CS(AR)-14/98-99

SPATIAL EVALUATION OF GROUNDWATER LEVELS AND ITS QUALITY IN KAKINADA TOWN, ANDHRA PRADESH

आपो हि ष्ठा मयोभुव

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1998-99

PREFACE

Groundwater is a hidden part of the hydrological cycle, main characteristics are ground water level and quality, which need to be monitored properly in order to understand geohydrological processes. Without sufficient data and knowledge it is impossible to manage and protect groundwater resources scientifically. One of the tools for monitoring the water levels is through monitoring wells(Hydrograph stations) which plays an important role in unraveling the secrets of the groundwater regime. They provide relevant data on groundwater levels and water quality, used to analyse the groundwater flow and solute transport processes in an area. The primary objective of the groundwater monitoring is to record the response of groundwater regime to the natural and artificial conditions of recharge and discharge.

Therefore, keeping in view the importance, the Deltaic Regional Centre of NIH, Kakinada had been started the monitoring of groundwater levels and its quality since 1994. As a part of the work programme of DRC for the year 1998-99 the study entitled ' ***Spatial evaluation of groundwater levels and its quality in Kakinada town, Andhra Pradesh*** ' has been carried out by Sri Y Ramji Satyaji Rao, Scientist 'C' and assisted by Sri T Vijaya, Sr. R.A and Sri D. Mohan Rangan, Technician under the guidance of Dr. K.S Ramasastri, Scientist 'F' and Co ordinator. The report is reviewed by Sri N.C Ghosh, Scientist 'E'.

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ABSTRACT

The Deltaic Regional Centre of NIH has been monitoring groundwater levels and its quality in and around Kakinada town since 1994. In continuation of this program the spatial analysis of groundwater levels and its quality for the year 1998 is discussed in the report.

Total 164 groundwater samples were collected from 41 observation wells during the months of Feb.98, May 98, Aug.98 and Nov.98. The area covered by these observation wells is around 82 Sq.kms. The groundwater table contours were plotted for pre monsoon (May 98) and post monsoon (Nov. 98) periods and the approximate flow direction had been demarcated.

Groundwater samples have been analysed for physical and chemical parameters. The variation in each parameter is discussed in the report. Further, samples have been classified according to Stiff, Piper's and U.S. Salinity laboratory classifications and observed their seasonal changes. The groundwater quality parameters are also compared with WHO (1984) and ISI (1983) drinking water standards. The groundwater quality maps of TDS, Total hardness, Chloride and SAR have been prepared for pre monsoon (May 98) and post monsoon (Nov.98) periods and observed the change in spatial distribution. More studies are necessary to understand the vertical variation of groundwater quality in the study area.

1.0 INTRODUCTION

All over the world during the past 25-50 years, there has been a massive anthropogenic change in the hydrological cycle, affecting water quality as well as global water budget. The extent of water resources, their spatial and temporal distribution are determined not only by natural climate variations but also by man's economic activities. In many parts of the world, water resources have become so depleted and much contaminated that they are already unable to meet the ever increasing demands made on them. This has become the main factor impending economic development and population growth. In India, groundwater resources play a key role in meeting the water needs of various sectors. The contribution of groundwater to irrigated agriculture is about 50% and it meets a major part of drinking and industrial needs (Prasad, 1995). It shall continue to play a key role in meeting the water needs of irrigated agriculture and related fields in a big way in the next millenium also. Given the greater convenience and reliability of groundwater and continuous technology development in water i.e well drilling and pumping devices, it is expected that there is going to be a much greater emphasis on groundwater development and utilization of this natural resource.

The science of groundwater sampling has advanced greatly in recent years, not only in our understanding of the techniques to be used but also in the development of materials and equipment used in sampling process. The first step in designing a ground water monitoring programme is to determine the purpose. There are atleast four major reasons to monitor groundwater. They are to determine the water quality and chemistry of a specific water-supply well or well field, to determine the extent of groundwater contamination from a known source and to monitor a potential source of contamination to determine the extent of ground-water contamination from known source, and to monitor a potential source of contamination to determine if the groundwater becomes contaminated. If the water quality of potential well site is being investigated, nearby wells may be sampled to establish regional water quality. In most cases it is desirable to construct a test well before a permanent well is installed. Handa (1986 a, b) studied the hydrogeochemical zones in a few places in India and indicated that the chemical composition of groundwater was affected by the land use practices. A similar situation has been reported in most of the metropoliton cities with growing urban centers(Kakar, 1988). The status of groundwater levels and its quality for the years 1995 and 1996 have been discussed by Satyaji Rao, Y.R et al (1996, 97). Some preliminary analysis on groundwater quality in Kakinda town is reported by Murali Krishna et al(1992).

1.1 Scope and Objectives of the study

Regional variations in groundwater quality can be determined by sampling water from wells drilled at sites intended to give representative coverage of the various conditions of occurrence. Partial analysis to determine the concentrations of the principal chemical constituents in a water may provide sufficient data for many investigations. Especially in urban areas increase in demand creates the high potential requirement with possibility of pollution of groundwater. Pollution of groundwater through tube wells which create suction of filthy surface water into the aquifer (Sharma, 1991). Thus constant monitoring of groundwater levels and its quality especially in coastal areas is needed so as to record any alteration in the quality and out break of health disorders. In this connections the Deltaic Regional Centre of NIH, has been monitoring groundwater levels and its quality in and around Kakinada since 1994. In this report the spatial distribution of groundwater levels and its quality for the year 1998 is discussed.

Objectives of the study

1. Analysis of Monthly groundwater levels in the study area and demarcation of Groundwater flow directions.
2. Physical and chemical analysis of ground water samples collected in the month of Feb.98, May 98, Aug.98 and Nov.98.
3. Spatial distribution of TDS, Cl, Hardness, SAR in the study area.
4. Classification of groundwater samples and its seasonal changes.
    - Stiff classification
    - Piper's trilinear classification
    - US salinity laboratory classification
    - Total Hardness Classification
    - SAR and % Na variations.
5. Comparison of groundwater quality parameters with WHO (1984) and ISI (1983) drinking water standards
6. Groundwater Quality maps

2.0 STUDY AREA

2.1 Location

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} 55' E to 17 ^{0} 5' E longitude. The area under the study is 82 Sq.km. The location of the study area is shown in Fig.1 . The Kakinada port is being upgraded as a major port on the east coast and is aiding in accelerating the industrialization in the town and thus creating dense population in the town and makes more stress on natural resources.

2.2 Hydrogeology

Kakinada township is coastal plain composed of fine sand, silt and clay in different proportions. These coastal plains are mainly of marine origin as it comprises of low beach ridges which were leveled, strandlines, mud flats, marshy areas and the present narrow beach zone. In the younger coastal area along the beach ridges and strand lines, groundwater can be explored down to 2 to 3 mt. by means of small diameter ring wells. Where as in older coastal plain areas ring wells or filter point wells can be constructed down upto 8 mt. Beach ridges and strand lines are suitable for groundwater usages. They render fresh groundwater, which occurs as a thin layer floating over the brackish water and water table conditions. While the areas of mud land and marshy areas are not suitable for groundwater utilization and they contain brackish water from top zone itself.

The average depth of groundwater table varies between 0.6 m to 3.5 m from ground level in the study area. The general groundwater quality in Kakinada varies potable to saline. The details of Geology and land use/cover is discussed by Satyaji Rao, Y .R et al (1997).

2.3 Climate

Kakinada coast is under tropical climate and frequently effected by cyclonic storms and depressions in Bay of Bengal. The city is very warm in April to June with a maximum temparature of 40^{0} C and winter months are December to January having minimum temperature 20^{0} C. The average monthly minimum and maximum temperatures, evaporation and humidity measured at Hydrometeorological observatory of Deltaic Regional Centre, NIH, Kakinada for the year 1998 is presented in the following Table 1.

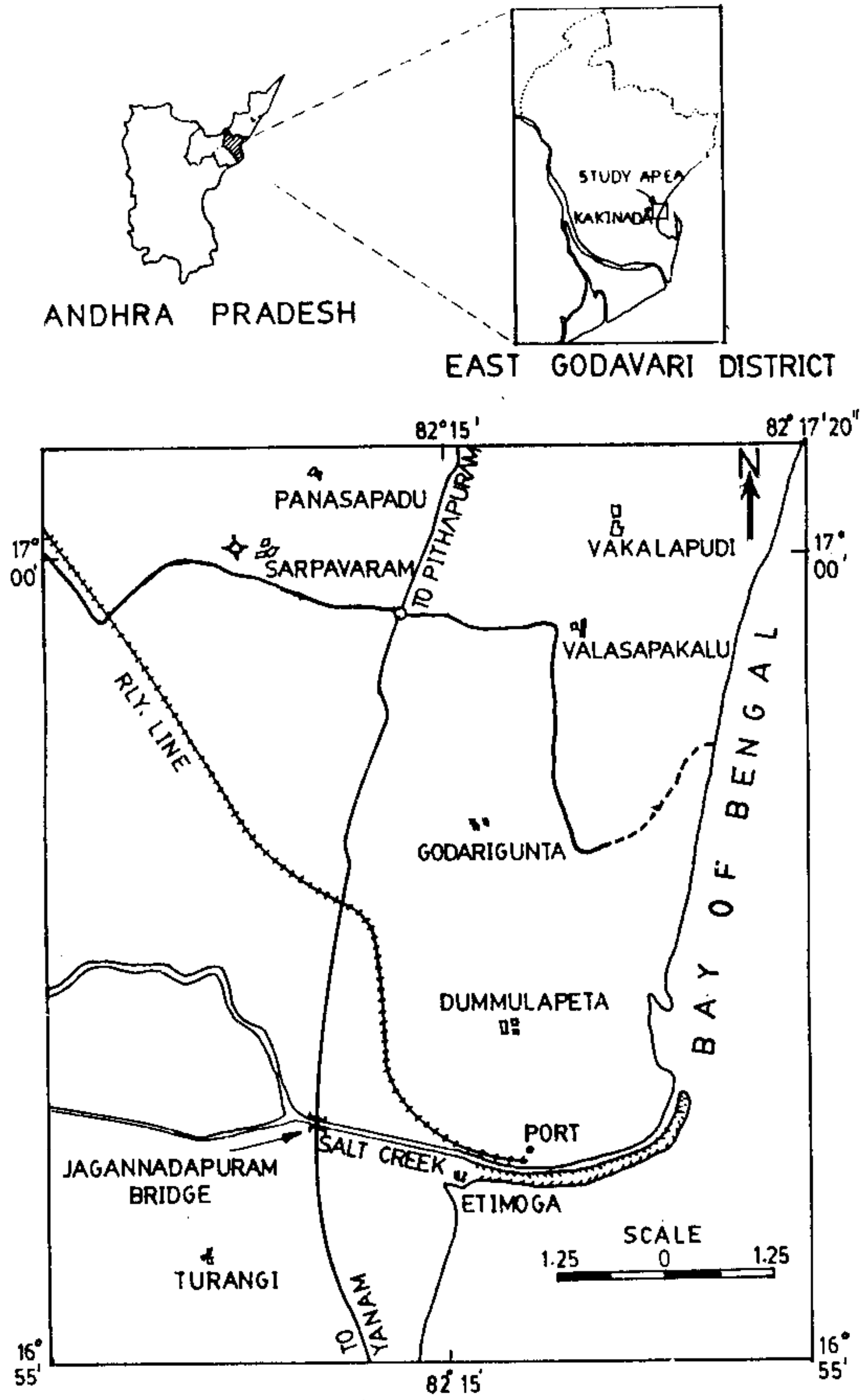


Fig 1 Location of the Study area

Table No.1 Climate data of the study area during the year 1998

	Months											
Parameter	**Jan.**	**Feb.**	**March**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Average Maximum Temp ° C	29.4	30.6	33.2	35.8	40.1	37.2	31.6	31.4	31.8	31.5	30.8	28.6
Average Minimum Temp ° C	21.4	21.1	24.2	25.6	30.4	27.8	26.5	24.9	25.2	23.8	22.8	18.3
Average Evaporation (mm/day)	3.1	3.9	5.6	6.2	7.3	5.7	2.4	2.7	2.9	2.8	3.1	2.9
Average Relative Humidity (%)	89	86	85	84	75	81	92	98	92	91	85	79
Total Rainfall (mm)	11	18	0	8	12	101	172	388	450	370	193	0
Normal Rainfall (mm)	8	9	12	20	42	122	191	145	152	238	141	17

Source: Hydrometeorological Observatory of DRC, National Institute of Hydrology, Kakinada.

3.0 METHODOLOGY

3.1 Monitoring of GroundWater Table

Groundwater is immensely important for human water supply in both the urban and rural areas of developing nations. Innumerable large towns and many new mega cities of these continents derive a major component of their domestic and industrial water supply from aquifers, both by municipal well fields and by very large number of private boreholes. In those parts of the tropics with a pronounced dry season or more generally arid climate, groundwater is also widely used as a source of primary or supplementary irrigation in agriculture development. Especially in coastal aquifers the fluctuation of groundwater table is to be kept always under safe zone to protect the saline water intrusion. In this connection a network of 29 shallow observation wells were selected to monitor the groundwater table fluctuation in the town since 1994 by DRC of NIH, Kakinada . However, to cover more area the present network of observations wells (29 Nos) has been increased upto 41. The area under the study is 82 sq. kms. The temporal and spatial variations of these water levels describe the hydrologic conditions in the study area. The monthly average ground water table during the year 1998 (Jan - Dec) is calculated by Isohytal method and the same had been compared with monthly rainfall in the study area. Further, the topographical contours of the study area and groundwater table contours during pre monsoon (May 98) and post monsoon (Nov.98) periods are prepared. Thus, the groundwater flow direction in the study area is demarcated.

