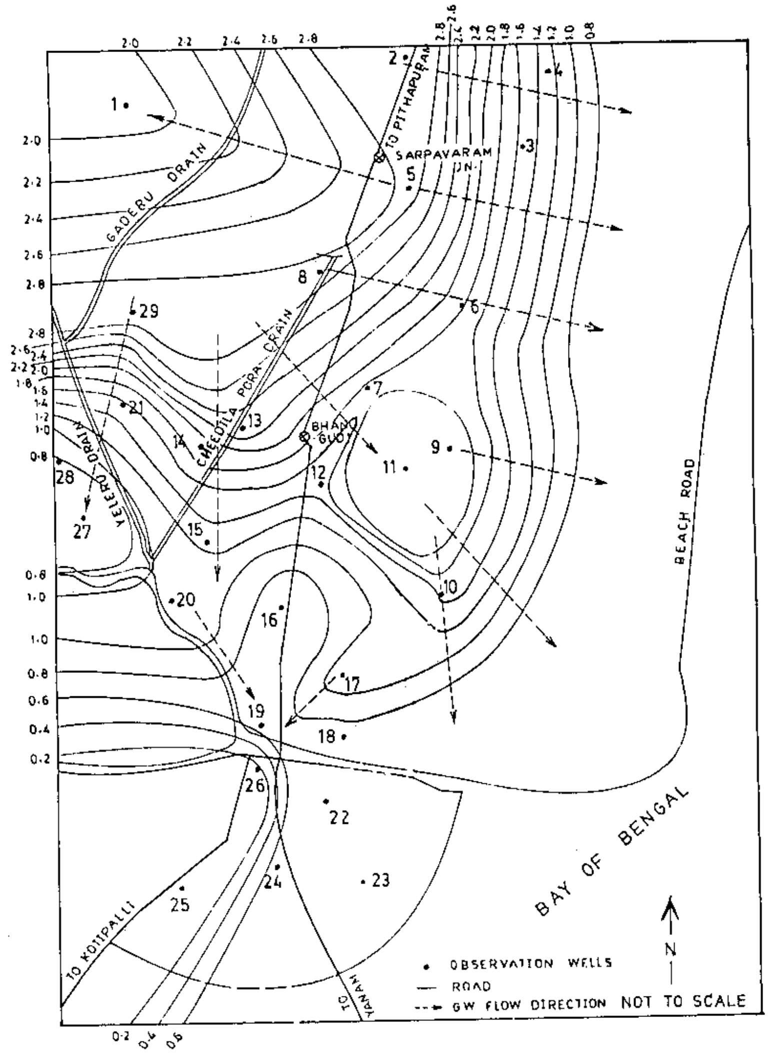


Fig. 7 Reduced groundwater table contours during premonsoon(June 96)

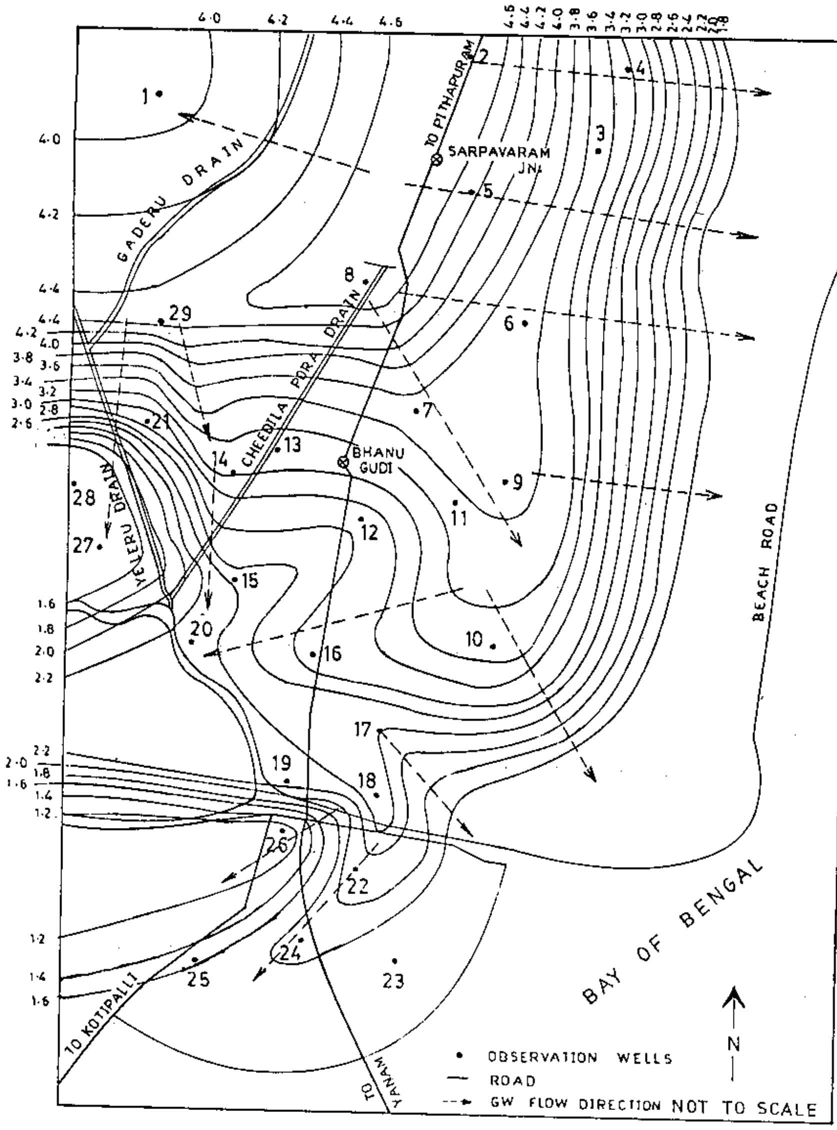


Fig.8 Reduced groundwater table contours during post monsoon(Sept. 96)

4.2 Groundwater quality parameters

The chemical analysis of groundwater samples collected in and around Kakinada town during the month of March 96, June 96, Sep.96 and Dec.96 are presented in Table 3, 4, 5 and 6 respectively. The Nitrate content of the samples collected in the month of Sep. 96 and Dec. 96 could not be analyzed. The Ion balance error of each sample (Nos.116) was less than ± 10%.

4.2.1 Variations in water quality parameters

4.2.1.1 Physical parameters

pH values are varied between 6.0 to 8.3and temperature range is between 20^{0}C to 27^{0}C in the study period.

The range of Electrical Conductivity values during the month of March 96, June 96, Sept. 96 and Dec. 96 are 320 to 3910, 250 to 3850, 500 to 3750 and 390 to 3280 μmoh/cm respectively.

4.2.1.2 Chemical parameters

Total dissolved solids:

Total dissolved solids in each sample has been calculated by electrical conductivity values (i.e. multiplied by a factor 0.64). The range of TDS in the study area during March 96, June 96, Sept. 96 and Dec. 96 are 205 to 2502, 160 to 2464, 320 to 2400 and 318 to 2061 ppm respectively. The spatial distribution of TDS during pre-monsoon (June 96) and post-monsoon (Sept 96) periods are shown in Fig. 9 and 10 respectively. It is observed that the TDS values were more at well No.3, salt creek and Kakinada locks. The average TDS value during premonsoon and post monsoon periods are 1036 and 1092 ppm respectively.

Alkalinity:

The presence of carbonate, bicarbonate and hydroxides are the most common cause of alkalinity in natural waters. The variation of alkalinity in the study area during the month of March 96, June 96, Sept. 96 and Dec. 96 are 156 to 872, 80 to 800,

