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SEASONAL CHANGES IN GROUNDWATER HYDROCHEMISTRY OF KAKINADA TOWN, A.P. DURING THE YEAR 1997

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LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The Deltaic Regional Centre of NIH has been monitoring shallow groundwater levels and its quality in and around Kakinada town since 1994. In continuation of this program the detailed hydrochemistry of Kakinada town during the year 1997 is presented in the report.

Total 164 groundwater samples were collected from 29 dug wells and 16 filter points during different seasons and analysed for its physical and chemical parameters. Further, the monthly groundwater levels were also measured in dug wells. The groundwater table contours (with reference to MSL) were plotted for pre monsoon (April 97) and post monsoon (Oct. 97) periods. The detailed hydrochemistry of dug wells and filter points are assessed through various classifications (Stiff, Piper and U.S.Salinity etc.) and the seasonal changes were analysed. The hydrochemistry of the study area shows that filter points are better than the dug wells for drinking water purposes. Further, the landuse/cover map of the study area was prepared on 1:50, 000 scale using IRS 1B, LISS II FCC imageries. The impact of fertiliser/land use on groundwater quality was assessed through SO_4/Cl ratio and it was found that the quality of groundwater is being influenced by fertiliser use.

The seasonal changes in water quality parameters are more in dug wells than in filter points. Much variation of TDS values observed between dug wells and filter points located in same place. More studies are necessary to find the groundwater quality at different depths in the study area rather than spatial distribution.

1.0 INTRODUCTION

1.1 General

The natural quality and quantity of groundwater varies throughout the nation. The contamination of groundwater may result from all aspects of human activities: agriculture, industry, transportation, domestic wastes and resource exploitation. The contamination due to man has occurred for centuries, but urbanisation, industrialization and increase in population density have greatly aggravated the problem especially in coastal areas. Therefore, it is important that the knowledge of the regional groundwater flow regime and its quality is necessary for planning and management of groundwater resources. Many ground water issues such as potential exploitation, sustainable yield and groundwater contamination require an understanding of regional groundwater flow processes.

To understand the groundwater flow processes, groundwater sampling is to be conducted to provide information on the condition of our sub surface water resources. Whether the goal of the monitoring effort is detection or assessment of contamination, the information gathered during sampling efforts must be known quality and be well documented. The most efficient way to accomplish these goals for water quality information is the development of a sampling protocol which is tailored to the information needs of the program and the hydrogeology of the site or region under investigation. The technical basis for the use of selected sampling procedures for environmental chemistry studies has been developed for surface-water applications over the last four decades. However, groundwater quality monitoring programs have unique needs and goals which are fundamentally different from previous investigative activities.

High quality chemical data collection is essential in groundwater monitoring programs. The technical difficulties involved in `Representative' sampling have been recognised only recently (Gibb et al. 1981; Grisak et al, 1978). It is important to keep in mind that short-term investigations may only provide a snapshot of contaminant levels or distributions. Since water quality monitoring data is normally collected on discrete dates, it is very important that reliable collection methods are used which assure high quality data over the course of the investigation. The reliability of the methods should be investigated thoroughly during the preliminary phase of monitoring network implementation.

Cost effective water quality sampling is difficult in groundwater systems, because proven field procedures have not been extensively documented. Regulations which call for 'Representative sampling' alone are not sufficient to ensure high quality data collection. The most appropriate monitoring and sampling procedures for a groundwater quality network will depend on the specific purpose of the program. In view of the importance of groundwater quality in the coastal areas, the port city Kakinada is chosen for monitoring the ground water levels and its quality for assessing the contamination levels and to observe the seasonal changes.

1.2 Review

Satyaji Rao et al (1995, 96) have analysed groundwater samples collected in Kakinada coastal aquifer and concluded that the TDS, Cl and Na concentrations are increasing towards the sea coast. According to Hardness classification, the Kakinada town falls under hard to very hard zone. The comparison of groundwater quality parameters with ISI drinking water standards showed that TDS, HCO_3 and NO_3 contents have been exceeded the maximum permissible limits. The average reduced groundwater table in the study area during pre monsoon (June 96) and post monsoon (Sep.96) periods were 1.464 and 2.592 Mts. respectively.