3.2 Monitoring of Groundwater Quality

In formulating an effective plan for control and maintenance of groundwater quality, full consideration must be given to geology, hydrology and cultural development within the area of the groundwater reservoir. A comprehensive investigational program for evaluation of these factors is essential. Groundwater should be sampled regularly on continuing basis. Sampling points should include shallow and deep wells, selected with due consideration to area distribution, geologic and hydrologic influences, pattern of pumpage, and waste disposal practices. Samples should be obtained when water levels are their lowest and also if possible, during the period of replenishment when water levels are high. In areas vulnarable to sea water intrusion, particular attention should be given to observe change in chloride concentration. Keeping the importance of groundwater quality in the town, the monitoring of groundwater quality in and around Kakinada had been started since 1994 with 29 observation wells. Now the observation well network had been increased from 29 to 41 wells, covering the area of 82 sq.kms. The location of these observation wells are shown in Fig 2.

3.2.1. Groundwater sampling

To study the spatial distribution of groundwater quality parameters in Kakinada town, four sampling surveys were conducted in the month of Feb. 1998, May 1998, Aug. 1998 and Nov. 1998. In each survey 41 samples (total 164) were collected and analysed for physical and chemical parameters. The wells from which samples were collected are being extensively used for drinking and other domestic purposes. The physical parameters of pH, temperature and EC values were measured at the time of sample collection and chemical anlaysis (major anions and cations) has been carried out in DRC laboratory. The procedure for physicochemical analysis of samples is adopted from Manual on Physico-chemical anlaysis of water and waste water (Jain C K et. al. 1987) and APHA (1985).

3.2.2. Physical Parameters

Temperature :

Seasonal temperature fluctuations are usually damped out below a depth of 10 to 20 m. Thus, groundwater temperature in this zone will be essentially constant and the same as local mean annual air temperature. Groundwater temperature increase with depth because of the hot interior of the earth. This increase normally is 1 to 5 ^{0}C (average about 2.5 ^{0}C) per 100 m depth increase (White, 1973). However, the present observation well network is limited to very shallow depths (i.e. less than 5 meters from ground level). These temperatures have been measured using microprocessor based thermometers.

pH and Electrical Conductivity:

The measured pH is a very important piece of information in many types of geochemical equilibrium or solubility calculations. Electrical conductance or conductivity, is the ability of a substance to conduct an electric current. Specific electrical conductance is the conductance of a body of unit length and unit cross section at a specified temperature. The specific conductance of the purest water that can be made would approach 0.05 (μmoh/cm), but ordinary single - distilled water or water passed through a deionizing exchange unit normally has a conductance of at least 1.0. Conductivity measurement is commonly used to determine the purity of demineralised water and total dissolved solids in irrigation and domestic waters. The EC values (μmho/cm) of all samples were measured at 25^{0}C with

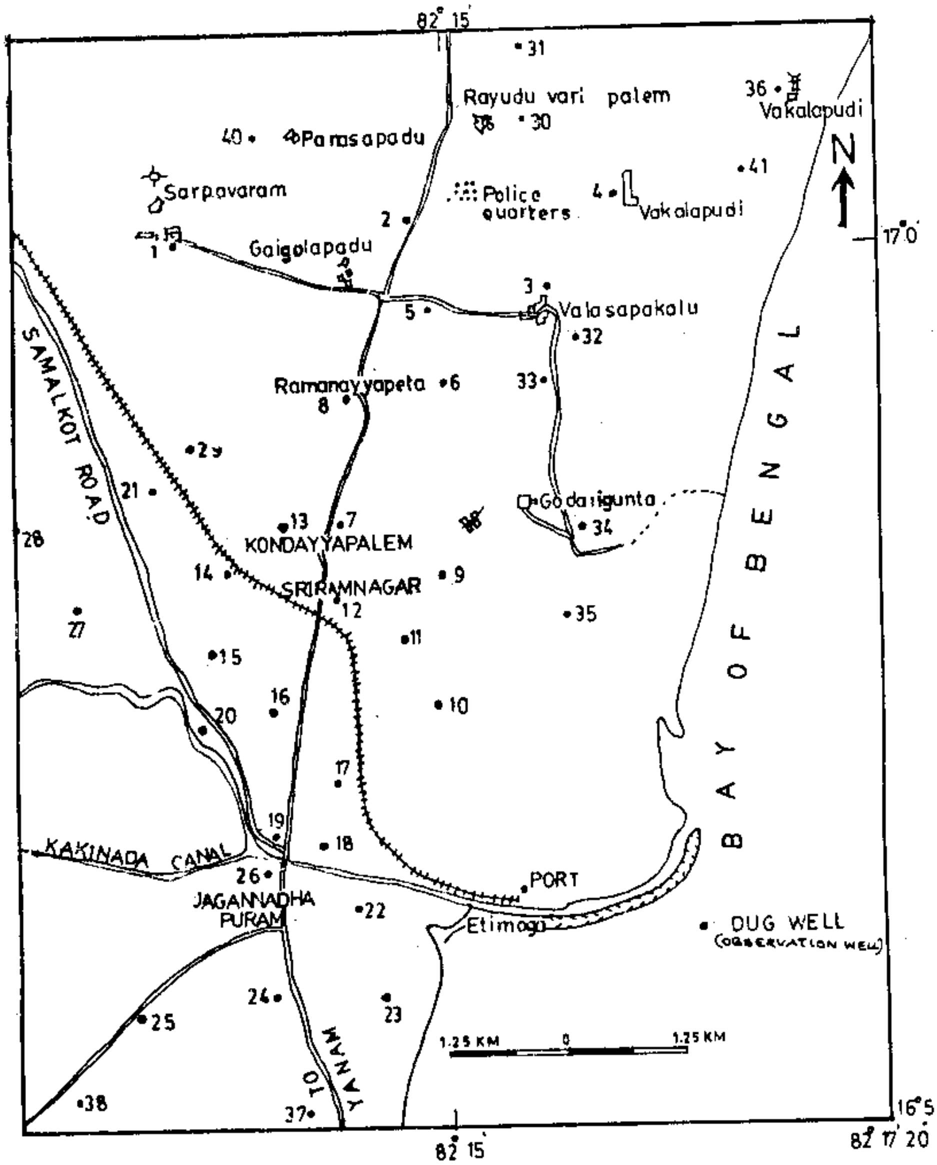


Fig. 2 Location of observation wells in the study area

portable water quality kits. The conductance of surface and groundwaters has a wide range, of course, and in some areas may be as low as 50 (µmho/cm) where precipitation is low in solutes and rocks are resistant to attack. In other areas, conductances of 50,000(µmho/cm) or more may be reached. This is the approximate conductance of seawater.

3.2.3. Chemical parameters

i) Major Anions

Carbonate and Bicarbonate (Total Alkaline):

The properties of alkalinity and acidity are important characteristics of natural and polluted waters and are almost always included in the chemical determinations. The alkalinity of a solution may be defined as the capacity for solutes it contains to react with and neutralize acid. The property of alkalinity must be determined by titration with a strong acid, and the end point of the titration is the pH at which virtually all solutes contributing to alkalinity have reacted.

The principal source of carbon dioxide species that produce alkalinity in surface or groundwater is the CO_2 gas fraction of the atmosphere or the atmospheric gases present in the soil or in the unsaturated zone lying between the surface of the land and the water table. Soils of humid, temperate regions may become depleted in calcium carbonate by leaching and the pH of groundwater at shallow depths may be rather low. The soil minerals in such areas may absorb H+, which could be released from time to time by addition of soil amendments or by other changes in chemical environmental to reinforce the hydrogen-ion content of groundwater recharge. The carbonate and bicarbonate contents in the samples are calculated by standard titrimetric methods using Phenopthalein and methyl orange as indicators.

Chloride:

The most common type of water in which chloride is the dominant anion is one in which sodium is the predominant cation. Waters of this type range from dilute solutions influential by rainfall near the ocean to brines near saturation with respect to sodium chloride. Seawater normally has a chloride concentration near 19,000 mg/l, but where mixing is impaired, higher or lower values may be observed. The determination of chloride is commonly assumed to be one of the simplest and most dependable procedures in water analysis. However, a commonly used procedure is the Mohr titration, which uses a standard silver nitrate solution with chromate as indicator.

Sulphate:

Sulfur is essential in the the process of plants and animals. The environmental aspects of sulfur have been reviewed by Nriagu (1978). Sulfur is widely distributed in reduced form in both igneous and sedimentary rocks as metallic sulfides. When sulfide minerals undergo weathering in contact with aerated water, the sulfur is oxidized to yield sulfate ions that go into solution in the water. The sulphate content in the samples collected in the study area is measured by gravimetric method.

Phosphate:

Phosphate is a rather common element in igneous rock. It is also fairly abundant in sediments, but concentrations present in solution in natural water are normally no more than a few tenths of a milligram per liter. The phosphate content is measured by spectrophoto meter method.

ii) Major cations

Calcium and Magnesium :

Calcium is an essential constituent of many igneous rock minerals, especially of the chain silicates pyroxent and amphibole, and the feldspars. Magnesium is a common element and is essential in plant and animal nutrition. In some aspects of water chemistry, calcium and magnesium may be considered as having similar effects as in their contributions to the property of Hardness. However, is substantially different from that of calcium. Magnesium ions are smaller than sodium or calcium ions. The Calcium and Magnesium contents in the samples are determined using titrimetric methods.

Sodium and Potassium:

Human activities can have a significant influence on the concentrations of sodium in surfacewater and groundwater. Pumping of groundwater, which alters hydraulic gradients, can induce lateral movement of seawater into fresh water coastal aquifers. The high sodium concentrations that can be reached before any precipitate is formed, the sodium concentrations in natural water can have a very wide range from less than 1 mg/l in rainwater and dilute stream runoff in areas of high rainfall to very high levels in brines associated with evaporite deposits and in brines of closed basins, where more than 100, 1000 mg/l may be present.

In most of freshwater aquifers if the sodium concentration substantially exceeds 10 mg/l the potassium concentrations commonly is half or a tenth that of Sodium.

Concentrations of potassium more than a few tens of mg/l are decidedly crucial except in water having high dissolved solids concentrations or in water from hot springs. The sodium or potassium contents of the samples are determined by Flame Emission method using flame photometer.

3.2.3 Classification of Groundwater Samples

1. Hardness Classification

Hardness of water relates to its reaction with soap to the scale and incrustation 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 $CaCO_3$. This hardness also called total hardness Calcium plus Magnesium hardness and hardness as $CaCO_3$ is calculated by adding the milliequivalents of Ca and Mg per litre and multiplying the sum by 50. Water is classified according to its hardness (mg/l hardness as $CaCO_3$) .

Soft	0 - 75
Moderately hard	75 - 150
Hard	150 - 300
Very hard	> 300

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.

2.Total Dissolved Solids

The total dissolved solids(TDS) content or total salt concentration of groundwater varies from less than 100 to more than 1,00,000 mg/l. The TDS content often is also expressed in terms of electrical conductance of the water normally in milli mhos per centimeter at 25 ^{0} C. The relation between conductance and TDS depends on the particular ions in the solution. For irrigation water and most other natural waters, 1 milli mho customarily is taken as equal to 640 mg/l (Salinity Laboratory, 1954). Groundwater is classified according to its TDS content as (Hem, 1970)

Fresh	< 1000 mg/l
Moderately Saline	3000 - 10000 mg/l
Very Saline	10000 - 35000 mg/l
Brine	> 35000 mg/l

The recommended maximum limit for the TDS content of drinking water is 500 mg/l, but water of double or even triple this concentration is used if no other water is available.

3. 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 of 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 changes in water types.

4. 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 Feb.98, May 98, Aug.98, and Nov.98 are plotted on Piper trilinear diagrams and inferred the hydrochemical facies. The changes in hydrochemical facies are studied with respect to time and space in the study area.

5. US Salinity Laboratory Classification

The suitability of groundwater of irrigation has been studied for each well by plotting their values of SAR and electrical Conductivity (µ mho/cm) on WILCOX diagrams (1954) and obtained the classification.

C2-S1 Medium salinity low alkali hazard
C3-S1 High salinity low alkali hazard
C3-S2 High salinity medium alkali hazard
C4-S3 Very high salinity high alkali hazard

6. 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 well has been studied in the study area. The following equations are being used to calculated %Na and SAR.

$$\% \text{ Na} = ((\text{Na}^{+} + \text{K}^{+}) / (\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^{+} + \text{K}^{+})) * 100$$

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

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

7. Potability of groundwater

The suitability of groundwater 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.

8. Groundwater quality maps

A useful procedure in the study of water quality data is to enter the information on a map of the area being investigated. A map of this kind is most likely to be useful in the study of groundwater in single, wide spread aquifers, but mapping also may have some value in surface water studies. If a systematic areal distribution of water quality features is observed, correlations with other characteristics of groundwater system can be made. If the map is started early in the investigations of an area and information is added as it is obtained, the areas needing closer field study often can be identified. These maps may help to show areas of recharge and discharge areas, leakage from other aquifer and directions of water movement. For the study area of Kakinada town, a map showing groundwater levels, TDS, total hardness, SAR, and Chloride have been prepared for pre monsoon (May 98)and post monsoon (Nov.98) periods using SURFER package.

4.0 RESULTS AND DISCUSSIONS

4.1 Groundwater table

Monthly groundwater levels have been measured in 41 observation wells in the study area. The average groundwater table in each month of the study area is calculated by isohytal method. The variation in monthly temperature and evaporation is shown in Fig.3(a) and 3(b) respectively. The comparison between monthly rainfall and average groundwater table in the study area is shown in Fig.3.c. It is observed that the change in groundwater table in the study area is mainly due to the rainfall recharge. The topographical contours in the study area at 0.4 m interval is shown in Fig.4. The overall ground slope is towards sea and steep slope has been observed into the salt creek which is acting as major drain in the study area. The spatial distribution of ground water levels during the month of May 98 and Nov. 98 are shown in Fig.5 and Fig.6 respectively. Based on the gradient of groundwater table the approximate flow direction had been demarcated on these maps. The recharge area is identified as a Balaji Nagar (Well No.2) in the study area. More investigations are necessary to confirm the recharge and discharge areas in the study area. It is also observed that the groundwater table gradient is followed by the surface gradient in the study area. Thus confirms the unconfined water table condition in the study area.