Table no. 3

CHEMICAL ANALYSIS OF GROUNDWATER SAMPLES COLLECTED DURING THE MONTH OF MARCH 1996

WELL NO.	Temp (C)	pH	EC (mhos/cm) at 25 C)	TDS (ppm)	Total Alkalinity (ppm)	Total Hardness (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Cl (ppm)	SO_4 (ppm)	PO_4 (ppm)	NO_3 (ppm)
1	26	6.6	1450	928	274	440	104.1	43.7	96.9	80.0	134.0	106.0	1.88	136.4
2	25	7.5	640	410	156	180	48.1	14.6	65.1	20.0	74.0	20.4	1.20	6.6
3	25	6.5	3910	2502	600	780	168.1	87.5	500.0	262.5	666.0	40.0	1.73	237.6
4	24	7.1	1710	1094	500	322	88.2	24.8	309.4	27.5	230.0	0.0	1.65	0.0
5	26	6.3	1320	845	290	336	89.8	27.2	84.5	28.0	122.0	88.0	5.10	138.6
6	26	7.6	1100	704	414	480	104.0	53.5	134.3	15.0	178.0	29.0	1.20	0.0
7	25	7.4	710	454	264	212	48.1	22.4	93.0	24.5	46.0	21.0	4.50	24.2
8	25	7.1	720	461	396	400	88.2	43.7	155.0	17.5	150.0	110.0	2.33	5.9
9	26	6.8	1880	1203	350	488	96.2	60.3	234.5	47.5	380.0	34.0	1.35	22.0
10	25	7.5	1660	1062	630	560	120.1	63.2	209.7	15.5	136.0	124.5	3.00	2.6
11	25	7.8	320	205	140	132	32.1	12.6	7.9	15.0	26.0	0.0	0.53	0.0
12	26	6.8	2200	1408	464	580	160.0	43.7	308.6	49.5	300.0	138.0	0.75	110.0
13	25	7.1	1370	877	320	260	48.1	34.0	102.0	110.0	118.0	66.0	7.50	114.0
14	25	7.3	1500	960	440	440	112.0	38.9	206.2	44.5	172.0	80.0	0.83	61.6
15	26	6.9	980	627	274	360	100.0	26.7	70.8	66.5	100.0	30.0	3.75	50.6
16	24	7.2	2200	1408	840	520	104.0	63.2	335.8	157.0	278.0	84.0	3.00	96.8
17	25	7.1	1840	1178	530	320	83.4	27.2	282.2	135.5	196.0	46.5	4.50	0.0
18	25	7.1	2420	1549	460	570	116.0	68.1	128.1	150.0	260.0	89.0	0.53	180.0
19	26	6.8	1920	1229	510	640	136.0	72.9	198.6	117.5	190.0	218.0	1.88	24.2
20	26	7.1	1470	941	362	420	96.2	43.7	125.3	101.0	112.0	36.5	6.15	134.2
21	25	7.2	590	377	250	252	59.4	25.3	48.5	34.5	28.0	40.0	0.98	40.0
22	24	7.2	2420	1549	872	400	83.4	46.7	480.8	34.0	272.0	81.0	1.58	17.6
23	25	8.3	2343	1500	620	203	37.0	27.0	314.8	26.0	216.0	18.0	3.00	0.0
24	26	7.4	830	531	232	180	40.1	19.4	97.2	55.5	106.0	33.0	0.75	2.2
25	26	7.2	2880	1843	350	900	216.0	87.5	344.3	16.0	626.0	133.5	0.45	145.2
26	25	6.7	3770	2413	680	980	160.0	140.0	525.0	216.5	726.0	208.0	0.60	250.8
27	26	6.8	2900	1856	574	670	168.0	60.8	425.1	117.5	550.0	174.0	7.20	127.6
28	26	6.7	1380	883	250	368	112.0	21.4	127.8	40.5	156.0	81.0	4.20	268.4
29	25	7.5	490	313	184	190	40.1	21.9	26.3	16.0	26.0	34.0	3.60	63.8

Table no.4

CHEMICAL ANALYSIS OF GROUNDWATER SAMPLES COLLECTED DURING THE MONTH OF JUNE 1996

WELL NO.	Temp (C)	pH	EC (mhos/cm) at 25 C)	TDS (ppm)	Total Alkalinity (ppm)	Total Hardness (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Cl (ppm)	SO_4 (ppm)	PO_4 (ppm)	NO_3 (ppm)
1	23	6.2	1420	909	224	508	109.0	57.3	109.9	22.5	144.0	108.0	0.90	220.0
2	23	6.7	610	390	176	156	40.1	13.6	45.8	11.0	64.0	0.0	0.75	44.0
3	23	6.5	3850	2464	684	728	112.0	108.0	525.1	313.5	680.0	138.0	0.52	215.6
4	24	6.3	1400	896	500	308	72.2	31.1	275.9	47.5	226.0	36.0	0.90	0.0
5	21	6.1	1320	845	242	380	80.2	43.7	100.0	125.0	124.0	91.5	2.78	182.8
6	22	7.2	1470	941	450	480	96.2	58.3	157.5	10.5	220.0	31.5	0.98	2.2
7	23	7.3	500	320	220	128	28.9	13.6	57.2	30.5	38.0	28.5	7.20	17.6
8	21	7.1	1140	730	370	280	64.2	29.1	183.9	19.5	116.0	57.0	3.00	2.4
9	23	6.5	2000	1280	368	460	96.2	53.4	233.9	46.0	414.0	52.5	0.38	11.0
10	21	7.4	1630	1043	560	544	102.0	69.9	224.2	17.5	134.0	98.0	1.13	0.0
11	24	8.0	250	160	104	128	24.1	16.5	3.4	18.0	14.0	0.0	0.98	0.4
12	23	6.8	2550	1632	610	480	64.2	77.7	440.1	35.0	392.0	108.0	1.13	94.6
13	21	6.8	1130	723	310	164	44.9	12.6	113.6	125.5	90.0	52.5	1.80	103.4
14	22	6.6	1620	1037	426	440	112.0	38.8	170.1	60.5	196.0	60.0	1.80	57.2
15	24	7.2	950	608	340	296	73.8	27.2	64.9	38.0	90.0	25.5	3.60	33.0
16	24	6.5	2170	1389	800	480	72.2	68.0	296.8	152.5	238.0	69.0	3.60	72.6
17	23	7.3	1350	864	620	308	80.2	26.2	280.5	170.5	266.0	79.5	3.90	13.2
18	23	7.0	2000	1280	474	600	136.0	63.1	147.9	182.5	226.0	85.5	1.28	237.6
19	24	7.1	1700	1088	440	616	128.0	71.9	128.4	105.0	184.0	130.5	3.90	66.0
20	21	6.8	1170	749	318	320	72.2	34.0	85.6	65.5	138.0	36.0	3.90	112.2
21	21	6.5	680	435	280	320	72.2	34.0	46.9	22.5	44.0	21.0	0.75	66.0
22	22	7.2	1900	1216	630	340	60.9	45.6	380.5	30.5	204.0	21.0	1.13	66.0
23	24	7.5	2103	1346	684	336	49.7	51.5	346.4	79.0	308.0	10.5	8.70	0.0
24	23	7.6	770	493	210	160	32.1	19.4	86.8	42.0	100.0	36.0	0.45	3.5
25	23	7.4	3180	2032	280	620	136.0	68.0	315.9	15.5	552.0	93.0	1.50	136.6
26	22	7.1	3300	2112	710	732	109.0	111.0	605.3	140.5	570.0	99.0	2.18	198.0
27	21	6.8	3100	1984	610	624	144.0	64.1	433.9	170.5	558.0	108.0	12.30	112.2
28	22	6.5	1180	754	80	228	51.3	24.3	44.1	20.5	98.0	45.0	4.20	107.6
29	21	7.2	536	343	202	240	40.1	34.0	9.3	11.0	28.0	10.5	1.80	30.6

Table no. 5

CHEMICAL ANALYSIS OF GROUNDWATER SAMPLES COLLECTED DURING THE MONTH OF SEPT. 1996

WELL NO.	Temp (C)	pH	EC (mhos/cm) at 25 C)	TDS (ppm)	Total Alkalinity (ppm)	Total Hardness (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Cl (ppm)	SO_4 (ppm)	PO_4 (ppm)
1	21	7.1	2250	1440	386	560	166.8	34.9	183.0	274.0	370.0	200.0	0.8
2	22	7.2	1400	896	296	408	128.0	21.3	93.0	21.0	234.0	65.0	0.0
3	22	6.5	3750	2400	738	500	112.0	53.4	317.0	232.0	498.0	315.0	0.8
4	23	7.4	1110	710	508	360	80.2	38.8	171.0	25.0	252.0	60.0	0.7
5	22	6.0	1248	799	236	284	72.1	25.2	77.0	60.0	136.0	115.0	0.2
6	23	7.2	520	333	208	180	56.1	9.7	20.0	3.0	26.0	50.0	0.5
7	20	7.5	1140	730	380	250	80.2	12.1	78.0	14.0	72.0	40.0	2.3
8	21	7.1	1550	992	478	460	108.0	46.1	142.0	17.0	190.0	170.0	1.4
9	22	7.5	1260	806	376	256	73.7	17.4	110.0	40.0	124.0	30.0	3.0
10	21	6.8	1400	894	460	449	69.3	67.0	114.0	16.0	72.0	120.0	1.1
11	22	6.9	500	320	102	122	24.0	15.0	20.0	10.0	16.0	35.0	0.0
12	21	6.5	1740	1114	510	370	100.0	29.1	280.0	17.0	246.0	125.0	2.0
13	21	7.4	1285	822	372	232	51.3	25.2	125.0	92.0	100.0	80.0	1.9
14	22	7.0	1435	918	418	480	112.0	46.6	93.0	20.0	162.0	110.0	0.0
15	23	7.0	1070	685	356	284	86.6	16.5	54.0	33.0	96.0	75.0	0.8
16	23	7.7	2900	1856	576	453	88.1	56.7	150.0	130.0	156.0	115.0	1.2
17	22	7.5	1480	947	852	460	80.2	63.1	333.0	140.0	586.0	120.0	2.6
18	21	7.3	2600	1664	544	760	192.0	68.0	117.0	140.0	378.0	180.0	0.8
19	20	6.8	1930	1235	480	534	112.0	61.8	125.0	92.0	225.0	325.0	1.4
20	22	6.7	1500	960	375	372	96.2	32.1	70.0	84.0	134.0	56.0	1.2
21	21	6.5	1080	691	350-	320	95.2	19.4	60.0	16.0	60.0	23.0	0.0
22	22	7.5	2300	1472	644	480	125.0	40.8	217.0	20.0	256.0	130.0	2.3
23	23	7.1	1946	1246	444	230	34.4	35.1	215.0	23.0	156.0	95.0	0.3
24	21	6.9	800	511	176	156	33.6	17.4	21.0	24.0	36.0	14.0	0.9
25	22	7.0	3650	2336	422	500	120.0	48.6	283.0	20.0	596.0	230.0	0.3
26	23	6.9	2800	1789	744	491	96.2	61.0	350.0	110.0	360.0	205.0	0.0
27	20	7.2	2600	1664	738	609	160.0	51.1	275.0	120.0	476.0	160.0	0.7
28	22	7.3	1530	977	150	232	52.1	24.8	35.0	10.0	58.0	40.0	2.1
29	21	6.8	760	486	176	203	46.5	21.1	16.0	5.0	26.0	60.0	0.5