Shivanna et al (1992) have studied the ground water salinity in coastal Midnapore area, West Bengal using geochemistry and Environmental Isotopes. They concluded that there is no large intrusion of modern sea water in the area of study and the aquifer is receiving recharge from north west and south western parts of coastal Midnapore area.

Hirschberg,K.J.B and Appleyard,S.J (1996) have conducted a baseline survey of non point source groundwater contamination in the Perth basin, western Australia and concluded that agricultural land use is effecting groundwater quality in some areas of Perth Basin, particularly those areas with intensive agriculture where there is heavy fertilizer use, and where the water table is shallow.

Love, A.J et al (1993) have used chemical and isotopic data as groundwater tracers in combination with hydraulic head data for understanding of groundwater movement in the gambier embayment of the Otway basin.

1.3 Objectives and Scope of the Study

i. Analysis of monthly groundwater levels in the study area
ii. Evaluation of seasonal changes in hydrochemistry of Kakinada coastal aquifer
iii. Comparison of hydrochemistry between dug wells and filter points in the study area
iv. Preparation of Landuse/cover map of the study area on 1:50,000 scale using satellite imageries.
v. Influence of fertiliser use/landuse on groundwater quality in the study area
vi. Identification of mixing areas (recharge areas) in the study area based on hydrochemical changes

The above analysis gives the present contamination levels in Kakinada coastal aquifer and suitability of groundwater for various purposes. The analysis of 164 groundwater samples collected in and around Kakinada during the year 1997 will act as a bench mark of groundwater quality of the coastal aquifer. Further, the information obtained from the study will be useful for local people, Municipal water supply departments, Environmental depts., Public health departments etc. The reduced monthly groundwater level data of shallow groundwater table will be the data base for groundwater flow modelling studies in the regional level. Prior to this study, the information on ground water quality in the Kakinada coastal aquifer mostly limited to one or two wells which are being monitored by A.P.State Groundwater Department and CGWB. Therefore, the present study with more number of observation wells will be very much useful for regional level information on groundwater quality.

2.0 STUDY AREA

2.1 Location

Kakinada is the headquarters of East Godavari district of Andhra Pradesh and situated on the east coast of India. The area of the study is around 85 Km^2 and it has the coast length of 8 Kms in eastern side. The location of the study area is shown in Fig.1. The details of hydrogeology and drainage pertaining to study area were presented by Satyaji Rao et al (1996).

2.2 Climate

The climatic information of Kakinada during the study period is presented in Table 1. Average daily maximum temperature (38^0C) was observed in the month of May 97 and minimum temperature (18^0C) during the month of Jan. 97. The variation of evaporation rate is between 2.8 mm/day to 6.9 mm/day during the study period. The highest monthly rainfall (515 mm) was observed in the month of Sep.97 with the normal rainfall 152 mm.

2.3 Land use

Land use of the study area falls under the urban terrain and 1 to 2 kms parallel to sea coast was marshy land. Some of the areas near Sarpavaram, Madhura Nagar are agriculture areas and recently are being converted into urban areas. The study area is under water logging condition during monsoon period. The detailed land use/cover map of the study area is shown in Fig. 2

2.4 Geology

Kakinada town and nearby area comes under the part of Godavari eastern delta system. The main geology of the area is alluvium. About 90% of the soils in Godavari eastern delta are of silt plus clayey type, while the rest are found to be sandy soils at Ramachandhrapuram, Machavaram, Jagannadhagiri and Hasanbada. The lithology of sample site at Sarpavaram which is located in the study area is shown in Fig. 3. The Godavari silts are considered to be rich in lime, potash and phosphate(SGWD, 1977).