4.2 Groundwater quality

Field surveys have been conducted in the month of Feb.98, May 98, Aug. 98 and Nov. 98 to collect groundwater samples from 41 observation wells located all over the town. These samples were analysed for physical parameters (pH, Temperature, Electrical Conductivity) at the time of sample collection. And the same were brought to the DRC, laboratory for chemical analysis. The chemical analysis includes major anions (HCO_3^-, Cl^-, SO_4^- and PO_4^-) and major cations (Ca^+, Mg^+, Na^+, K^+). The physical and chemical parameters of groundwater samples collected in the months of Feb.98, May 98, Aug. 98 and Nov.98 are presented in Table Nos. 2, 3, 4 and 5 respectively. The ion balance of each sample is observed to be less than ± 10 %.

4.2.1 Physical parameters

The pH value in the study area lies in the range of 6.60 to 8.14. The average temperature in the month of Feb.98, May 98, Aug.98 and Nov.98 are 26^0 C, 31.6^0 C, 32.5^0 C

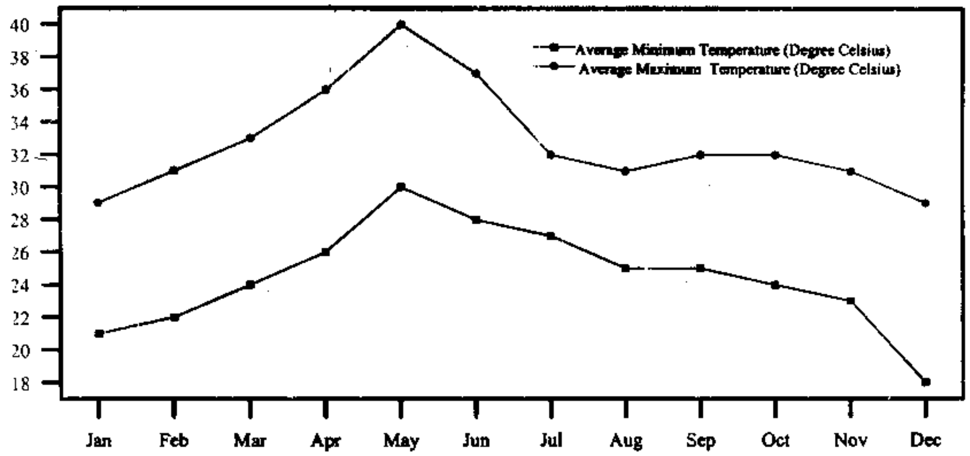


Fig 3.(a)Average monthly maximum and minimum temperature during the year 1998

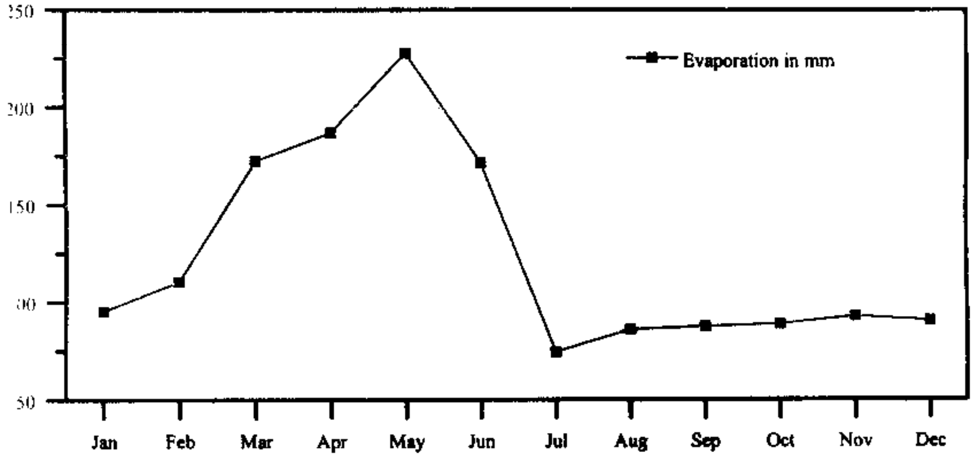


Fig.3(b). Monthly Evaporation during the year 1998

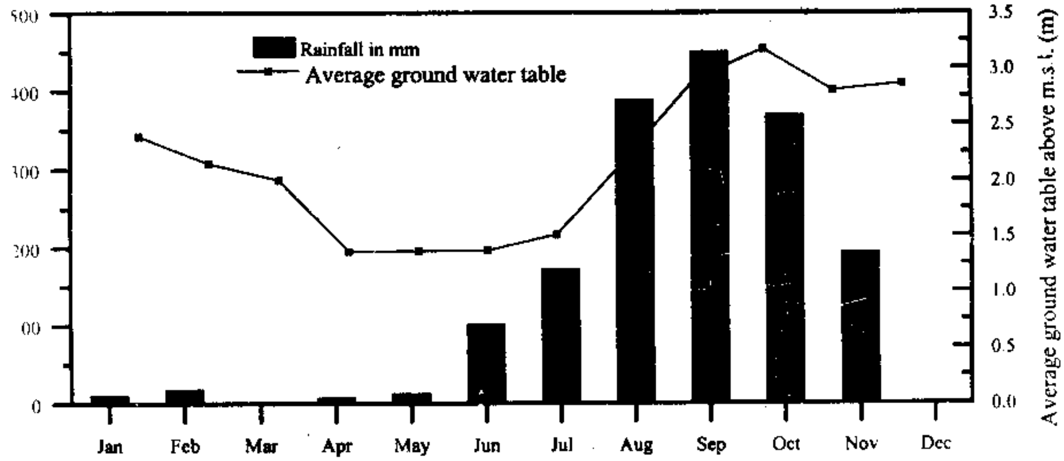


Fig.3(c). Comparison of monthly rainfall and average groundwater table

FIG. 4 TOPOGRAPHICAL CONTOURS(ABOVE MSL IN MTS) IN THE STUDY AREA

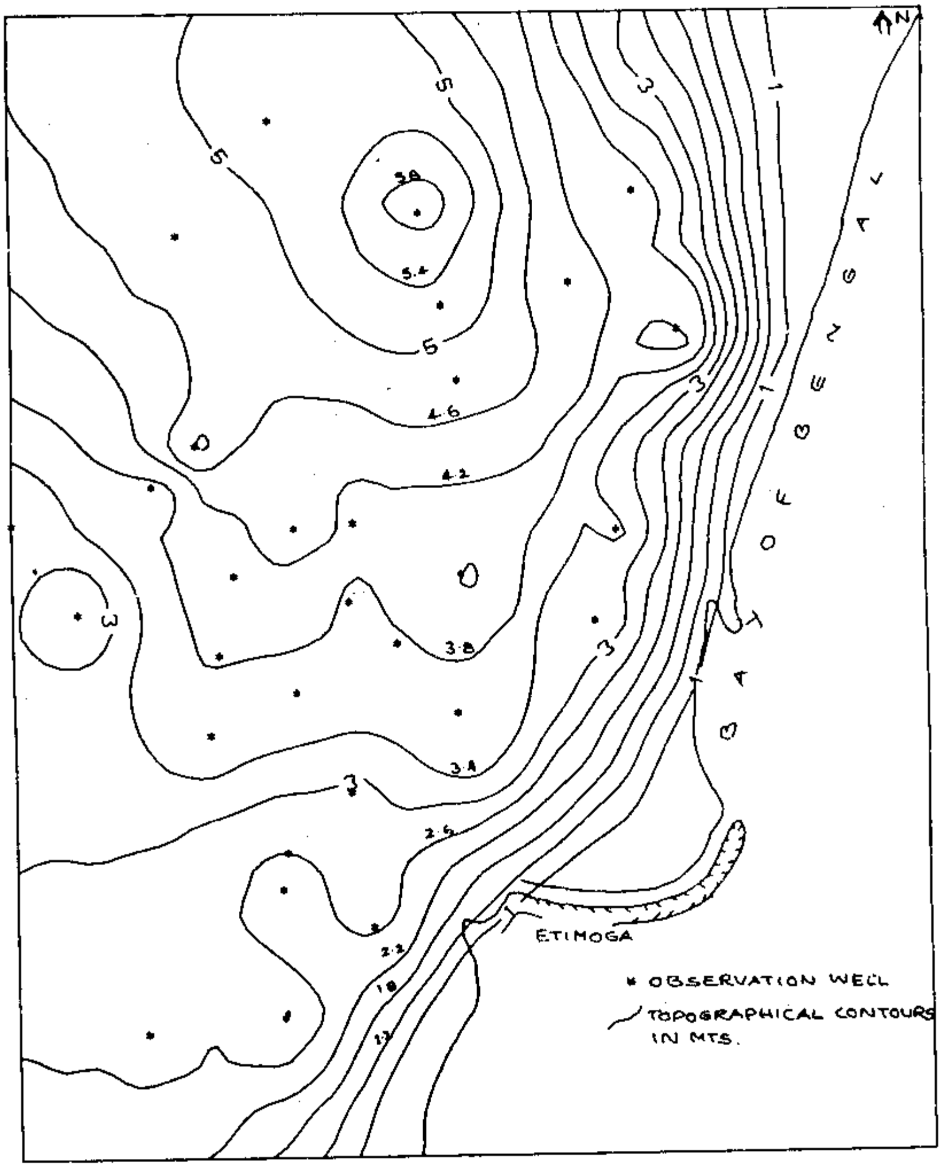


FIG5GROUNDWATER TABLE CONTOURS(ABOVE MSL IN MTS) DURING PREMONSOON PERIOD(MAY 98)

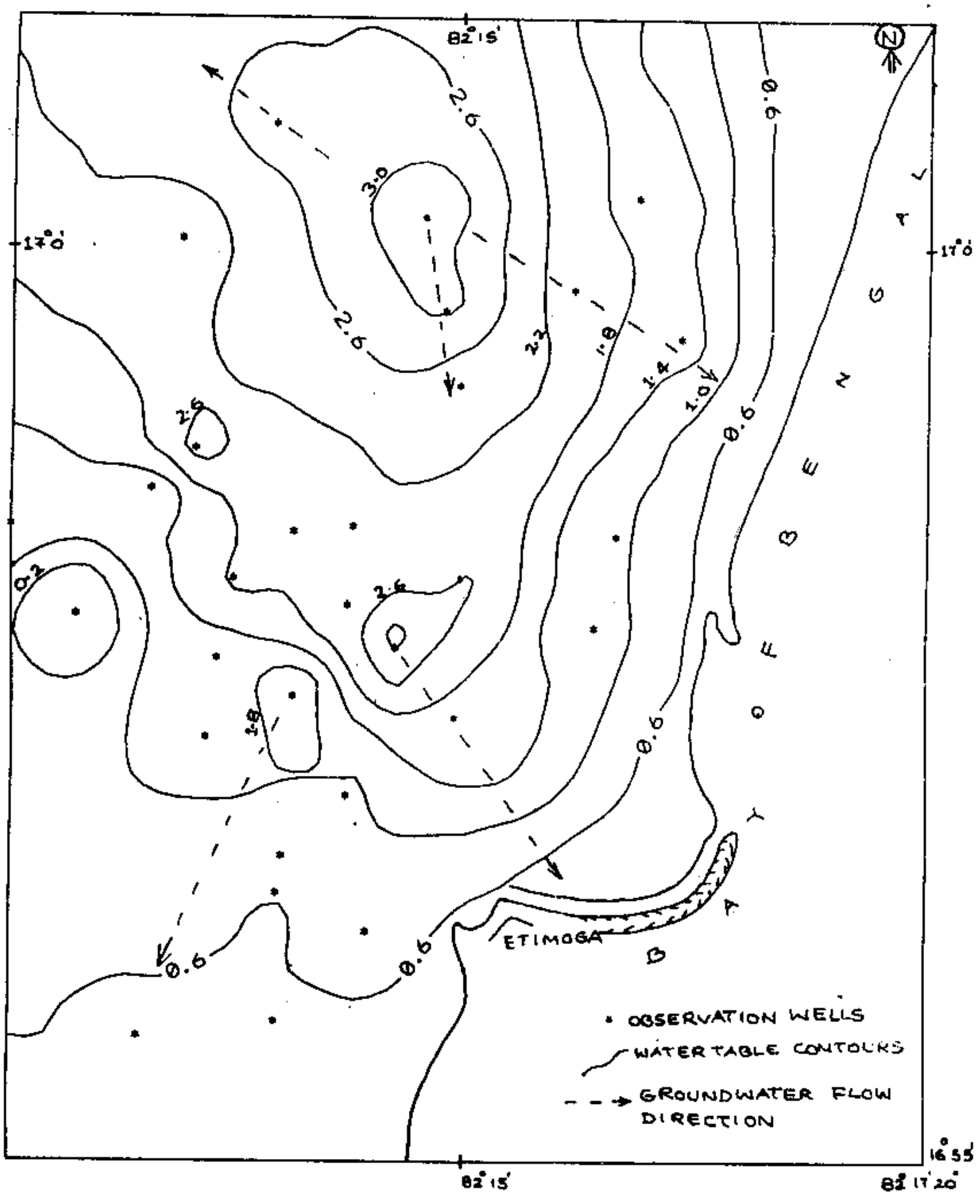


FIG.6 GROUNDWATER TABLE CONTOURS(ABOVE MSL IN MTS) DURING POSTMONSOON PERIOD(OCT.98)