Table no. 6

CHEMICAL ANALYSIS OF GROUNDWATER SAMPLES COLLECTED DURING THE MONTH OF DEC. 1996

WELL NO.	Temp (C)	pH	EC (mhos/cm) at 25 C)	TDS (ppm)	Total Alkalinity (ppm)	Total Hardness (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	Cl (ppm)	SO_4 (ppm)	PO_4 (ppm)
1	27	6.9	1580	1011	320	320	80.2	29.1	95.0	125.0	224.0	82.5	3.9
2	26	7.1	1450	928	240	440	144.0	19.4	125.0	10.0	234.0	15.0	0.0
3	26	6.9	3220	2061	720	520	104.0	63.1	300.0	220.0	474.0	244.5	0.4
4	26	7.3	1770	1133	496	360	80.2	38.8	200.0	20.0	256.0	69.0	0.0
5	27	7.1	1174	751	220	130	32.0	12.1	90.0	75.0	98.0	120.0	1.2
6	27	7.6	498	318	220	210	48.1	21.8	30.0	5.0	24.0	6.0	1.1
7	26	7.5	820	525	320	330	96.2	21.8	100.0	15.0	58.0	28.5	1.9
8	27	7.2	730	467	330	210	56.1	17.0	165.0	15.0	34.0	108.0	0.6
9	27	7.1	1313	840	390	140	40.1	9.7	145.0	50.0	164.0	52.5	4.7
10	26	7.1	946	604	240	240	64.1	19.4	20.0	10.0	58.0	31.5	3.1
11	26	7.5	390	249	130	140	36.1	12.1	30.0	5.0	14.0	25.0	0.0
12	26	7.6	1780	1139	490	400	104.0	34.0	225.0	25.0	212.0	120.0	5.4
13	27	7.4	990	633	330	240	48.1	29.1	110.0	85.0	74.0	67.5	0.5
14	27	6.5	990	633	350	280	64.1	29.1	105.0	20.0	140.0	76.0	0.0
15	27	7.4	1070	685	300	400	96.2	38.8	50.0	30.0	90.0	68.0	2.1
16	26	7.2	1620	1037	770	240	48.1	29.1	275.0	145.0	194.0	144.0	1.9
17	27	6.9	3280	2099	840	240	72.2	14.5	480.0	130.0	624.0	139.5	0.1
18	26	6.9	2360	1510	588	633	164.0	54.3	230.0	125.0	304.0	213.0	0.8
19	26	7.2	1850	1184	444	449	94.0	52.1	185.0	70.0	208.0	63.0	1.0
20	27	7.2	1300	832	372	288	76.0	24.0	95.0	70.0	98.0	37.0	0.0
21	26	6.4	600	384	258	280	80.2	19.4	50.0	15.0	26.0	19.5	3.8
22	26	7.5	2480	1587	600	374	110.0	24.3	230.0	25.0	320.0	144.0	3.9
23	27	7.4	1790	1146	448	202	32.1	29.7	195.0	20.0	146.0	84.5	0.1
24	26	7.6	830	531	204	160	32.8	18.9	55.0	35.0	76.0	57.0	0.0
25	27	7.6	3000	1920	428	440	84.2	55.8	345.0	10.0	516.0	169.7	2.7
26	26	7.1	2300	1472	684	380	96.2	34.0	325.0	135.0	274.0	183.0	1.6
27	27	7.1	1650	1056	390	500	144.0	34.0	225.0	60.0	212.0	148.5	2.9
28	26	7.2	1080	690	160	200	40.1	24.3	55.0	10.0	54.0	80.0	4.6
29	26	7.4	500	320	190	180	54.5	10.6	20.0	5.0	10.0	15.0	0.0