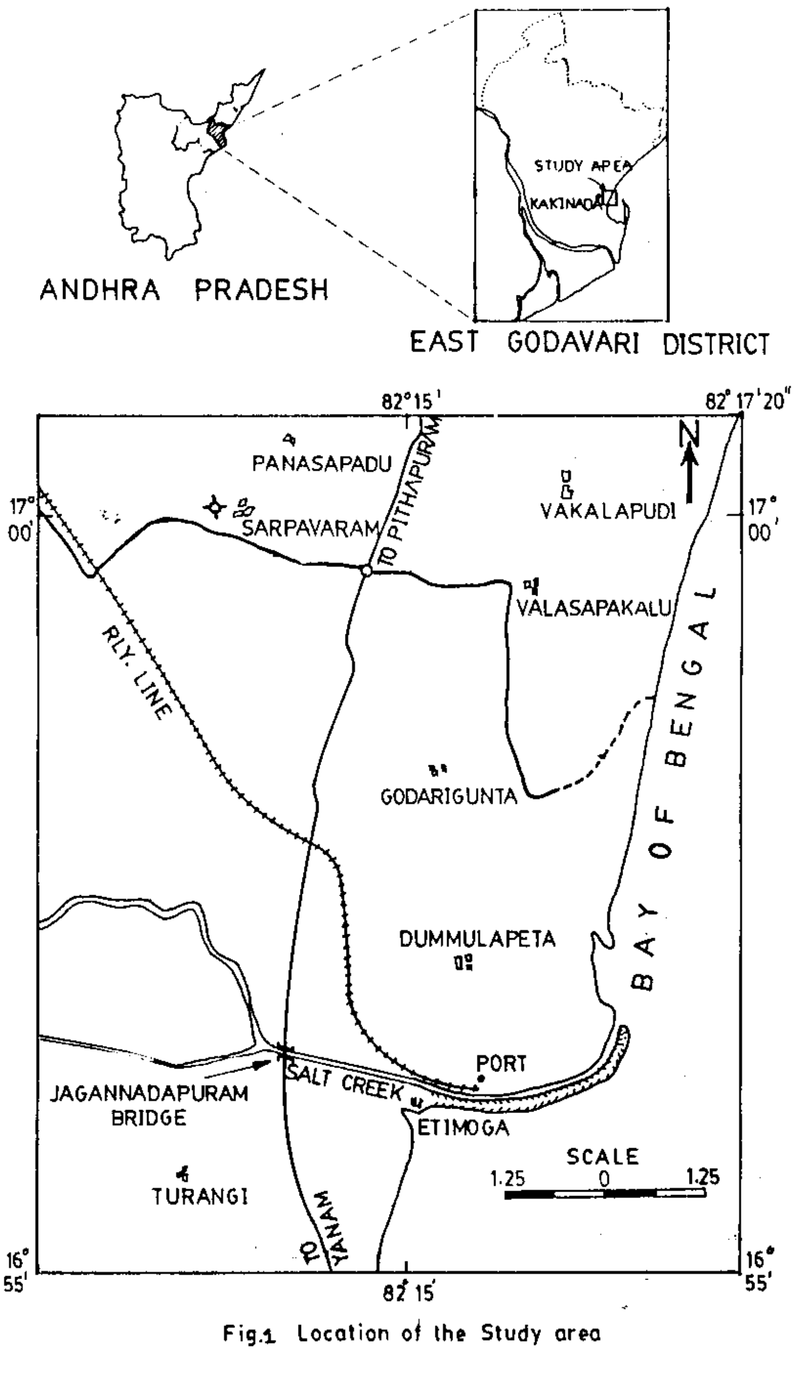


Fig.1 Location of the Study area

Table No.1

Climate data of the study area during the year 1997

Months	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Average Max Temp ^{0} C	27.7	30.9	33.7	34.4	38.0	37.4	34.0	33.9	33.1	31.8	30.3	28.8
Average Min. Temp ^{0} C	18.3	19.8	22.0	23.5	27.0	27.5	26.2	26.0	25.6	24.6	23.9	22.9
Average Evaporation (mm/day)	2.8	3.4	4.9	5.1	6.4	6.9	5.2	5.1	3.4	3.5	3.6	3.1
Average Relative Humidity (%)	86	85	84	85	82	81	91	93	91	90	91	95
Total Rainfall (mm)	6.2	0.0	30.6	79.1	0.0	53.1	169	66.6	515	182	50.1	64.5
Normal Rainfall (mm)	8.1	9.1	11.7	20.3	42.4	121.7	190.7	145	151.9	237.7	141	16.5