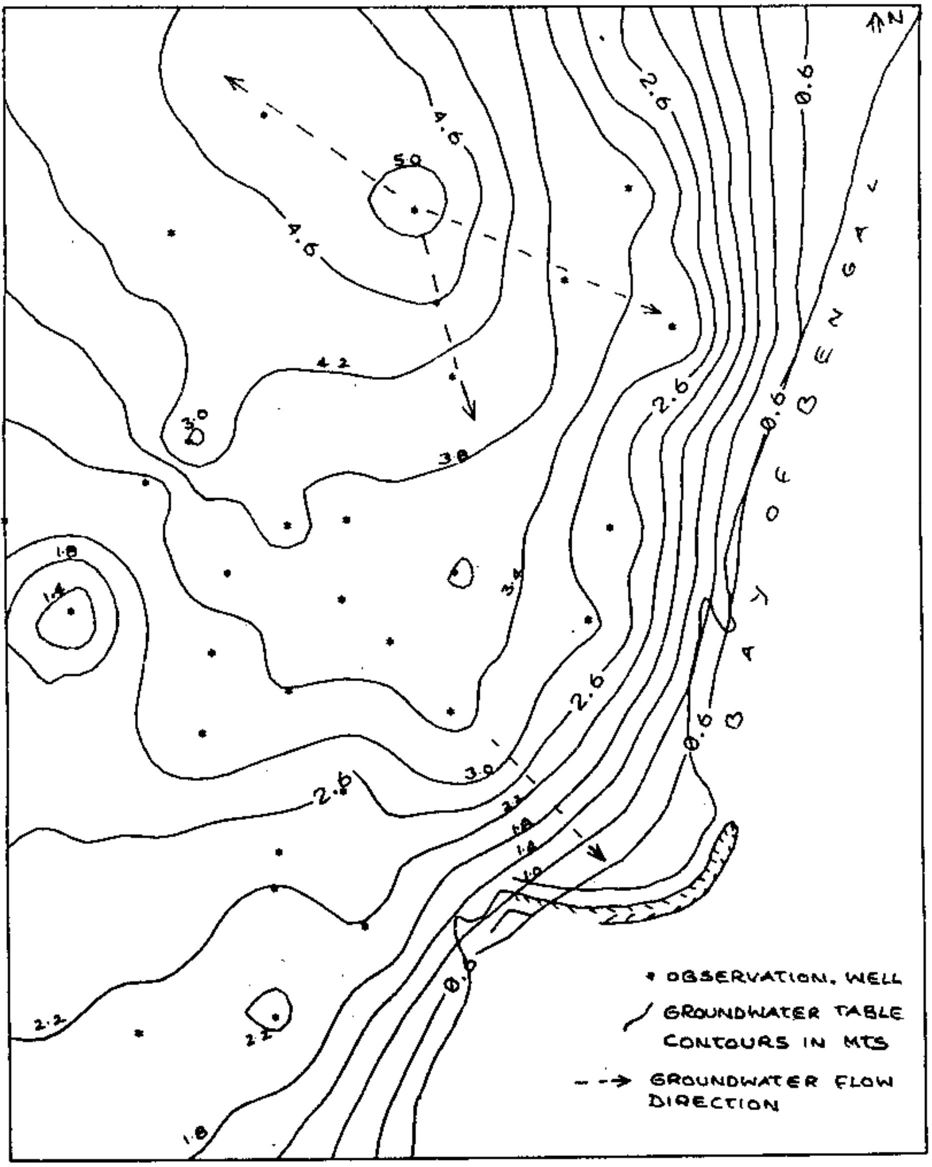


Table 2. Groundwater quality parameters of samples collected during the month of Feb. 98.

Well No.	Temp °C	pH	EC µ mho/cm	TDS (ppm)	T.H. (ppm)	Ca^{+2} (ppm)	Mg^{+2} (ppm)	Na^{+} (ppm)	K^{+} (ppm)	HCO_3^{-} (ppm)	Cl^{-} (ppm)	SO_4^{-} (ppm)	PO_4^{-} (ppm)	SAR	%Na
1	26	7.28	1100	706	420	96	44	150	90	268	256	140	1	3.18	51
2	27	7.23	600	385	280	83	17	40	13	252	148	17	0	1.04	27
3	26	7.71	2600	1669	680	125	89	325	190	680	608	278	0	5.42	58
4	25	7.77	1600	1027	520	99	66	150	29	496	344	94	1	2.86	41
5	27	7.19	1000	642	368	96	31	70	55	244	156	90	7	1.59	38
6	26	7.92	1100	706	396	95	39	80	62	420	180	65	2	1.75	39
7	25	7.55	800	514	360	80	39	65	19	420	112	39	1	1.49	32
8	26	7.92	435	279	260	77	17	50	18	268	64	30	0	1.35	34
9	26	7.82	1500	963	424	96	45	90	46	372	344	69	0	1.90	38
10	27	7.47	845	542	288	58	36	55	8	180	80	88	1	1.41	31
11	26	8.14	750	482	236	45	30	16	3	200	60	9	0	0.45	14
12	25	7.94	2500	1606	632	132	74	295	37	640	564	191	2	5.10	52
13	26	7.80	1650	1059	272	61	29	200	148	360	240	132	1	5.27	70
14	26	7.52	1400	899	300	71	30	193	39	440	272	88	1	4.83	61
15	25	7.34	1018	654	360	87	35	120	37	368	168	98	5	2.75	46
16	25	8.13	1400	899	472	91	59	253	118	672	256	105	3	5.06	60
17	26	7.66	2150	1380	420	111	35	178	70	512	220	64	1	3.77	53
18	27	7.60	2300	1477	760	213	55	265	162	688	380	162	1	4.02	50
19	27	7.50	2100	1348	872	249	61	474	178	860	636	855	3	6.98	59
20	27	7.62	1100	706	372	77	44	148	68	460	160	70	3	3.33	52
21	26	7.65	400	257	160	29	21	70	6	248	80	49	1	2.41	50
22	26	7.42	2220	1425	512	124	50	350	35	696	364	92	2	6.73	61
23	25	7.34	1275	819	244	83	9	30	2	176	72	16	0	0.83	22
24	27	8.10	750	482	164	64	25	78	45	316	128	79	2	2.08	46
25	26	7.80	2850	1830	608	132	68	474	25	420	688	148	2	8.36	64
26	26	7.80	2600	1669	472	85	63	215	102	616	280	136	2	4.31	56
27	27	7.75	1326	851	348	79	37	216	82	508	228	97	2	5.04	62
28	25	7.52	1600	1027	340	109	17	326	94	540	332	151	4	7.66	71
29	25	7.66	340	218	236	58	22	45	5	240	80	20	2	1.27	31
30	27	7.50	1050	674	412	104	37	90	81	276	192	97	3	1.93	42
31	27	7.35	650	417	252	48	32	70	43	164	136	71	2	1.92	45
32	26	7.98	1850	1188	352	64	47	590	38	672	468	172	0	13.68	79
33	26	7.75	1270	815	440	88	53	190	4	368	308	80	0	3.94	49
34	25	7.66	2900	1862	448	96	51	520	33	460	728	199	7	10.68	72
35	27	8.00	1800	1156	100	27	8	245	86	400	132	76	3	10.60	86
36	27	7.50	4000	2568	704	128	93	850	29	760	1200	189	3	13.94	73
37	27	7.30	4180	2684	496	96	62	1100	46	1184	1320	116	2	21.48	83
38	26	7.71	6000	3852	852	233	66	1380	348	684	1796	897	0	20.55	80
39	27	7.32	1100	706	372	111	23	180	67	368	244	78	0	4.06	56
40	27	7.70	1360	867	372	99	30	216	122	432	252	132	1	4.87	63
41	26	7.62	1550	995	276	75	21	264	144	380	316	124	3	6.91	73

EC - Electrical Conductivity at 25 °C , TDS - Total Dissolved Solids, T.H. - Total Hardness, SAR - Sodium Absorption Ratio.

Table 3. Groundwater quality parameters of samples collected during the month of May. 98.

Well No.	Temp °C	pH	EC µ mho/cm	TDS (ppm)	T.H. (ppm)	Ca^{+2} (ppm)	Mg^{+2} (ppm)	Na^{+} (ppm)	K^{+} (ppm)	HCO_3^{-} (ppm)	Cl^{-} (ppm)	SO_4^{-} (ppm)	PO_4^{-} (ppm)	SAR	%Na
1	31	7.30	1690	1085	620	144	63	145	48	320	268	245	2	2.53	38
2	30	6.79	470	302	660	66	26	105	25	240	144	29	2	2.90	51
3	32	7.34	3510	2253	620	104	87	435	118	580	516	255	2	7.60	64
4	32	7.22	2130	1367	460	96	53	280	20	520	332	96	1	5.68	58
5	31	7.03	1396	896	400	96	39	125	46	400	140	90	5	2.72	45
6	30	7.60	1412	907	340	55	50	170	4	280	212	45	1	4.01	52
7	32	7.50	1015	652	332	77	34	100	16	360	92	67	2	2.39	42
8	30	8.09	545	350	260	34	24	65	6	320	32	26	0	1.75	36
9	30	7.45	1682	1080	420	74	57	240	32	480	316	39	0	5.09	57
10	31	7.22	1469	943	536	80	42	130	5	620	108	38	1	2.93	44
11	31	7.41	301	193	160	40	15	25	3	160	12	33	1	0.86	27
12	32	7.48	2710	1740	548	95	76	330	29	540	512	176	0	6.13	58
13	31	7.28	1870	1201	436	88	52	150	89	380	228	90	5	3.12	50
14	30	7.26	1664	1068	444	101	47	165	35	440	212	76	3	3.41	48
15	32	7.25	940	603	340	80	34	80	26	340	80	66	5	1.89	38
16	33	7.89	1862	1195	360	87	59	245	80	720	212	96	8	4.96	58
17	31	7.45	3760	2414	512	85	73	480	114	700	748	113	6	9.23	70
18	33	7.45	2750	1766	532	96	71	265	135	640	320	140	8	5.00	58
19	30	7.21	1957	1256	628	144	65	130	67	420	236	375	7	2.26	37
20	32	7.24	1089	699	332	99	20	75	41	360	92	44	5	1.79	39
21	32	7.28	511	328	176	42	17	30	5	200	32	39	3	0.98	29
22	31	7.53	1726	1108	300	48	44	225	12	592	176	116	8	5.65	63
23	33	7.49	1116	716	216	37	30	145	14	448	132	66	4	4.29	61
24	33	7.61	600	385	444	75	62-	95	54	280	352	57	2	1.96	38
25	31	7.26	2950	1894	572	104	76	290	13	280	652	149	6	5.27	53
26	32	7.26	2483	1594	496	77	54	245	61	440	284	161	7	5.24	60
27	33	7.35	1700	1091	800	160	97	300	92	520	515	125	12	4.61	49
28	32	7.45	1300	835	1160	249	131	485	78	308	1128	108	11	6.19	50
29	31	7.34	384	247	184	38	21	30	2	180	40	54	11	0.96	27
30	32	7.03	1248	801	348	83	34	60	45	200	124	149	3	1.40	35
31	33	6.71	854	548	272	61	29	40	16	160	108	56	2	1.05	28
32	32	7.48	2890	1855	324	47	51	420	18	640	460	95	3	10.15	74
33	31	7.72	1606	1031	408	72	55	145	3	300	268	71	4	3.12	44
34	32	7.33	3630	2330	928	180	117	400	17	360	812	74	5	5.71	49
35	32	7.81	1461	938	156	32	18	200	8	440	204	86	11	6.96	74
36	31	7.18	4180	2684	640	104	92	475	58	620	920	92	13	8.17	63
37	32	7.44	5290	3396	600	97	80	900	19	860	1412	114	10	16.38	78
38	33	7.37	5660	3634	1532	209	46	695	340	360	1672	122	1	11.34	73
39	31	7.10	1345	863	392	87	43	110	37	280	196	161	3	2.42	42
40	32	7.22	1993	1280	568	128	60	155	74	380	248	180	3	2.83	43
41	33	7.10	2160	1380	492	77	73	175	84	380	292	227	4	3.43	50

EC - Electrical Conductivity at 25 °C , TDS - Total Dissolved Solids, T.H. - Total Hardness, SAR - Sodium Absorption Ratio.

Table 4. Groundwater quality parameters of samples collected during the month of Aug. 98.

Well	Temp	pH	EC	TDS	T.H.	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{-}	PO_4^{-}	SAR	%Na
No.	°C		µ mho/cm	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)		
1	32	7.15	1600	1027	456	160	14	170	82	280	256	190	2	3.46	51
2	32	6.71	600	385	320	85	26	100	19	288	184	20	2	2.43	43
3	33	7.30	3010	1932	788	138	108	485	165	704	608	347	2	7.52	62
4	33	7.30	1970	1265	560	122	62	300	50	576	456	133	1	5.51	56
5	32	7.14	1080	693	416	99	41	120	74	372	176	177	2	2.56	46
6	32	7.25	784	503	372	112	22	135	12	400	136	77	1	3.04	45
7	33	7.16	787	505	376	112	23	155	31	400	156	101	1	3.47	50
8	32	6.60	1338	859	448	128	31	140	118	320	216	206	1	2.87	50
9	33	7.44	1400	899	272	63	28	260	47	304	308	61	1	6.86	70
10	33	7.40	780	501	464	99	52	150	14	524	152	127	1	3.03	43
11	32	7.15	500	321	332	85	29	140	10	340	168	93	1	3.34	49
12	33	7.50	1415	908	608	126	72	325	37	620	376	210	1	5.73	55
13	33	7.30	1300	836	288	77	23	195	14	372	166	54	2	5.00	61
14	33	7.32	847	544	324	109	13	150	40	396	180	59	2	3.62	54
15	33	7.50	1050	674	332	82	31	180	13	344	160	102	3	4.30	55
16	32	7.67	1106	710	384	71	51	280	120	716	236	137	3	6.22	67
17	33	7.36	2308	1482	360	79	40	360	112	712	360	116	3	8.25	72
18	32	7.28	2600	1669	540	144	44	275	144	580	304	145	3	5.14	59
19	32	7.16	2710	1740	932	180	118	490	145	736	616	561	3	6.98	57
20	33	7.40	695	446	344	88	30	105	62	336	128	65	2	2.46	47
21	32	7.35	410	263	312	69	34	140	12	332	156	99	4	3.45	51
22	32	7.31	2500	1605	568	146	50	255	36	464	264	178	3	4.65	51
23	33	7.46	1350	867	536	111	63	235	24	524	210	152	2	4.41	50
24	32	7.80	957	614	424	82	53	110	54	332	248	115	1	2.32	42
25	33	7.70	2697	1731	636	146	66	255	19	364	496	173	3	4.40	48
26	33	7.50	3500	2247	396	77	50	320	85	604	256	112	3	6.99	67
27	32	7.16	1253	804	480	96	58	160	84	600	316	181	5	3.18	49
28	32	7.05	3000	1926	320	71	35	115	13	360	188	105	5	2.80	45
29	33	7.70	900	578	184	38	21	30	8	164	60	22	5	0.96	29
30	32	7.20	960	616	332	88	27	95	48	232	128	120	2	2.27	45
31	33	6.90	900	578	360	80	39	95	31	196	180	81	3	2.18	41
32	33	7.43	2900	1862	324	69	37	600	39	404	600	183	3	14.50	81
33	32	7.35	1390	892	408	79	52	240	11	380	300	163	3	5.17	57
34	33	7.40	2816	1808	448	104	46	480	23	476	564	214	5	9.86	71
35	33	7.51	1739	1116	220	45	26	290	16	504	200	74	4	8.50	75
36	32	7.26	4300	2761	624	98	92	1060	72	896	1396	295	4	18.46	79
37	32	7.20	4030	2587	616	98	90	980	43	1100	1436	150	4	17.18	78
38	33	7.35	6510	4179	1632	196	278	1130	285	784	1964	945	4	12.17	63
39	31	7.15	880	565	348	82	35	130	50	292	152	142	3	3.03	50
40	33	7.20	1970	1265	676	133	84	205	80	488	320	159	3	3.43	45
41	32	7.24	1850	1188	620	112	83	240	108	484	356	151	3	4.19	52

EC - Electrical Conductivity at 25 °C , TDS - Total Dissolved Solids, T.H. - Total Hardness, SAR - Sodium Absorption Ratio.