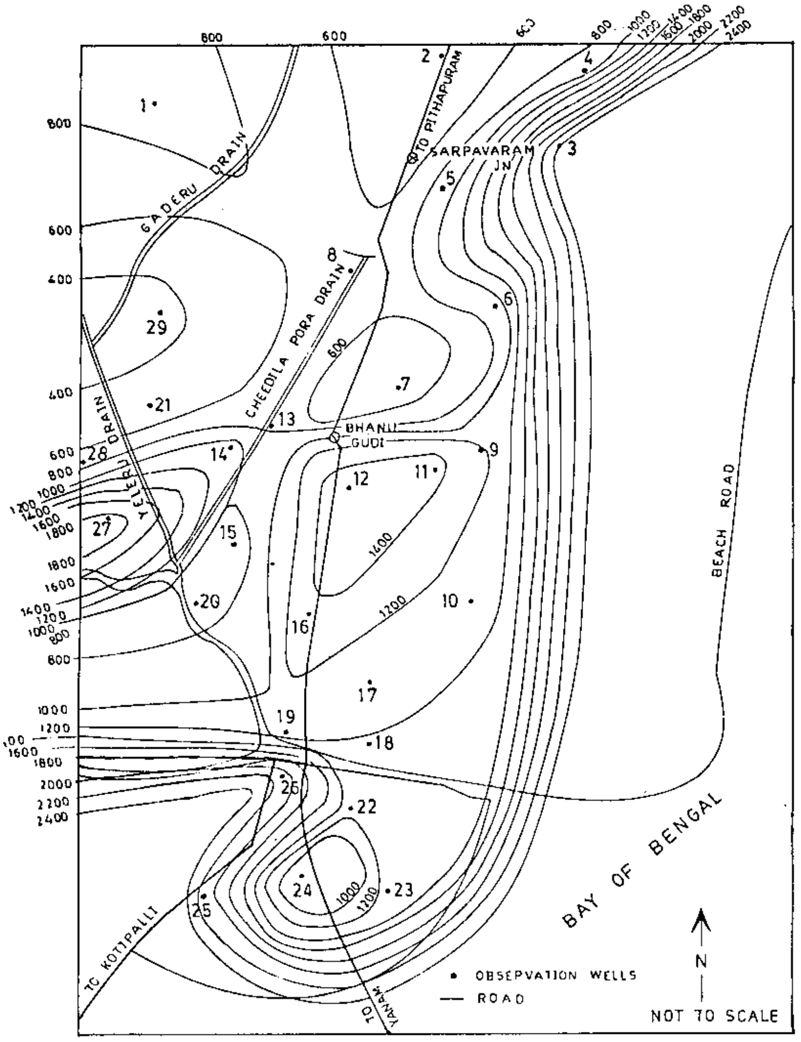


Fig. 9 TDS contours during premonsoon (June 96) period

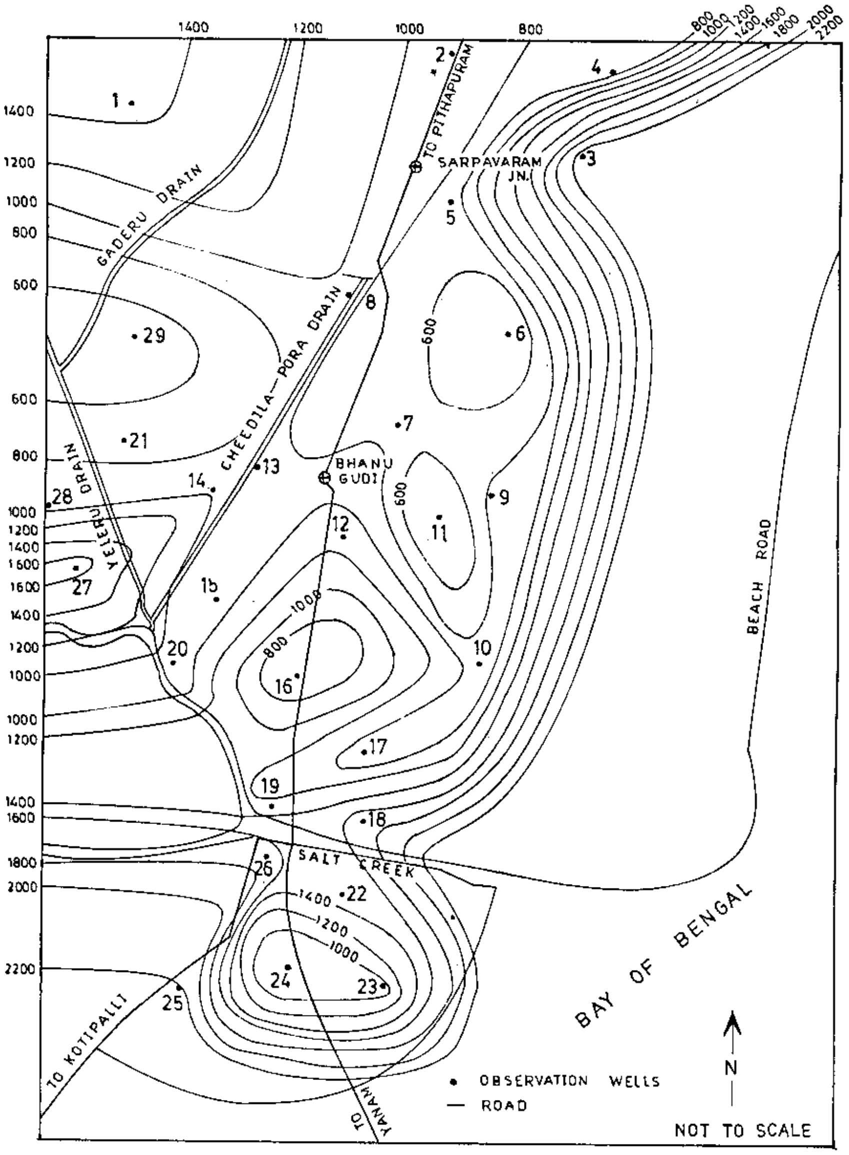


Fig. 10 TDS contours during postmonsoon (Sept. 96) period

102 to 852 and 130 to 770 ppm respectively. The highest alkalinity (872) was observed in well No. 22 during the month of March 96.

Sodium:

The range of sodium content in groundwater samples collected during the month of March 96, June 96, Sept. 96 and Dec. 96 are 7.9 to 525, 3.4 to 525, 16 to 350 and 20 to 480 ppm respectively. The average sodium content in the study area during pre and post monsoon are 200 and 143 ppm respectively . This indicates dilution of sodium content from Pre-monsoon to Post monsoon period. The highest sodium content was observed in well Nos. 3(Marshy land) and 26(salt creek).

Calcium, Magnesium and Total Hardness:

Sample survey in the month of March 96, June 96, Sep. 96 and Dec. 96 the calcium content in the study area varied in the range of 32 to 216, 32 to 144, 24 to 166 and 32 to 164ppm respectively. There is no much variation in the calcium content in the study period.

Similarly the range of Magnesium content during the above months are 12 to 140, 12 to 111, 10 to 68 and 9 to 63 ppm respectively. The average Magnesium content in the study area during pre monsoon and postmonsoon periods are 47 and 36 ppm respectively.

Total hardness (as $CaCO_3$) in the study area was more than 150 ppm in almost all observation wells during four surveys. According to hardness classification the study area falls under hard to very hard zone. Very high values of hardness have been observed in wells nearby salt creek and near to the sea. The precautions are necessary to eliminate temporary hardness when the water is using for drinking water purposes.

Chloride:

Mainly chloride content is important for taste considerations. The range of chloride content in the observation wells during the month of March 96, June 96, Sep. 96 and Dec. 96 are 26 to 726, 14 to 680, 16 to 596 and 10 to 624 ppm respectively. The average chloride content in the study area during pre monsoon and post monsoon periods are 222 to 210 ppm respectively.

Sulfate:

The range of Sulphate content in the study area during the month of March 96, June 96, Sep. 96 and Dec. 96 are 0 to 218, 0 to 138, 14 to 325 and 6 to 244 respectively. The average sulphate content in the study area during pre-monsoon and post-monsoon period were 115 and 59 ppm respectively. The change may be due to the leaching of sulfate from upper soil layers and local conditions of nearby wells.

Phosphate:

Very low phosphate values have been observed in the study area. The range varies between 1 ppm to 12 ppm. The highest phosphate content (12 ppm) had been observed in well No.27 which is near to Yeleru drain. The high value may be due to the domestic water and irrigation return flows in the Yeleru drain.

Nitrate:

Nitrate content was measured only in the month of March 96 and June 96 during the study period. The range of Nitrate in these months are 0 to 268 and 0 to 220 ppm respectively. Wells which are exceeded the maximum permissible limits are given in the Table 8. Especially well Nos. 1, 3, 18, 26 and 28 were exceeded more than 200 ppm. Hence, these wells may be avoided mainly for drinking water purposes. High Nitrate content in the water may be danger to the pregnant women. The reason for high Nitrate in well No. 1 is due to agricultural fields. Marshy land, salt creek and Yeleru drain are the main sources of high Nitrate in other wells. Therefore, monitoring of Nitrate content in the study area is very much essential to avoid long term health hazards.

4.2.1.3 Variation of groundwater quality parameters from the sea

Variation of total dissolved solids, chloride, sodium, bicarbonate, calcium, megnisium, sulphate and nitrate contents in ppm from the sea coast during the month of March 96, June 96, Sep. 96 and Dec. 96 are shown in Fig.11 and 12 respectively.

The concentration of TDS, Cl, Na , HCO_3 are decreasing with the distance from the sea coast. The other parameters like Ca, Mg, SO_4 and NO_3 concentrations have not followed any increasing or decreasing trend from the sea coast. Thus, it indicates sea water influence is mainly on TDS, Cl, Na and HCO_3.

The chemical analysis data of Nitrate during the month of Sep 96 and Dec 96 was not available. The high concentration of Nitrate in Well No.22 is mainly due to the Yeleru drain near to the Kakinada lock. The Yeleru drain mainly carries irrigation return flows from the upper reaches. Therefore the sources of Nitrate in ground water is mainly from irrigation return flows and local domestic waste water in the town.

4.3 Shallow groundwater Hydrochemistry

4.3.1 Stiff classification

Major cation and anion of samples collected during the study period are given in the Table 7. The change in major cation and anion indicates that the mixing of shallow groundwater in the study area. However few wells remain same during the study period.

4.3.2 Pipers trilinear classification:

Chemical analysis of groundwater samples in the month of March 96, June 96, Sep. 96 and Dec. 96 are plotted on Piper's trilinear diagrams and shown in Fig. 13, 14, 15 and 16 respectively. The hydrochemical facies inferred from these diagrams are presented in the Table 8. Mainly four hydrochemical facies have been identified in the study area. They are (I) Ca + Mg + Cl + SO_4, (II) Na + K + Cl + SO_4 , (III) Na + K + CO_3 + HCO_3 and (IV) Ca + Mg + CO_3 + HCO_3 . In well Nos. 3, 13, 16, 21, 23 and 29 the hydrochemical facies remains same during the study period. The change in hydrochemical facies of other wells in the study area was mainly due to the seasonal variations. More elaborative studies are necessary to understand the hydrochemical facies changes in the study area.