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

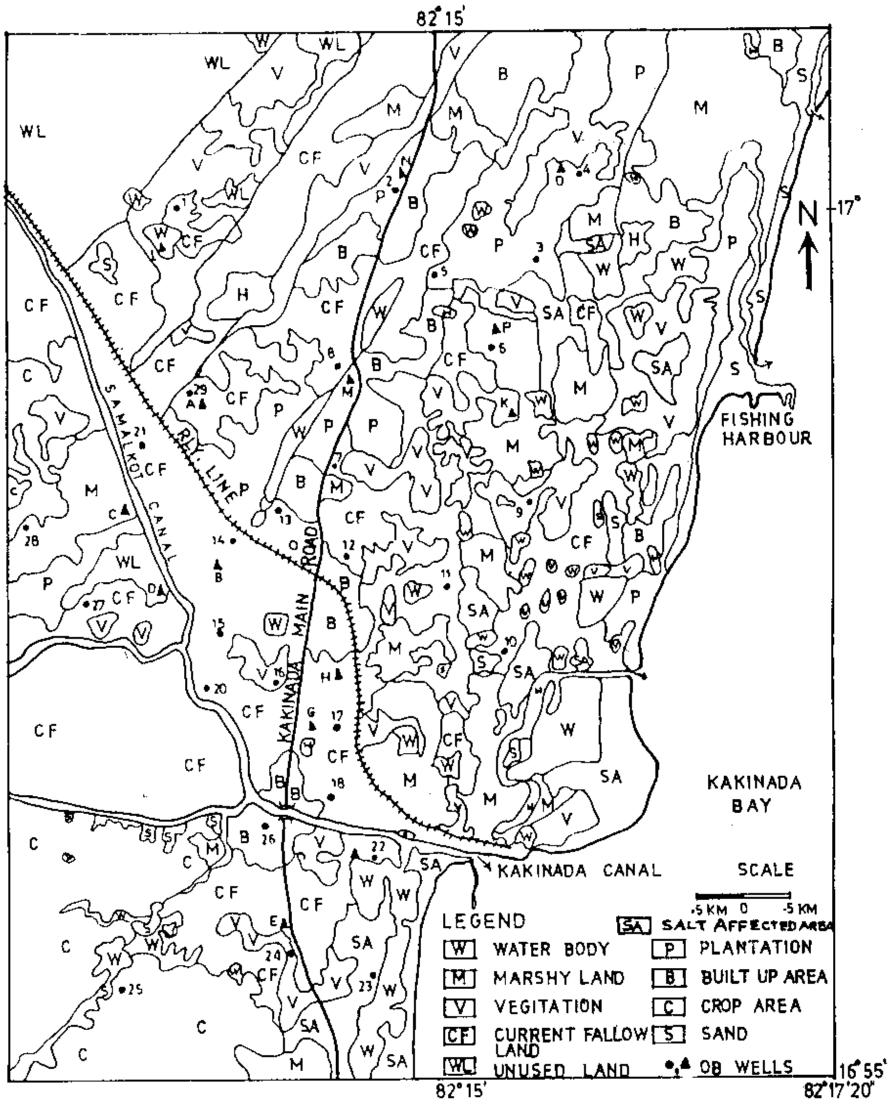
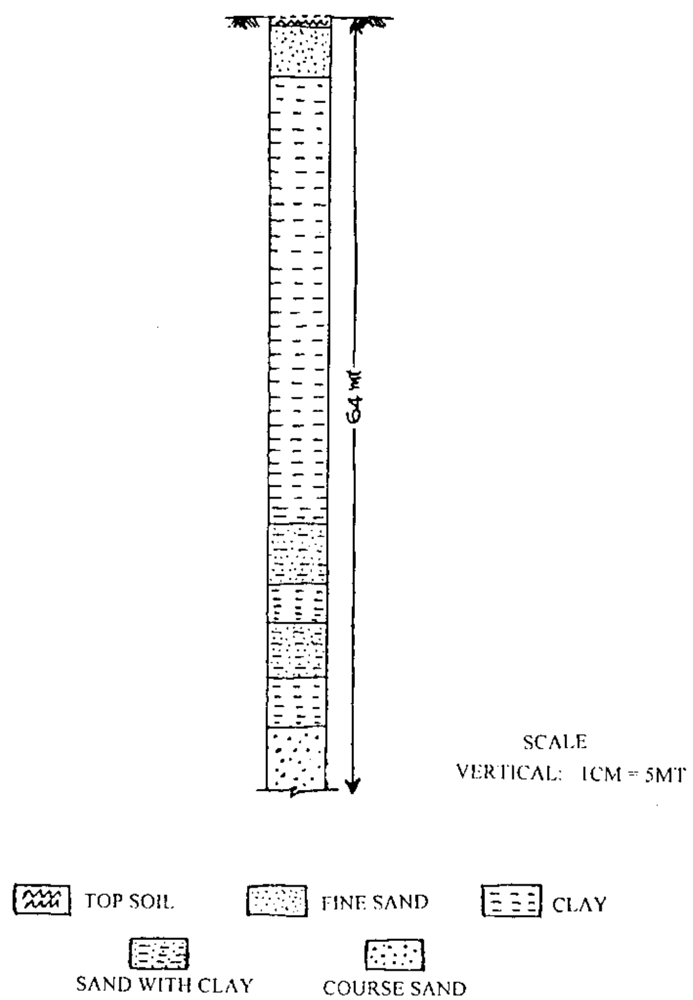