Table 5. Groundwater quality parameters of samples collected during the month of Nov. 98.

Well No.	Temp ° C	pH	EC µ mho/cm	TDS (ppm)	T.H. (ppm)	Ca^{+2} (ppm)	Mg^{+2} (ppm)	Na^{+} (ppm)	K^{+} (ppm)	HCO_3^{-} (ppm)	Cl^{-} (ppm)	SO_4^{-} (ppm)	PO_4^{-} (ppm)	SAR	%Na
1	29	7.0	2260	1451	560	120	63	200	95	536	340	180	2	3.68	50
2	30	6.9	940	603	320	82	28	60	25	220	240	47	3	1.46	34
3	29	7.4	3460	2221	716	120	101	500	170	912	548	170	2	8.13	65
4	29	7.4	1740	1117	464	88	59	350	60	600	324	122	1	7.07	64
5	29	7.1	980	629	348	80	36	140	80	412	140	115	5	3.26	54
6	30	7.1	296	190	152	45	10	150	20	308	136	54	1	5.29	70
7	29	7.2	952	611	364	96	30	180	40	456	120	88	2	4.10	55
8	29	7.6	1120	719	420	88	49	160	125	476	136	184	0	3.40	55
9	30	7.3	1570	1008	380	80	44	280	50	596	200	111	0	6.25	64
10	29	7.4	946	607	192	35	25	170	28	404	128	91	2	5.34	68
11	29	7.5	270	173	192	37	24	160	20	320	52	103	1	5.02	66
12	29	7.5	1240	796	356	64	48	350	45	564	258	238	0	8.07	70
13	29	7.4	1012	650	264	55	31	210	25	380	180	60	5	5.62	65
14	29	7.4	1020	655	320	80	29	140	50	356	198	77	4	5.84	65
15	30	7.4	1020	655	380	104	29	150	25	400	132	109	5	4.46	55
16	31	7.8	1430	918	340	64	44	300	125	692	240	132	6	7.08	70
17	29	7.5	3530	2266	440	69	65	380	130	688	300	154	7	7.88	69
18	29	7.2	2980	1913	800	118	62	310	160	560	364	146	8	4.77	52
19	29	7.3	1630	1046	504	133	42	320	165	636	580	389	7	6.20	64
20	29	7.4	1420	912	436	109	40	125	75	400	176	111	5	2.60	46
21	30	7.4	990	636	320	74	33	160	20	340	136	173	4	3.89	54
22	29	7.7	1632	1048	516	120	52	280	45	700	228	154	9	5.36	56
23	29	7.3	2390	1534	700	168	68	260	35	700	356	117	3	4.27	47
24	29	7.2	1602	1028	552	115	64	140	65	384	356	154	2	2.59	41
25	31	7.5	3236	2078	780	168	87	270	25	556	624	156	7	4.21	44
26	29	7.8	3570	2292	640	125	80	340	90	600	432	166	8	5.85	57
27	29	7.2	1700	1091	440	91	62	180	93	480	236	147	10	3.73	54
28	29	7.4	1370	880	392	91	40	140	27	360	152	77	10	3.08	46
29	30	7.4	410	263	200	40	24	25	15	244	20	31	11	3.54	57
30	29	7.2	910	584	316	82	27	95	55	228	120	110	3	3.06	52
31	31	7.1	940	603	260	56	29	135	38	280	160	91	2	3.64	57
32	29	7.5	2550	1637	292	61	40	650	42	828	444	208	3	16.55	83
33	29	7.4	1700	1091	520	132	47	280	18	412	272	199	4	5.34	55
34	30	7.4	2620	1682	312	87	23	500	28	492	636	246	5	12.31	78
35	29	7.2	2049	1315	488	106	54	310	22	796	228	71	12	6.10	59
36	29	7.3	2180	1400	360	58	52	1100	85	880	1220	261	14	25.22	87
37	29	7.5	5452	3500	576	64	125	1000	55	1104	1352	181	10	16.73	77
38	31	7.2	6810	4372	1380	176	228	1160	300	712	1874	275	3	13.59	68
39	29	7.3	620	398	220	48	24	160	60	264	142	125	3	4.69	66
40	29	7.3	1710	1098	500	112	53	155	100	480	196	111	3	3.02	48
41	31	7.3	1610	1034	368	69	48	225	114	394	328	138	5	5.10	63

EC - Electrical Conductivity at 25 ° C , TDS - Total Dissolved Solids, T.H. - Total Hardness, SAR - Sodium Absorption Ratio.

and 29.4^0 C respectively. The range of electrical conductivity at 25^0 C in these months are 340 - 600, 301 - 5660, 410 - 6510 and 270 - 6810 μ mhos/cm respectively. Among 164 samples collected in the year 1998, 80% of samples are having conductivity values above 1000 μ mhos/cm. The average EC values during pre monsoon (May 98) and post monsoon (Nov. 98) periods are 1934 and 1850 μ mhos/cm respectively.

4.2.2 Chemical parameters

The range of major anions and major cations in the study area are shown in Table 6. The average values of major anions HCO_3, Cl, SO_4 and PO_4 in the year 1998 are 464, 358, 139 and 3.5 ppm respectively. Similarly the average values of major cations Ca, Mg, Na and K are 95, 50, 267 and 61 ppm respectively. The concentration of TDS and Total hardness have been decreased from pre monsoon (May 98) to post monsoon (Nov.98) periods. It may indicates dilution of groundwater quality in the study area.

4.2.3 Classification of Groundwater samples

Groundwater samples collected in the year 1998 have been classified according to Total hardness, TDS, Stiff(1951), Pipers trilinear (1953), U S Salinity laboratory, SAR, %Na and comparison with drinking water standards to characterize the groundwater samples for irrigation and drinking water purposes. Further, it is also discussed about the seasonal changes in classification types. The classification of irrigation water ensured that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage, quantity of water used and salt tolerance of crop.

Stiff Classification:

The Stiff classification (Stiff, 1951) is used to define the type of water based on the presence of dominant cations and anions. The Stiff classification of all the samples collected in the year 1998 is presented in the Table .7. The classification indicates that the majority of the samples in Kakinada nearby area are of Sodium bicarbonate type ($NaHCO_3$) except well nos 25, 34, 36, 37 and 38. These wells are located nearby seacoast and drain (fig.2.) The change in the water type from pre monsoon to post monsoon period was observed only in well Nos.2, 11, 17, 19, 20, 21, 24, 28, 30, 31. Thus may indicate the mixing of shallow groundwater nearby these wells.

Table 6. Range of groundwater quality parameters in the study area

Feb' 98.	Temp °C	pH	Ec (µ mho /cm)	TDS (ppm)	T.H. (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	HCO_3 (ppm)	Cl (ppm)	SO_4 (ppm)	PO_4 (ppm)	SAR	% Na
Average	26.15	7.65	1683.15	1080.58	411.02	96.94	41.72	261.04	68.89	456.29	355.90	139.15	1.88	5.29	52.92
Minimum	25.00	7.19	340.00	218.28	100.00	27.27	8.00	16.00	2.00	164.00	60.00	9.20	0.30	0.45	13.87
Maximum	27.00	8.14	6000.00	3852.00	872.00	248.62	93.31	1380.00	348.00	1184.00	1796.00	897.33	6.90	21.48	86.42
May' 98.															
Average	31.61	7.35	1934.12	1241.71	486.54	91.96	54.16	228.29	48.51	415.80	361.93	108.06	4.63	4.50	50.10
Minimum	30.00	6.71	301.00	193.24	156.00	32.08	14.58	25.00	2.10	160.00	12.00	25.50	0.75	0.86	26.62
Maximum	33.00	8.09	5680.00	3633.72	1532.00	248.62	131.22	900.00	340.00	860.00	1672.00	375.00	12.50	16.38	77.64
Aug' 98.															
Average	32.47	7.30	1821.76	1169.57	472.68	101.91	53,10	284.88	59.76	470.73	369.06	165.81	2.66	5.51	55.10
Minimum	31.00	6.60	410.00	263.22	184.00	38.50	12.64	30.00	8.00	164.00	60.00	20.19	1.02	0.96	29.09
Maximum	33.00	7.80	6510.00	4179.42	1632.00	195.69	277.99	1130.00	285.00	1100.00	1964.00	945.48	5.23	18.46	80.70
Nov' 98.															
Average	29.41	7.36	1850.39	1187.90	443.41	90.24	51.44	297.56	69.39	515.85	348.88	143.22	4.83	6.28	59.76
Minimum	29.00	6.90	270.00	173.00	152.00	35.00	10.00	25.00	15.00	220.00	20.00	31.00	0.00	1.46	34.00
Maximum	31.00	7.80	6810.00	4372.00	1380.00	176.00	228.00	1160.00	300.00	1104.00	1874.00	389.00	14.00	25.22	87.00

Table No.7. STIFF classification of groundwater samples collected from observation wells during the year 1998

Well No.	Location	February 98	May 98 (Premonsoon)	August 98	November 98 (Post monsoon)
01	Sarpavaram	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
02	Balaji Nagar	$CaHCO_3$	$NaHCO_3$	$NaHCO_3$	$CaCl_2$ *
03	Valasapakalu	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
04	Vakalapudi	$NaHCO_3$	$NaHCO_3$	NaHCO3	$NaHCO_3$
05	Ramanayyapeta	$CaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
06	R.R.Nagar	$CaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
07	Madhavnagar	$CaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
08	Nagamallithota	$CaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
09	Godarigunta	$CaHCO_3$	$NaHCO_3$	NaCl	$NaHCO_3$
10	Sambamurthynagar	$CaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
11	Shantinagar	$CaHCO_3$	$CaHCO_3$	$NaHCO_3$	$NaHCO_3$*
12	Perrajupeta	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
1$_3$	Kondayyapalem	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
14	Gandhinagar	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
15	Ramarao peta	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
16	Suryarao peta	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
17	Suryanarayanapuram	$NaHCO_3$	NaCl	$NaHCO_3$	$NaHCO_3$*
18	Budampeta	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
19	Temple street	$NaHCO_3$	$CaHCO_3$	$NaHCO_3$	$NaHCO_3$*
20	Frazer Peta	$NaHCO_3$	$CaHCO_3$	$NaHCO_3$	$NaHCO_3$*
21	Pratap nagar	$NaHCO_3$	$CaHCO_3$	$NaHCO_3$	$NaHCO_3$*
22	Revenue colony	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
23	Gogudanayya peta	$CaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
24	MSN Charties area	$NaHCO_3$	NaCl	$NaHCO_3$	$NaHCO_3$*
25	Turangi	NaCl	NaCl	NaCl	NaCl
26	Paradesamma peta	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
27	Indrapalem	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
28	Chidiga	$NaHCO_3$	NaCl	$NaHCO_3$	$NaHCO_3$*
29	Madhura Nagar	$CaHCO_3$	$CaHCO_3$	$CaHCO_3$	$CaHCO_3$
30	Rayudupalem	$CaHCO_3$	$CaHCO_3$	$NaHCO_3$	$NaHCO_3$*
31	Penumarthy	$NaHCO_3$	$CaHCO_3$	$NaHCO_3$	$NaHCO_3$*
32	V.Pakalu-NFCL Road	$NaHCO_3$	$NaHCO_3$	NaCl	$NaHCO_3$
33	NFCL Road	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
34	Santhanpuri colony	NaCl	NaCl	NaCl	NaCl
35	Sitarama Nagar	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
36	China vakalpudi	NaCl	NaCl	NaCl	NaCl
37	Raghavendra palem	NaCl	NaCl	NaCl	NaCl
38	Velamala Turangi	NaCl	NaCl	NaCl	NaCl
39	Rajendra Nagar	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
40	Panasapadu Rd.	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$
41	Peda Vakalpudi	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$	$NaHCO_3$

* Change in classification from premonsoon to post monsoon periods

Piper's Trilinear Classification:

The chemical analysis data of the groundwater samples collected in Kakinada town have been plotted on trilinear diagrams and the hydrochemical facies inferred from these diagrams are summarized in Table 8. Total four types of facies observed 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 = $Ca+Mg+CO_3+HCO_3$. The change in water types from pre monsoon to post monsoon period are shown in Table 8.

U.S.Salinity Laboratory Classification:

Sodium concentration is an important criterion in irrigation water classification because sodium reacts with the soil to create sodium hazards by replacing other cations. The extent of this replacement is estimated by Sodium Absorption ratio. The diagram for use in studying the suitability of groundwater for irrigation purposes is based on the SAR and electrical conductivity of water expressed in μS/cm. The chemical analysis data of all the water samples have been plotted on Wilcox diagrams and the classification is given in Table 9. According to the US Salinity classifications the groundwater quality in Kakinada is suitable for irrigation purposes except wells NOs. 32, 34, 36 and 38 which are located near sea coast. The change in classification from pre monsoon to post monsoon period is given in Table 9.