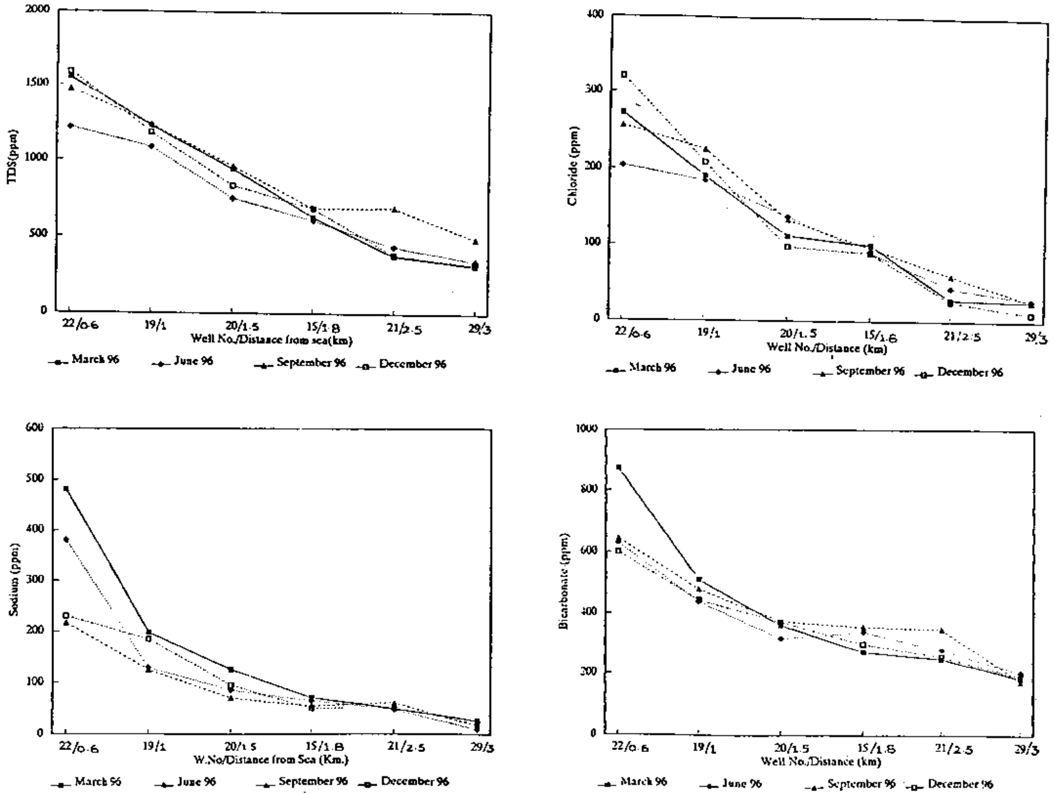


Fig.14 Variation of water quality parameters (TDS, Cl, Na, HCO_3) from the sea

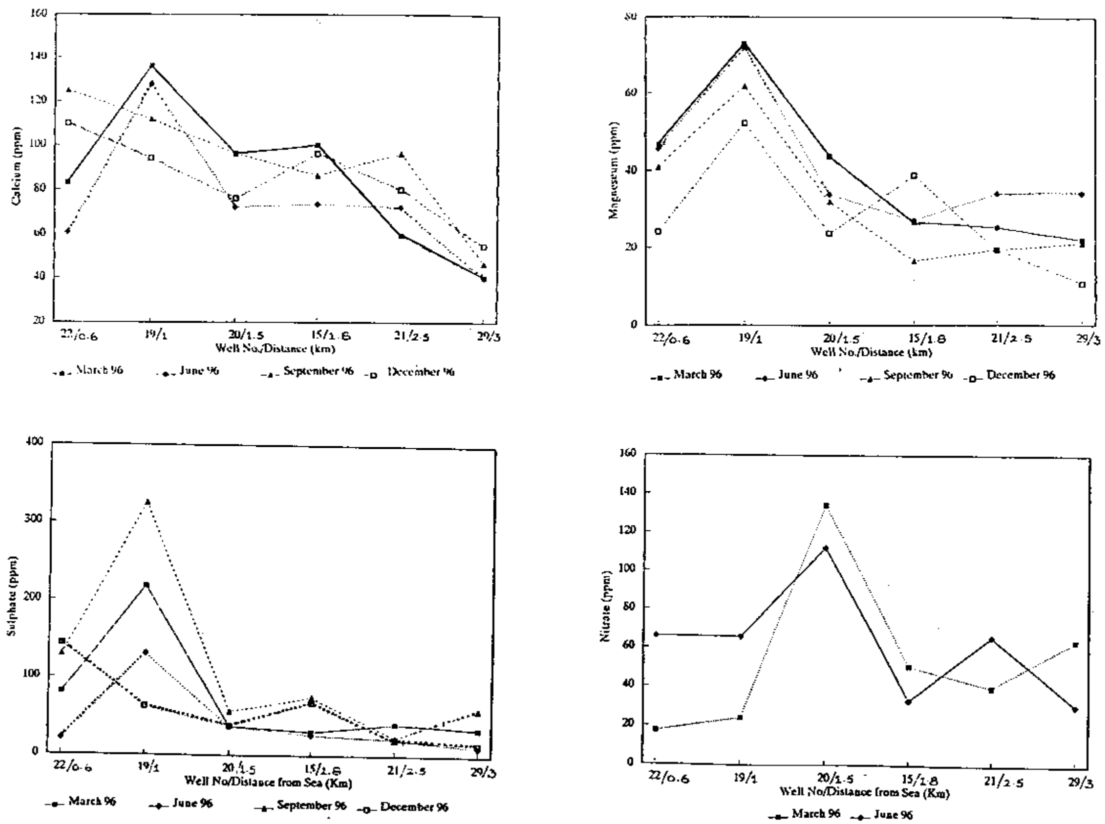


Fig. 12 Variation of water quality parameters (Ca, Mg, SO_4, NO_3) from the sea

Table No. 7

Stiff Classification of Groundwater Samples Collected during the year 1996

Well No.	March 96	June 96	September 96	December 96
1	$NaHCO_3$	$CaHCO_3$	NaCl	$NaHCO_3$
2	$NaHCO_3$	$NaHCO_3$	$CaCl_2$	$CaCl_2$
3	NaCl	NaCl	$NaHCO_3$	$NaHCO_3$
4	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
5	$CaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
6	$NaHCO_3$	$NaHCO_3$	$CaHCO_3$	$CaHCO_3$
7	$NaHCO_3$	$NaHCO_3$	$CaHCO_3$	$CaHCO_3$
8	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
9	NaCl	NaCl	$NaHCO_3$	$NaHCO_3$
10	$NaHCO_3$	$NaHCO_3$	$MgHCO_3$	$CaHCO_3$
11	$CaHCO_3$	$MgHCO_3$	$MgHCO_3$	$CaHCO_3$
12	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
13	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
14	$NaHCO_3$	$NaHCO_3$	$CaHCO_3$	$NaHCO_3$
15	$CaHCO_3$	$NaHCO_3$	$CaHCO_3$	$CaHCO_3$
16	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
17	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	NaCl
18	$NaHCO_3$	$NaHCO_3$	$CaHCO_3$	$NaHCO_3$
19	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
20	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
21	$NaHCO_3$	$CaHCO_3$	$CaHCO_3$	$CaHCO_3$
22	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
23	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
24	$NaHCO_3$	$NaHCO_3$	$CaHCO_3$	$NaHCO_3$
25	NaCl	NaCl	NaCl	$NaHCO_3$
26	NaCl	NaCl	$NaHCO_3$	$NaHCO_3$
27	NaCl	NaCl	$NaHCO_3$	$NaHCO_3$
28	$NaHCO_3$	$CaCl_2$	$CaHCO_3$	$NaHCO_3$
29	$CaHCO_3$	MgHCO3	$CaHCO_3$	$CaHCO_3$

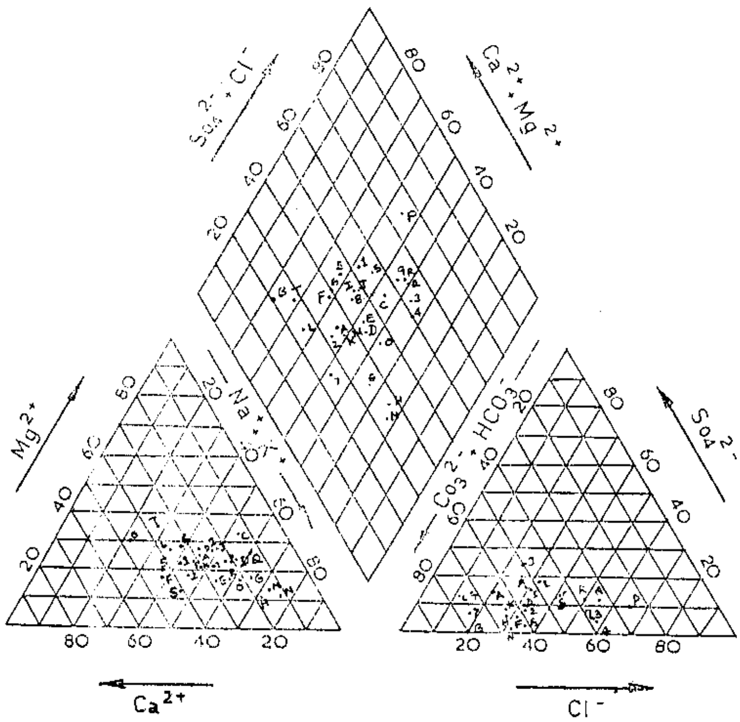


Fig. 13 Pipers Trilinear diagram showing chemical analysis of ground water samples collected during the month of March 96

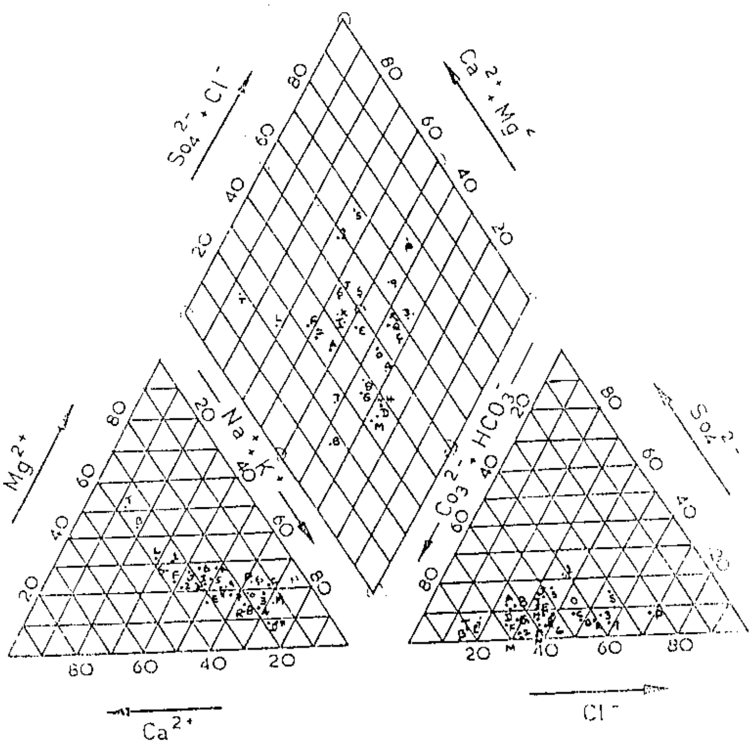


Fig. 14 Pipers Trilinear diagram showing chemical analysis of ground water samples collected during the month of June 96