Hardness Classification:

The total hardness of each sample collected in the month of Feb.98, May. 98, Aug.98 and Nov.98 are given in table 2, 3, 4 and 5 respectively. The range and average values in these months are given in Table 6. According to Hardness Classification most of the study area falls under hard to very hard. The concentration of hardness in the study area may be due to the garbage disposal areas and acid leachate from contaminated water.

Total Dissolved solids:

The total dissolved solids indicates the general nature of water salinity. Water containing 500 mg/l of TDS is desirable limit for drinking water. The TDS content of each sample collected in the month of Feb.98, May 98, Aug.98 and Nov.98 are shown in Table 2, 3, 4 and 5 respectively. However, the average TDS value in these months are 1080, 1241,

Table No . 8. Piper's Trilinear classification of groundwater samples collected during the year 1998

Well No.	Location	February 98	May 98 (Premonsoon)	August 98	November 98 (Post monsoon)
01	Sarpavaram	II	I	II	I
02	Balaji Nagar	I	II	I	I*
03	Valasapakalu	II	II	II	II
04	Vakalapudi	I	II	II	II
05	Ramanayyapeta	I	IV	I	III*
06	R.R.Nagar	IV	II	IV	III*
07	Madhavnagar	IV	IV	III	III*
08	Nagamallithota	IV	IV	II	III*
09	Godarigunta	I	II	II	III*
10	Sambamurthynagar	I	IV	IV	III*
11	Shantinagar	IV	IV	I	III*
12	Perrajupeta	II	II	II	II
13	Kondayyapalem	II	II	III	II
14	Gandhinagar	II	I	III	II*
15	Ramarao peta	I	IV	II	IV
16	Suryarao peta	III	III	III	III
17	Suryanarayanapuram	III	II	II	II
18	Budampeta	II	II	II	II
19	Temple street	II	I	II	II*
20	Frazer Peta	III	IV	IV	I*
21	Pratap nagar	III	III	II	II*
22	Revenue colony	II	III	II	III
23	Gogudanayya peta	IV	III	II	I*
24	MSN Charities area	I	I	I	I
25	Turangi	II	II	I	I*
26	Paradesamma peta	II	II	III	II
27	Indrapalem	II	I	I	II*
28	Chidiga	II	I	I	IV*
29	Madhura Nagar	IV	IV	IV	IV
30	Rayudupalem	I	I	I	II
31	Penumarthy	I	I	I	II*
32	V.Pakalu-NFCL Road	II	II	II	II
33	NFCL Road	I	I	II	II*
34	Santhanpuri colony	II	I	II	II*
35	Sitarama Nagar	III	II	III	III*
36	China Vakalpudi	II	II	II	II
37	Raghavendra palem	II	II	II	II
38	Velamala Turangi	II	II	II	II
39	Rajendra Nagar	II	I	I	II*
40	Panasapadu Rd.	II	I	I	IV*
41	Peda Vakalpudi	II	I	II	II*

* Change in classification from Pre-monsoon to post-monsoon period

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

Table No. 9. U S Salinity Laboratory Classification of groundwater samples collected during the year 1998

Well No.	Location	February 98	May 98 (Premonsoon)	August 98	November 98 (Post monsoon)
01	Sarpavaram	C3-S1	C3-S1	C3-S1	C4-S1*
02	Balaji Nagar	C2-S1	C2-S1	C2-S1	C3-S1*
03	Valasapakalu	C4-S1	C4-S1	C4-S1	C4-S1
04	Vakalapudi	C3-S1	C3-S1	C3-S1	C3-S1
05	Ramanayyapeta	C3-S1	C3-S1	C3-S1	C3-S1
06	R.R.Nagar	C3-S1	C3-S1	C3-S1	C2-S1*
07	Madhavnagar	C3-S1	C3-S1	C3-S1	C3-S1
08	Nagamallithota	C2-S1	C2-S1	C3-S1	C3-S1*
09	Godarigunta	C3-S1	C3-S1	C3-S1	C3-S1
10	Sambamurthynagar	C3-S1	C3-S1	C3-S1	C3-S1
11	Shantinagar	C3-S1	C2-S1	C2-S1	C2-S1
12	Perrajupeta	C4-S1	C4-S1	C3-S1	C3-S1*
13	Kondayyapalem	C3-S1	C3-S1	C3-S1	C3-S1
14	Gandhinagar	C3-S1	C3-S1	C3-S1	C3-S1
15	Ramarao peta	C3-S1	C3-S1	C3-S1	C3-S1
16	Suryarao peta	C3-S1	C3-S1	C3-S1	C3-S1
17	Suryanarayanapuram	C3-S1	C4-S1	C4-S1	C4-S1
18	Budampeta	C4-S1	C4-S1	C4-S1	C4-S1
19	Temple street	C3-S1	C3-S1	C4-S1	C3-S1
20	Frazer Peta	C3-S1	C3-S1	C2-S1	C3-S1
21	Pratap Nagar	C2-S1	C2-S1	C2-S1	C3-S1*
22	Revenue colony	C3-S1	C3-S1	C4-S1	C3-S1
23	Gogudanayya peta	C3-S1	C3-S1	C3-S1	C4-S1*
24	MSN Charities area	C3-S1	C2-S1	C3-S1	C3-S1*
25	Turangi	C4-S1	C4-S1	C4-S1	C4-S1
26	Paradesamma peta	C4-S1	C4-S1	C4-S1	C4-S1
27	Indrapalem	C3-S1	C3-S1	C3-S1	C3-S1
28	Chidiga	C3-S1	C3-S1	C4-S1	C3-S1
29	Madhura Nagar	C2-S1	C2-S1	C3-S1	C2-S1
30	Rayudupalem	C3-S1	C3-S1	C3-S1	C3-S1
31	Penumarthy	C2-S1	C3-S1	C3-S1	C3-S1
32	V.Pakalu-NFCL Road	C3-S2	C4-S2	C4-S2	C4-S2
33	NFCL Road	C3-S1	C3-S1	C3-S1	C3-S1
34	Santhanpuri colony	C4-S2	C4-S1	C4-S1	C4-S2*
35	Sitarama Nagar	C3-S2	C3-S1	C3-S1	C3-S1
36	China Vakalpudi	C4-S2	C4-S1	C4-S3	C3-S3*
37	Raghavendra Palem	C4-S3	C4-S2	C4-S2	C4-S1*
38	Velamala Turangi	C4-S3	C4-S2	C4-S2	C4-S2
39	Rajendra Nagar	C3-S1	C3-S1	C3-S1	C2-S1*
40	Panasapadu Rd.	C3-S1	C3-S1	C3-S1	C3-S1
41	Peda Vakalpudi	C3-S1	C3-S1	C3-S1	C3-S1

*Change in water type from premonsoon to post monsoon period

C2-S1 - Medium salinity low alkali hazard (Na)

C3-S1 - High salinity low alkali hazard (Na)

C3-S2 - High salinity medium alkali hazard (Na)

C4-S3 - Very high salinity high alkali hazard (Na)

1169 and 1187 ppm respectively. Most of the wells in the study area are exceeded the limit of 500 ppm of total dissolved solids.

Sodium Absorption Ratio (SAR) and % Na:

The SAR and % Na values in each sample collected in the month of May 98, Feb 98, Aug. 98 and Nov.98 are shown in Table No. 2, 3, 4 and 5 respectively. The range of SAR in the study area is between 0.45 to 25.22. Similarly, the percentage of Sodium varies between 14 to 87%. Based on SAR values the Sodium hazard of groundwater in the study area is between medium hazard to high hazard.

Potability of Groundwater:

Groundwater quality parameters of pH, TDS, Ca, Mg, HCO_3, SO_4 and Cl were compared for WHO (1984) and ISI (1983) drinking water standards. The range of each parameter and the wells exceeded the maximum permissible limits are given in the Table 10. The wells located near sea coast, salt creek, drains are exceeded the desirable limits. Therefore, these wells may be avoided for drinking water purposes.

4.3 Groundwater quality maps

The spatial distribution of TDS, Total Hardness, Chloride and SAR in the study area during the month of May 98 and Nov. 98 were plotted using SURFER package. The spatial distribution maps of these parameters may give an idea of areal view of the groundwater quality in the study area. Further the comparison between pre monsoon and post monsoon periods indicates the change in spatial distribution of different concentrations in the study area. The TDS distribution in the study area during pre monsoon and post monsoon periods are shown in Fig.7 and 8 respectively. From these figures it is observed that the increasing trend of TDS has been observed towards sea coast except in few places. Most of the study area falls under medium salinity zone to high salinity zone.

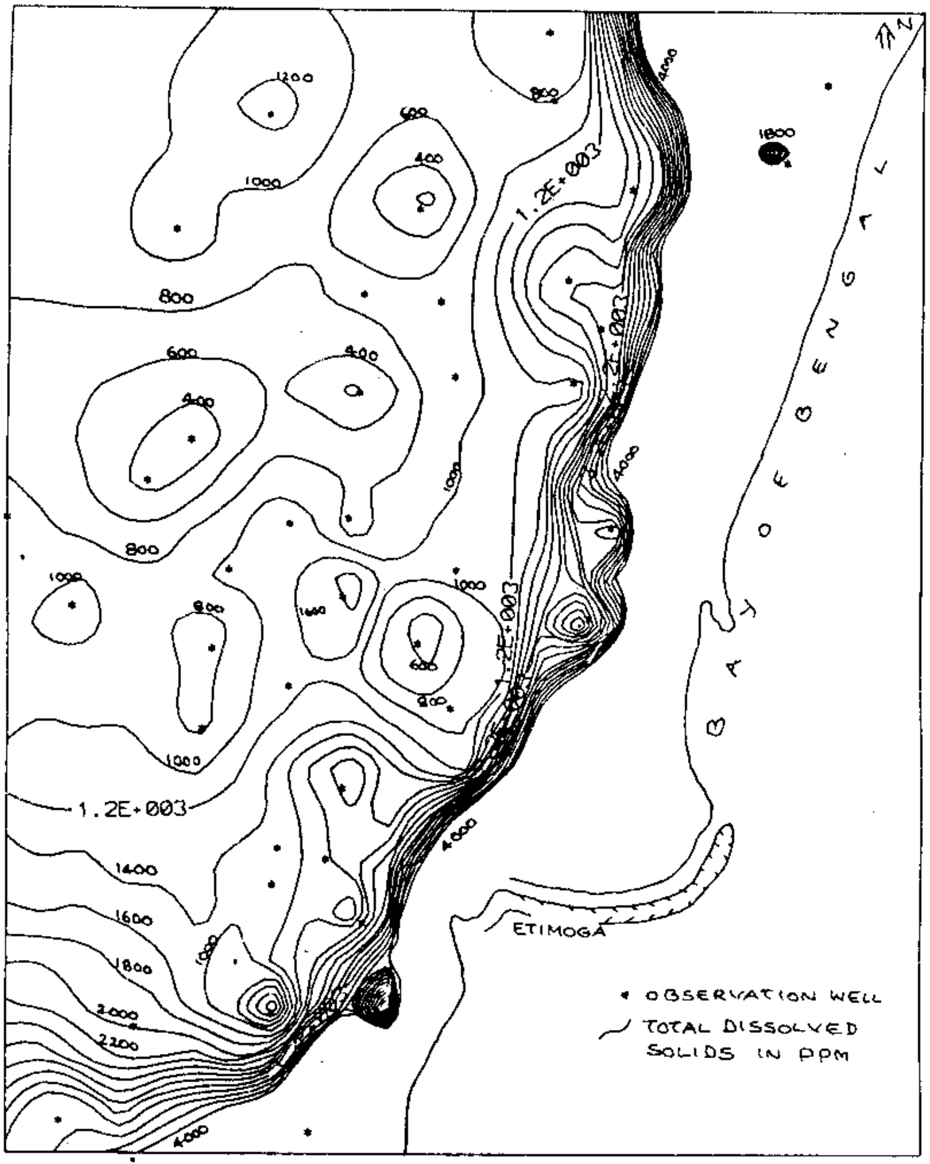
The spatial distribution of Total hardness in the study area during pre monsoon and post monsoon periods are shown in Fig. 9 and 10 respectively. According to hardness classification most of the study area falls under hard to very hard zone. The comparison between these two diagrams shows that the concentration of total hardness had been decreased from pre monsoon to post monsoon period.

Table No. 10. Comparison of chemical parameters of observation wells WHO (1984) and ISI(1983) drinking water standards during the year 1998

Parameters	Range in the study area	WHO(1984)	ISI (1983)		Well Nos. exceeded the ISI Maximum Permissible Limits
			Highest desirable	Maximum Permissible	
pH	6.6 - 8.14	6.5 - 8.5	7.0 - 8.5	6.5 - 9.2	
TDS	173 - 4372	1000	500	1500	3, 12, 17, 18, 23, 25 26, 34, 36, 37, 38
Ca^{2+}	29 - 249	500	75	200	18, 19, 28, 38
Mg^{2+}	8 - 228	-	30	100	3, 28, 34,37 , 38
Na^+	16 - 1380	200	-	-	-
HCO_3^-	160 - 1184	-	300	600	3, 4, 10, 12, 16, 18, 19, 22, 23, 26, 32, 35, 36, 37, 38
SO_4^-	9 - 945	400	150	400	19, 38
Cl^-	12 - 1964	250	250	1000	28, 36, 37, 38

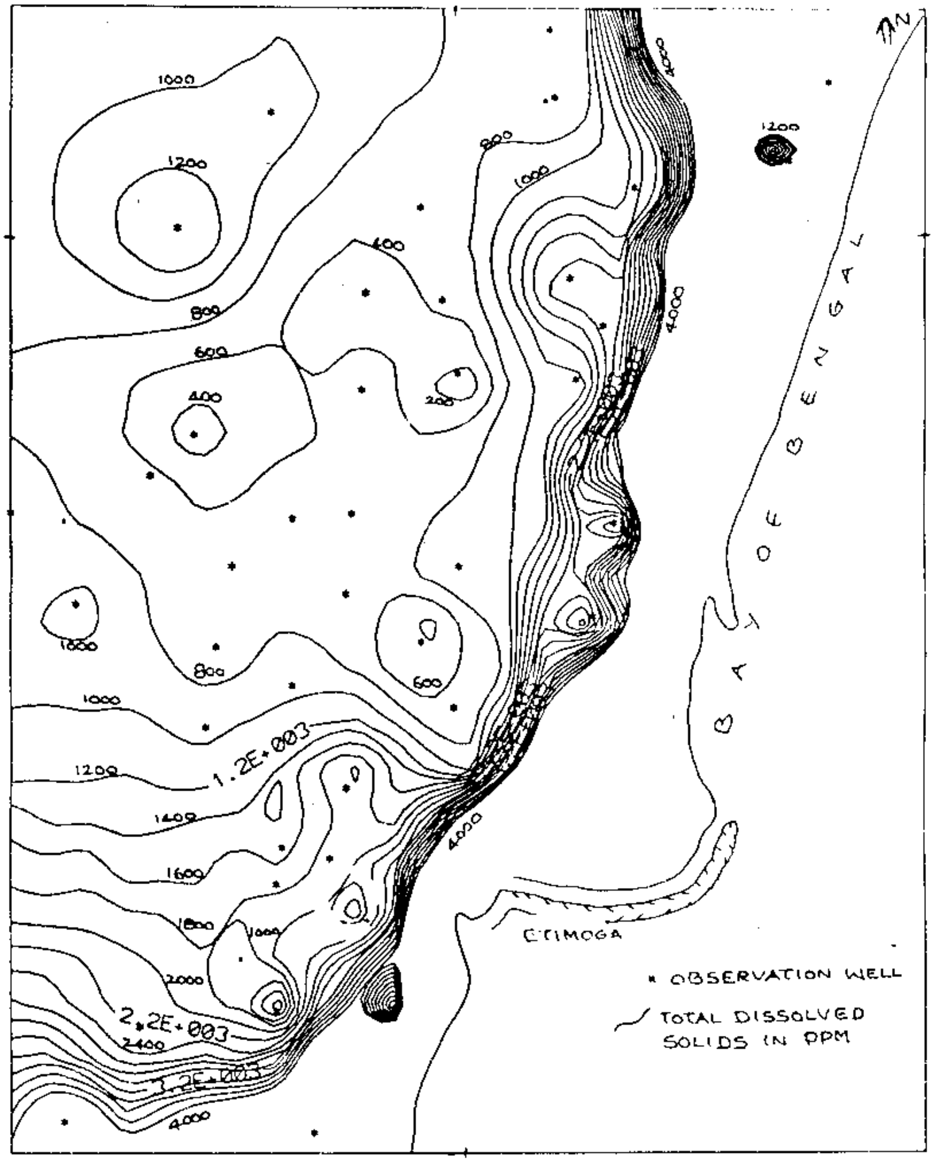
Units = mgl^{-1}

FIG.7 SPATIAL DISTRIBUTION OF TDS DURING PREMONSOON PERIOD(MAY 1998)



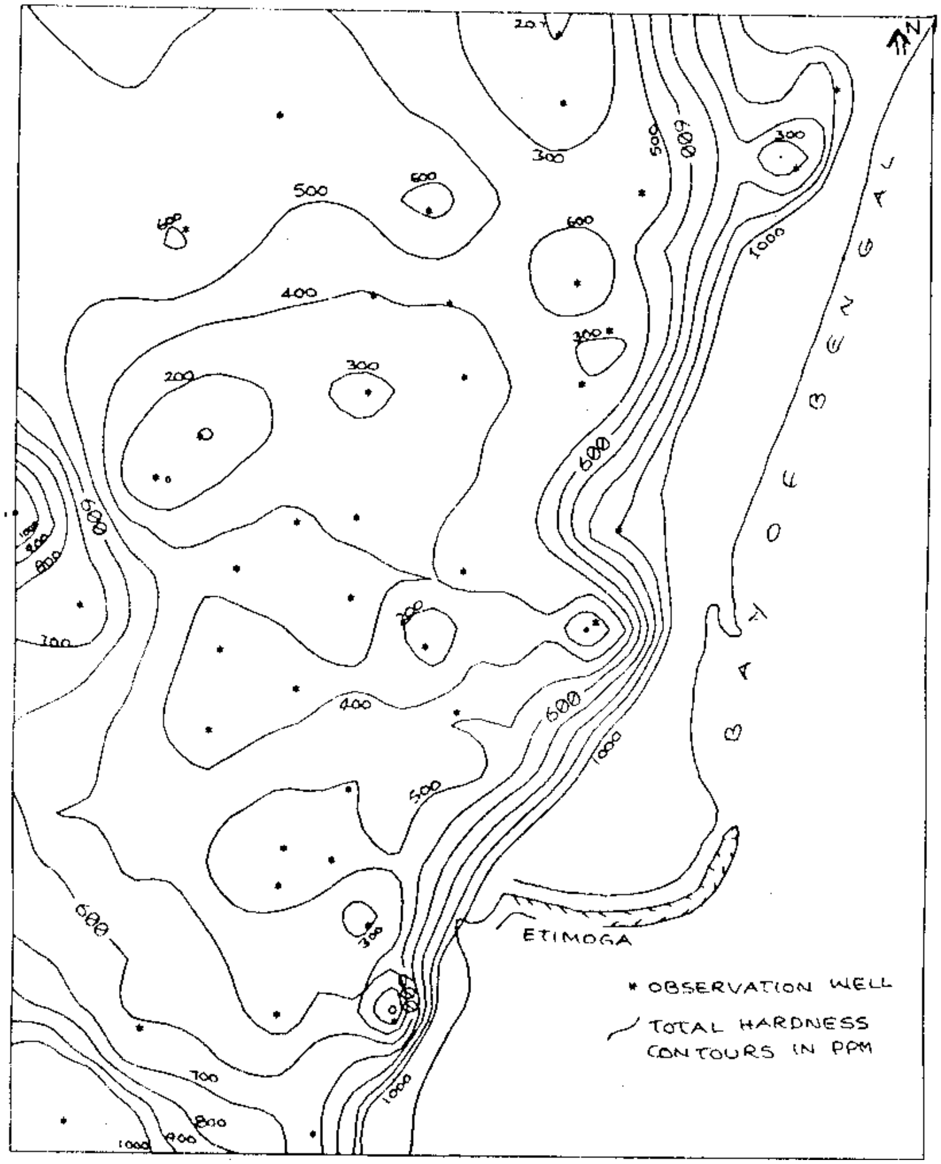
< 200 LOW SALINITY ZONE ; 200 - 500 MEDIUM SALINITY ZONE; 500 - 1500 HIGH SALINITY ZONE, 1500 - 3000 VERY HIGH SALINIT ZONE.

FIG.8 SPATIAL DISTRIBUTION OF TDS DURING POSTMONSOON PERIOD(NOV. 1998)



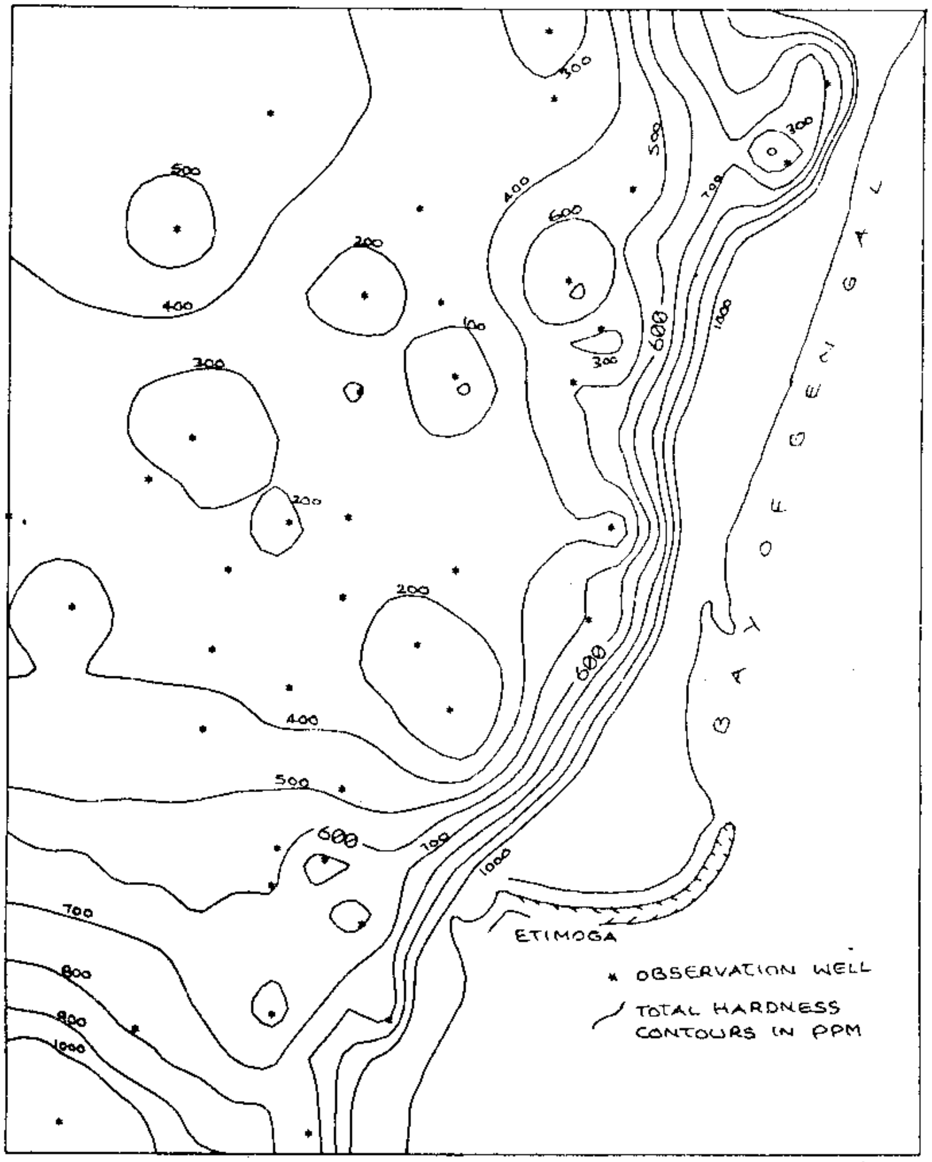
< 200 LOW SALINITY ZONE ; 200-500 MEDIUM SALINITY ZONE
500 - 1500 HIGH SALINITY ZONE ; 1500-3000 VERY HIGH SALINITY ZONE.

FIG.9 SPATIAL DISTRIBUTION OF TOTAL HARDNESS DURING PREMONSOON PERIOD(MAY 1998



0 - 75 SOFT ; 75-150 MODERATELY HARD ; 150-300 HARD
>300 VERY HARD.

FIG.10 SPATIAL DISTRIBUTION OF TOTAL HARDNESS DURING POSTMONSOON PERIOD(NOV. 98)



0-75 SOFT ; 75-150 MODGRATELY HARD, 150-300 HARD
>300 VERY HARD

FIG.11 SPATIAL DISTRIBUTION OF CHLORIDE DURING PREMONSOON PERIOD(MAY 98)

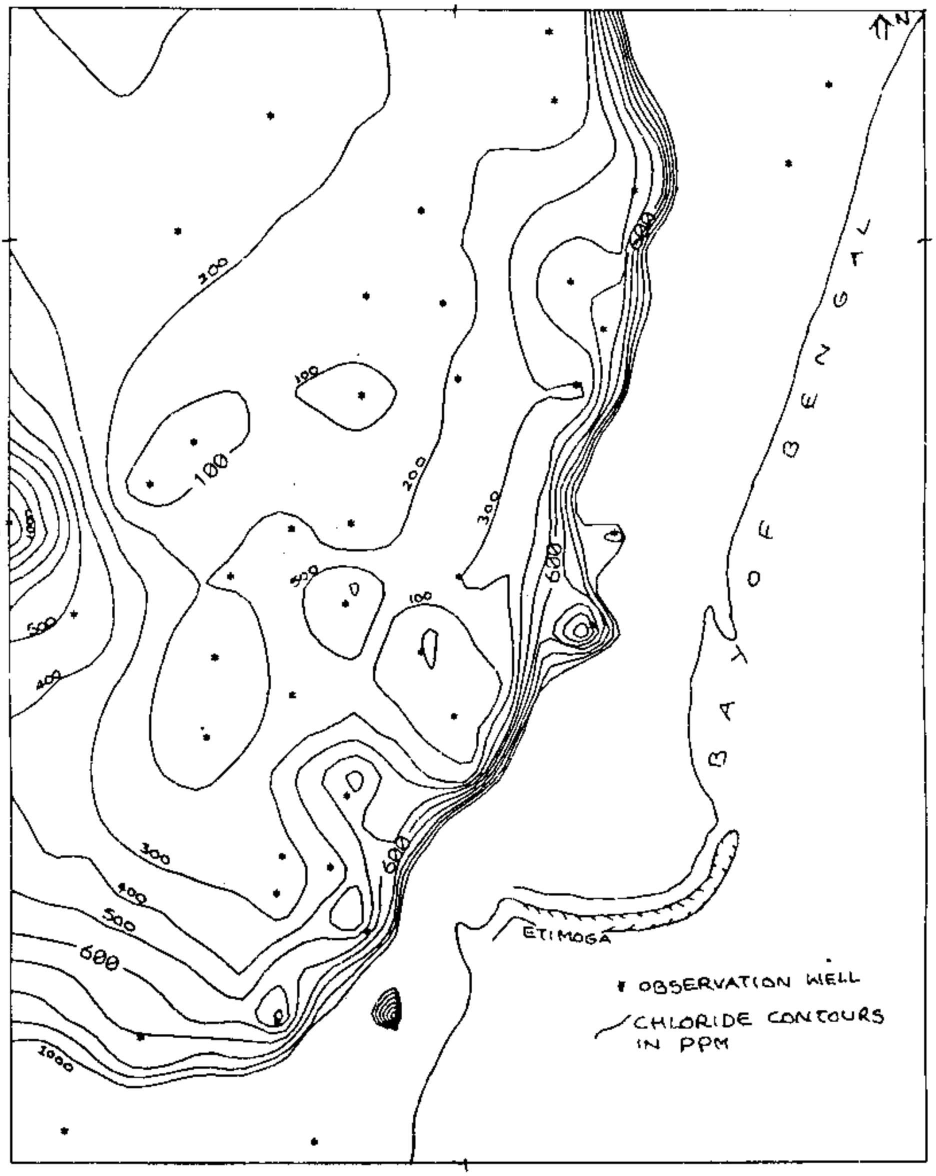


FIG.12 SPATIAL DISTRIBUTION OF CHLORIDE DURING POSTMONSOON PERIOD(NOV.98)