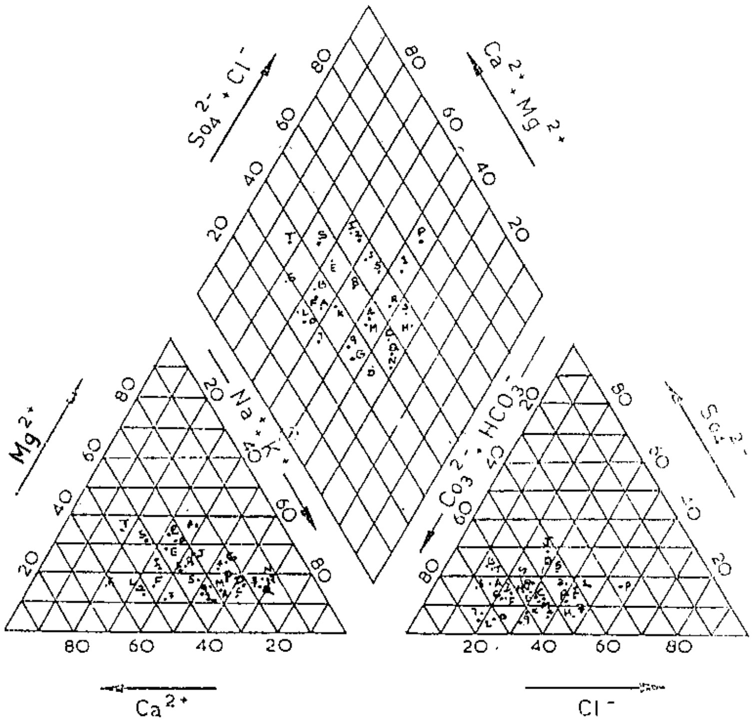


Fig. 15 Pipers Trilinear diagram showing chemical analysis of ground water samples collected during the month of Sept. 96

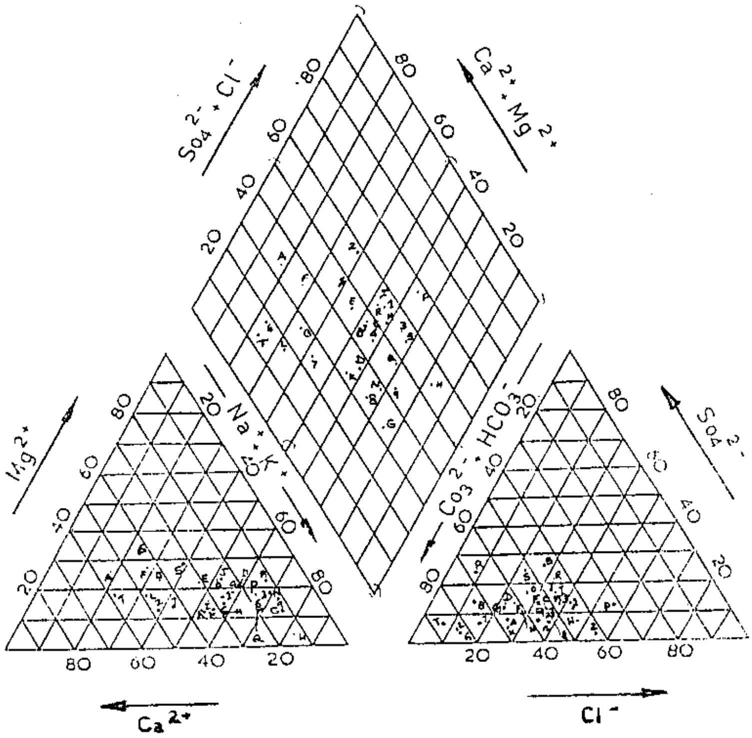


Fig. 16 Pipers Trilinear diagram showing chemical analysis of ground water samples collected during the month of Dec.96

Table No. 8

Pipers Trilinear classification of groundwater samples collected during the year 1996

Well No. (LABLE)	HYDROCHEMICAL FACIES March 96	June 96	Sept. 96	Dec.96
1	I	I	II	II
2	IV	IV	I	IV
3	II	II	II	II
4	II	III	III	III
5	IV	I	I	II
6	IV	IV	IV	IV
7	III	III	IV	IV
8	IV	III	IV	III
9	II	II	II	III
10(A)	IV	IV	IV	IV
11(B)	IV	III	IV	IV
12(C)	II	II	III	III
13(D)	III	III	III	III
14(E)	III	III	IV	IV
15(F)	IV	IV	IV	IV
16(G)	III	III	III	III
17(H)	III	III	II	II
18(I)	IV	IV	I	II
19(J)	IV	IV	I	III
20(K)	IV	IV	IV	III
21(L)	IV	IV	IV	IV
22(M)	IV	III	III	II
23(N)	III	III	III	III
24(O)	III	III	IV	III
25(P)	I	II	II	II
26(Q)	II	II	III	III
27(R)	II	II	II	II
28(S)	I	I	IV	IV
29(T)	IV	IV	IV	IV

I = Ca + Mg + Cl + So_4 ; II = Na + K + Cl + So_4 ; III = Na + K + Co_3 + HCO_3 ; IV = Ca + Mg + Co_3 + HCO_3

4.3.3 U S Salinity Laboratory Classification:

The sodium adsorption ratio and electrical conductivity values of each well were plotted on Wilcox diagrams for obtaining the classification of water for irrigation purposes. The classification of each sample collected during the month of March 96, June 96, Sep. 96 and Dec. 96 are given in the Table 9. Mainly five types of waters have been observed in the study area. These types are classified (U S Salinity Laboratory classification) as follows:

C1 - S1 = Low salinity and low SAR

C2 - S1 = Moderate salinity and low SAR

C3 - S1 = Medium high salinity and low SAR

C4 - S2 = Very high salinity and Medium SAR

C4 - S1 = High salinity and low SAR

C1 - S1, C2 -S1, C3 - S1 and C4 - S1 are good waters for irrigation purposes and C4 - S2 moderate water for irrigation purposes. SAR as an index for Sodium hazard (S) and EC as an index of Salinity hazard (C). From the Table 9 it is observed that the influence of season on SAR was negligible in the study area. However the salinity values in the groundwater is being changed with respect to the seasons. Few wells located near marshy land, saltcreek, Kakinada lock have showed same type of water during the study period.

4.3.4 Hydrochemical ratios in the study area

Ratios of Mg/Cl, Cl/HCO_3 and Mg/Ca were calculated for each well during the study period and presented in the Table 10. The variations in these ratios during the study period are shown in Fig. 17.

In general Mg/Cl ratio more than 1 in shallow groundwater indicates mixing up of freshwater with saline water in the deltaic region. The range of Mg/Cl ratio in the study area during the month of March 96, June 96, Sep. 96 and Dec. 96 were 0.31 to 2.45, 0.28 to 3.53, 0.23 to 2.72 and 0.06 to 3.11 respectively.

High Cl/HCO_3 values indicate brackish water near to the coast and further indicates sea water contamination due to low level groundwater table conditions in the area. The

Table No. 9

U.S.Salinity Laboratory Classification of groundwater Samples collected during the year 1996

Well No.	March 96	June 96	September 96	December 96
1	C3-S1	C3-S1	C3-S1	C3-S1
2	C2-S1	C2-S1	C3-S1	C3-S1
3	C4-S1	C4-S1	C4-S1	C4-S1
4	C3-S1	C3-S1	C3-S1	C3-S1
5	C3-S1	C3-S1	C3-S1	C3-S1
6	C3-S1	C3-S1	C2-S1	C2-S1
7	C2-S1	C2-S1	C3-S1	C3-S1
8	C2-S1	C3-S1	C3-S1	C2-S1
9	C3-S1	C3-S1	C3-S1	C3-S1
10	C3-S1	C3-S1	C3-S1	C3-S1
11	C2-S1	C1-S1	C2-S1	C2-S1
12	C3-S1	C4-S1	C3-S1	C3-S1
13	C3-S1	C3-S1	C3-S1	C3-S1
14	C3-S1	C3-S1	C3-S1	C3-S1
15	C3-S1	C3-S1	C3-S1	C3-S1
16	C3-S1	C3-S1	C4-S1	C3-S1
17	C3-S1	C3-S1	C3-S1	C4-S2
18	C4-S1	C3-S1	C4-S1	C4-S1
19	C3-S1	C3-S1	C3-S1	C3-S1
20	C3-S1	C3-S1	C3-S1	C3-S1
21	C2-S1	C2-S1	C3-S1	C2-S1
22	C4-S1	C3-S1	C4-S1	C4-S1
23	C1-S1	C3-S1	C3-S1	C3-S1
24	C3-S1	C3-S1	C3-S1	C3-S1
25	C4-S1	C4-S1	C4-S1	C4-S1
26	C4-S1	C4-S1	C4-S1	C4-S1
27	C4-S1	C4-S1	C4-S1	C3-S1
28	C3-S1	C3-S1	C3-S1	C3-S1
29	C2-S1	C2-S1	C3-S1	C2-S1