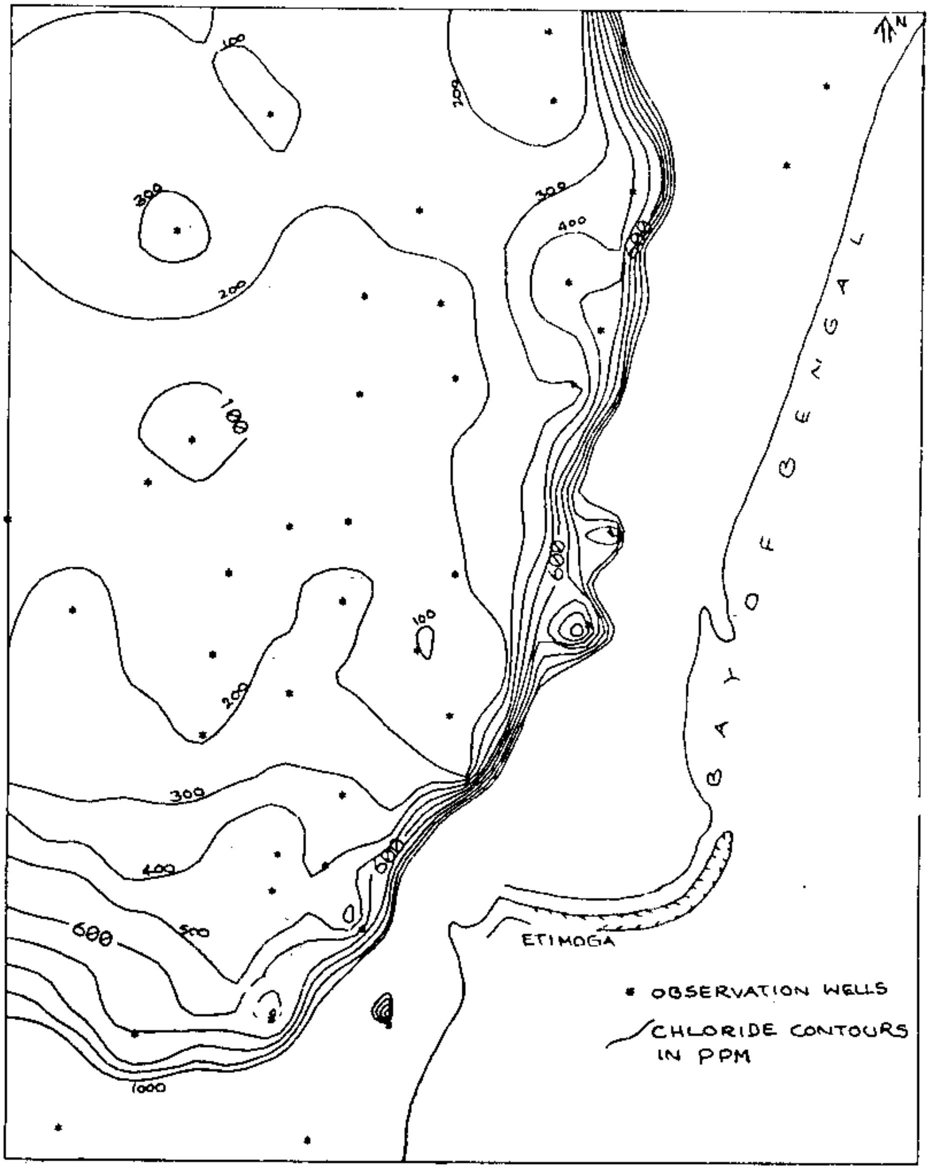
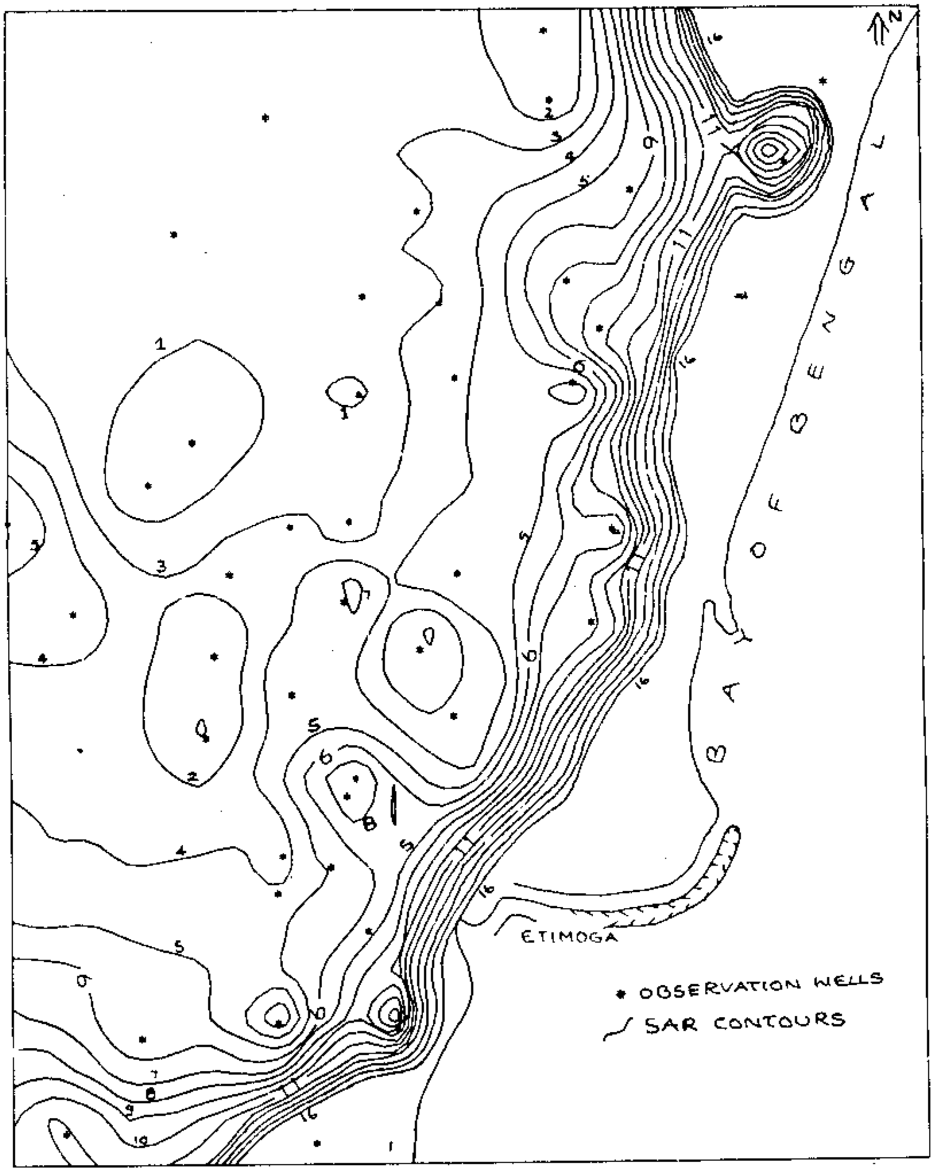
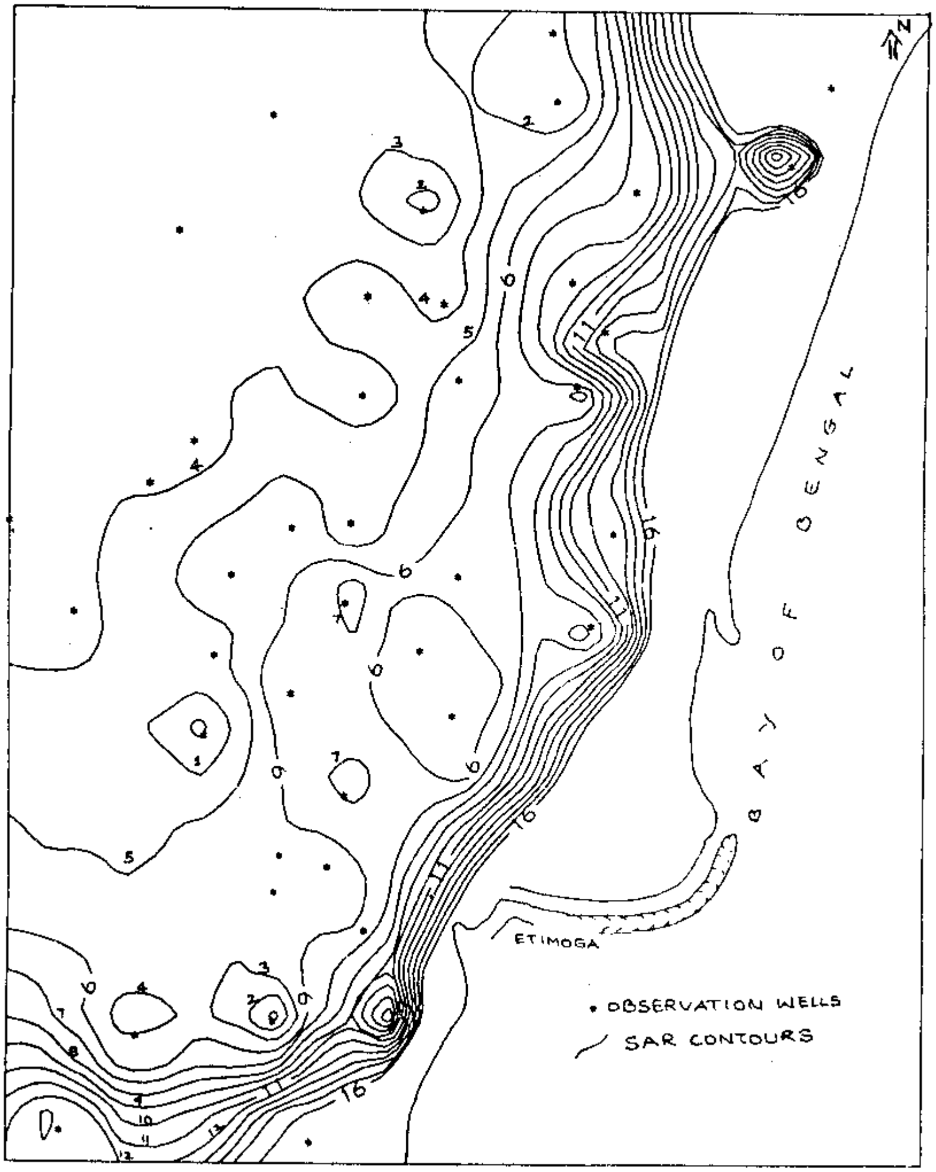


FIG.13 SPATIAL DISTRIBUTION OF SAR DURING PREMONSOON PERIOD(MAY 1998)



2 - 10 LITTLE DANGER FROM ALKALI HAZARD
7 - 18 MEDIUM HAZARD

FIG.14 SPATIAL DISTRIBUTION OF SAR DURING POSTMONSOON PERIOD(NOV. 1998)



2-10 LITTLE DANGER FROM ALKALI HAZARD

7-18 MEDIUM HAZARD

The Chloride distribution in the study area during pre monsoon and post monsoon periods are shown in Fig. 11 and 12 respectively. The comparison between these two figures indicates that there is no much significant change from pre monsoon to post monsoon period. However, the high chloride concentration was observed along sea coast and nearby salt creek area.

The spatial distribution of Sodium Adsorption ratio in the study area during pre monsoon and post monsoon periods are shown in Fig. 13 and 14 respectively. During these periods the study area falls under little danger from sodium to medium hazard of sodium.

The comparison between these two figures indicates that there is no significant change in SAR values from pre monsoon to post monsoon period.

5.0 CONCLUSIONS

The groundwater table and its quality variations have been studied in the Kakinada town covering an area of 82 Sq.Km. Total 41 Observation wells were monitored to assess the change in groundwater table and its quality. The sampling survey has been conducted in the month of Feb. 98, May 98, Aug. 98 and Nov. 98 and analysed total 164 samples for physical and chemical parameters at Water Quality Laboratory of Deltaic Regional Centre of NIH, Kakinada . Based on the groundwater table gradient, the approximate flow direction had been demarcated in the study area. The average monthly groundwater table has been compared with monthly rainfall in the study area. The main recharge to groundwater storage is from monsoon rainfall.

The variation in each physical and chemical parameter of groundwater samples collected from the study area is presented. The groundwater samples were classified according to Stiff, Piper's and U.S. Salinity laboratory classifications and observed the seasonal changes in the water types. Further, the total hardness, SAR and % Na values were calculated for each sample and classified according to their limits.

The groundwater quality parameters have been compared with WHO(1984) and ISI (1983) drinking water standards. The wells located nearby sea coast, salt creek and drains are exceeded the maximum permissible limits.

The contour maps of TDS, total hardness, chloride and SAR have been prepared using SURFER package for pre monsoon (May 98) and Post monsoon periods (Nov. 98). The comparison of these maps shows the significant change in TDS and total hardness. However, there is no significant change in chloride and SAR. The trend of chloride and SAR is observed as increasing towards sea coast in the study area except at few places.

The spatial analysis of groundwater quality parameters and continuous monitoring of water levels and quality leads to the identification of sources and type of groundwater pollution in the study area. Further, the chemical data of groundwater will help in understanding the hydrogeochemical processes in the study area, which is very much essential for coastal aquifers. Further, it is recommended to study the vertical variation of groundwater quality in the study area.

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