Table No. 10

Hydrochemical ratios during the year 1996

	March 96			June 96			Sep.96			Dec.96		
Well No.	Mg/Cl	Cl/HCO_3	Mg/Ca	Mg/Cl	Cl/HCO_3	Mg/Ca	Mg/Cl	Cl/HCO_3	Mg/Ca	Mg/Cl	Cl/HCO_3	Mg/Ca
1	0.94	0.68	0.68	1.15	0.90	0.86	0.27	1.35	0.34	0.37	0.98	0.59
2	0.57	0.66	0.49	0.61	0.51	0.55	0.26	1.11	0.27	0.24	1.37	0.22
3	0.38	1.56	0.85	0.46	1.40	1.58	0.31	0.95	0.78	0.38	0.92	0.99
4	0.31	0.64	0.46	0.40	0.63	0.70	0.44	0.69	0.79	0.44	0.72	0.79
5	0.64	0.59	0.49	1.02	0.72	0.89	0.54	0.81	0.57	0.36	0.62	0.62
6	0.87	0.60	0.84	0.77	0.68	0.99	1.08	0.17	0.28	2.65	0.15	0.74
7	1.41	0.24	0.76	1.04	0.24	0.77	0.49	0.26	0.24	1.09	0.25	0.37
8	0.84	0.53	0.81	0.73	0.44	0.74	0.70	0.55	0.69	1.45	0.14	0.49
9	0.46	1.52	1.02	0.37	1.58	0.91	0.41	0.46	0.38	0.17	0.59	0.39
10	1.35	0.30	0.86	1.51	0.33	1.11	2.70	0.22	1.58	0.97	0.34	0.49
11	1.41	0.26	0.64	3.43	0.18	1.12	2.72	0.22	1.02	2.52	0.15	0.55
12	0.42	0.91	0.44	0.57	0.90	1.98	0.34	0.67	0.47	0.46	0.60	0.53
13	0.83	0.51	1.15	0.40	0.40	0.46	0.73	0.37	0.80	1.14	0.31	0.99
14	0.65	0.55	0.56	0.57	0.64	0.56	0.87	0.54	0.70	0.60	0.56	0.74
15	0.77	0.51	0.43	0.87	0.37	0.60	0.50	0.37	0.31	1.25	0.42	0.66
16	0.66	0.46	0.99	0.83	0.41	1.54	1.05	0.38	1.05	0.43	0.35	0.99
17	0.40	0.52	0.53	0.28	0.60	0.53	0.31	0.96	1.29	0.06	1.04	0.33
18	0.76	0.79	0.96	0.81	0.67	0.75	0.52	0.97	0.57	0.51	0.72	0.54
19	1.11	0.52	0.87	1.13	0.58	0.91	0.80	0.66	0.90	0.72	0.65	0.90
20	1.13	0.43	0.74	0.71	0.61	0.77	0.69	0.50	0.54	0.71	0.37	0.51
21	2.62	0.15	0.69	2.24	0.22	0.77	0.94	0.24	0.33	2.17	0.14	0.39
22	0.49	0.43	0.91	0.65	0.45	1.22	0.46	0.55	0.53	0.22	0.75	0.36
23	0.36	0.49	1.19	0.48	0.63	1.69	0.65	0.49	1.66	0.58	0.46	1.51
24	0.53	0.64	0.79	0.56	0.67	0.99	1.41	0.28	0.85	0.72	0.52	0.94
25	0.40	2.51	0.66	0.35	2.77	0.81	0.23	1.98	0.66	0.31	1.69	1.08
26	0.56	1.50	1.44	0.57	1.13	1.67	0.49	0.68	1.03	0.36	0.56	0.57
27	0.32	1.34	0.59	0.33	1.28	0.72	0.31	0.90	0.52	0.46	0.76	0.38
28	0.39	0.87	0.31	0.72	1.72	0.77	1.24	0.54	0.78	1.30	0.47	0.99
29	2.45	0.19	0.89	3.53	0.19	1.38	2.36	0.20	0.74	3.11	0.07	0.32

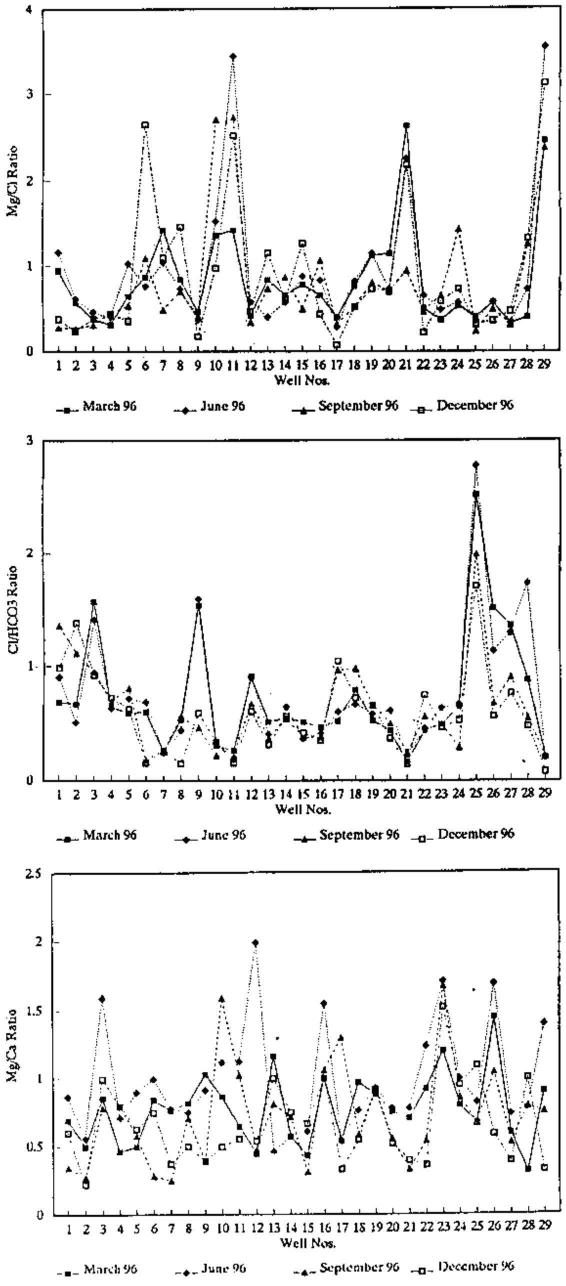


Fig. 14 Distribution of Hydrochemical ratios

range of Cl/HCO$_3$ values in the study area during the month of March 96, June 96, Sep. 96 and Dec. 96 were 0.15 to 2.51, 0.18 to 2.77, 0.17 to 1.98 and 0.07 to 1.69 respectively.

Mg/Ca ratio used for diagnostic characteristics for geochemical environment of the groundwater. The low values (< 1) indicates recharge areas, when calcite-dolomite solution equilibrium reached, in ocean water the Mg/Ca ratios is 5.2. The range of Mg/Ca values in the study area during the month of March 96, June 96, Sept. 96 and Dec. 96 were 0.31 to 1.44, 0.46 to 1.69, 0.24 to 1.66 and 0.22 to 1.51 respectively.

The variation in above hydrochemical ratios at different distances from the sea are shown in Fig. 18(a), 18(b) and 18(c) respectively.

From the Figure 18 (a) it has been noted that the mixing in groundwater was more (high values of Mg/Cl ratio) in well no. 29 and less in well no. 22 which is located near to sea coast. Further the ratio of Mg/Cl during pre-monsoon (June 96) period is greater than in post monsoon period (Sept.96). Thus indicates the mixing of groundwater from one season to other season.

From the Figure 18(b) it has been observed that the Cl/HCO$_3$ values were decreasing from the sea coast. Thus indicated that the concentration of brackishwater was more nearby sea coast. The Cl/HCO$_3$ ratio values in the study area shows less than one during the study period. Thus indicates the contamination due to the sea water in shallow groundwater table is almost negligible in the study area.

From the Figure 18(c) it has been observed that there was no specific trend of Mg/Ca ratio as increasing the distance from the sea coast. In general Mg/Ca ratio used for diagnostic characteristics of geochemical environment of the groundwater. When Calcite and Dolamite equilibrium reached in sea water the ratio of Mg/Ca is 5.2

4.3.5 SAR and % Na variations

The SAR and % Na values of each well during the study period are given in Table 11. The range of Sodium Adsorption Ratio during March 96, June 96, Sep. 96 and Dec. 96 are 0.2 to 10.4, 0.2 to 8.9, 0.4 to 6.7 and 0.5 to 13.4 respectively. Similarly the range of

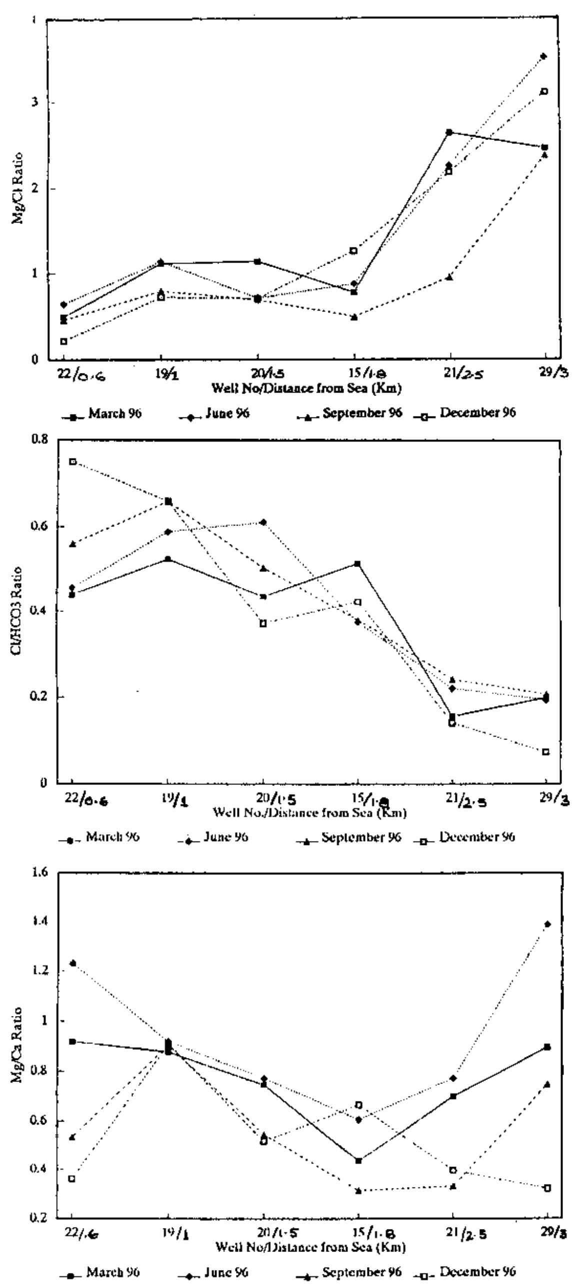


Fig. 18 Variation of Hydrochemical ratios from sea

Table No. 11

Variations in Sodium Absorption Ratio and percentage of Sodium during the year 1996

	March 96		June 96		Sep. 96		Dec.96	
Well No.	SAR	%Na	SAR	%Na	SAR	%Na	SAR	%Na
1	2.0	41.5	2.1	34.5	3.3	57.1	2.3	53.3
2	2.0	48.1	1.5	42.1	2.0	35.9	2.5	39.2
3.	7.7	64.5	8.4	67.9	6.1	66.3	5.7	64.2
4	7.4	68.7	6.8	68.2	3.9	52.8	4.5	56.1
5	2.0	39.5	2.2	49.8	1.9	46.2	3.4	69.1
6	2.6	39.3	3.1	42.5	0.6	20.7	0.9	25.4
7	2.7	52.4	2.1	56.0	2.1	42.8	2.3	41.7
8	3.3	47.3	4.7	60.2	2.8	41.8	5.5	66.7
9	4.6	53.9	4.7	55.2	2.9	53.1	5.3	73.0
10	3.8	45.9	4.1	48.4	2.3	37.4	0.5	18.9
11	0.2	21.6	0.1	19.2	0.7	31.6	1.1	33.8
12	5.5	55.8	8.7	67.6	6.3	63.0	4.8	56.5
13	2.7	58.2	3.8	71.2	3.5	62.6	3.0	59.1
14	4.2	53.4	3.5	50.3	1.8	32.1	2.7	47.5
15	1.6	39.8	1.6	39.0	1.3	35.9	1.0	26.8
16	6.4	64.1	6.0	64.6	3.0	52.0	7.7	76.5
17	6.8	71.0	6.9	72.8	6.7	66.2	13.4	83.4
18	2.3	45.2	2.6	48.0	1.8	36.3	3.9	51.0
19	3.4	47.6	2.2	40.1	2.3	42.1	3.7	52.2
20	2.6	48.9	2.0	45.7	1.5	41.0	2.4	50.6
21	1.3	37.2	1.1	28.9	1.4	32.0	1.2	31.3
22	10.4	73.1	8.9	71.8	4.3	50.8	5.1	58.6
23	9.6	77.9	8.2	71.8	6.1	68.3	5.9	68.9
24	3.1	61.0	2.9	60.2	0.7	32.8	1.8	50.6
25	4.9	46.0	5.5	53.2	5.5	56.1	7.1	63.4
26	7.2	59.1	8.1	63.6	6.8	64.7	7.2	69.8
27	7.1	61.5	7.5	65.0	4.8	55.1	4.3	53.0
28	2.8	47.2	1.2	34.8	0.9	27.6	1.6	39.8
29	0.8	29.0	0.2	12.4	0.4	16.8	0.6	21.6

percentage of Sodium in the above months are 21 to 77, 12 to 72, 16 to 68 and 19 to 83 respectively. The Sodium hazard in water samples based on SAR values are as follows:

SAR Range	Remarks
2-10	little danger from sodium
7-18	medium hazards
11-26	high hazards
>26	Very high hazards

The study area falls under the medium hazard of the sodium except wells located at saltcreek.

4.3.6 Comparison of water quality parameters with drinking water standards

The detailed comparison of chemical parameters with WHO (1984) and ISI (1983) drinking water standards is given in Table 12. Wells which are exceeded the maximum permissible limits requires appropriate precautions to avoid its impact on the human health. Further detailed investigation are to be initiated to find the sources of nitrate pollution in the study area.

Table No. 12

Comparison of chemical parameters with WHO (1984) and ISI(1983) drinking water standards during the year 1996

Parameters	Range in the study area	WHO(1984)	ISI(1983) Highest desirable	ISI(1983) Maximum Permissible	Well No. exceeded the ISI Maximum Pemissible Limits
EC (mohs/cm)	250 - 3900	1400	-	-	-
pH	6.1 - 8.3	6.5 - 8.5	7.0 - 8.5	6.5 - 9.2	-
Temparature(° C)	20 - 27	-	-	-	-
TDS	160 - 2500	1000	500	1500	3, 12, 16, 17, 18, 25, 26, 27
Ca^{2+}	24 - 216	500	75	200	25
Mg^{2+}	10 - 140	-	30	100	26, 3
Na^{+}	34 - 525	200	-	-	-
K^{+}	3 - 313	-	-	-	-
HCO^{-}_{3}	80 - 872	-	300	600	3, 10, 12, 16, 17, 22, 23, 24, 26, 27
SO^{2-}_{4}	0 - 325	400	150	400	-
NO^{-}_{3}	0 - 268	-	45	45	1, 3, 5, 12, 13, 14, 16, 18 19, 20, 21, 22 25, 26, 27, 28 29
PO^{3-}_{4}	0 - 12	-	-	-	-
Cl^{-}	10 - 726	250	250	1000	-

Units = mgl^{-1}

5.0 CONCLUSIONS

Groundwater levels measured in all observation wells were connected to the Mean Sea level.

The trends in rainfall pattern and groundwater level fluctuations are similar in the sudy area. Thus, indicates the major recharge of groundwater is from rainfall.

The average reduced groundwater table in the study area during pre-monsoon (June 96) and post-monsoon (Sep.96) periods are 1.464 and 2.892 mts respectively.

The flow of groundwater is controlled by the drainage of the area and subdued replica of surface topography except at well No. 5. More studies are necessary to confirm groundwater divide line in the study area. The direction of groundwater flow is perpendicular to the sea coast.

The concentration of TDS, Cl, Na, and HCO_3 are increasing towards sea coast. Thus, confirms the influence of sea on shallow groundwater in the study area. However, the concentration of Ca, Mg, SO_4 and NO_3 were not followed any trend in the study area. The sources of these parameters are different at each well. According to hardness classification the study area falls under hard to very hard zone. Precautions are necessary to eliminate temporary hardness when the water is using for drinking water purposes.

Stiff classification of groundwater samples collected during the study period shows the mixing of shallow groundwater in the study area.

Four hydrochemical facies inferred from Piper's trilinear diagrams of groundwater samples collected during the study period. They are (I) Ca + Mg + Cl + SO_4, (II) Na + K + Cl + SO_4, (III) Na + K + CO_3 + HCO_3 and (IV) Ca + Mg + CO_3 + HCO_3. These facies are not maintained same type throughout the year. Detailed studies are necessary to identify the reasons for change in hydrochemical facies in the study area.

U S Salinity laboratory classification shows that the groundwater in the study area is suitable for irrigation purposes.

The hydrochemical ratios of Mg/Cl, Cl/HCO_3, Mg/Ca are less than 3.11, 2.77 and 1.69 respectively in the study area. Low values of Mg/Cl observed near to the sea coast. Thus indicates stagnate water near coast. The high ratio of Cl/HCO_3 nearby sea coast indicates the brackish water presence in the groundwater. Mg/Ca ratio used for diagnostic characteristics of geochemical environment of the groundwater. Low values of Mg/Ca indicated that Calcite and Dolamite equilibrium not reached in the study area.

The analysis of SAR and %Na indicated that the study area falls under the medium hazard of sodium except nearby saltcreek area.

The comparison of groundwater quality parameters with WHO(1984) and ISI(1983) drinking water standards indicated that TDS, HCO_3, and NO_3 contents are exceeded the maximum desirable limits. Hence approximate precautions are necessary to avoid its impact on the human health. Further detailed investigations are to be initiated to find the sources of Nitrate pollution in the study area.

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