Fig 2 Land use/cover map of the study area



SOURCE: (SGWD, 1975)

FIG. 3 LITHOLOGY OF WELL LOCATED AT SARPAVARAM

2.5 Non-point source of groundwater contamination in urban areas

Practically all human activities have the potential to impact on groundwater quality. Groundwater contamination may result from the leaching of chemicals/salts from the land surface over a large area. This type of 'diffuse' or 'non-point source' groundwater contamination is commonly less severe than that derived from point sources, but may contribute to most of the contamination in a region. For example, areas with high density of septic tanks falls into this category. Groundwater contamination may also occur as the result of the accidental or deliberate disposal of solid or liquid wastes in a small area. Leachate from these point sources of contamination moves downward through the soil profile until it reaches the water table and contaminates groundwater. A distinct groundwater contamination plume may be formed that extends in the direction of groundwater flow for some distance away from the pollution source. In coastal aquifer, chances are more for groundwater contamination, so a monitoring network will help in identifying the contamination sources in the study area.

3.0 METHODOLOGY

3.1 Investigation Procedure

To achieve the overall contamination levels or hydrochemistry of the shallow groundwater in Kakinada coastal aquifer, total 45 wells have been considered within the area of 85 Km^2. Among which 29 were dug wells and 16 were filter points. Groundwater samples collected from dug wells are at the depth of 2 to 5 Mts. from ground level. Similarly the groundwater samples collected from filter points are at the depth of 5 to 7 Mts. from ground level. The depth of the water table is one of the major factor that may influence the groundwater quality. The sample survey was conducted during the month of Feb.97, May 97, Aug.97 and Nov.97.

Monthly groundwater levels were measured in 29 shallow observation wells (Dug wells) spread in and around Kakinada town. Then the monthly reduced groundwater level in each observation well was obtained. Based on monthly groundwater level conditions April 97 and October 97 are being considered as pre and post monsoon periods respectively for the analysis of groundwater levels in the study area. The groundwater table contour maps for pre monsoon (April 97) and post monsoon (Oct. 97) periods are prepared. Further, the average groundwater table fluctuation in the study area is compared with the corresponding monthly rainfall. The location of dug wells and filter points in the study area is shown in Fig.4.

A field data sheet was compiled for each well detailing information on land use and well details(Table 2). Each well was assigned sample label and it was also used for identifying the results of all chemical analysis. Well owners were interviewed prior to sampling to obtain information about the usage and to confirm bore (filter point) depths, pump capacity etc. In all wells readings for the electrical conductivity, pH and temperature were measured, and all readings were entered on the data sheet. After completion of field readings, a series of samples were taken from each well for chemical analysis. A 500 ml sample was taken in a clear plastic bottle for analysis of major ions. All samples were put into

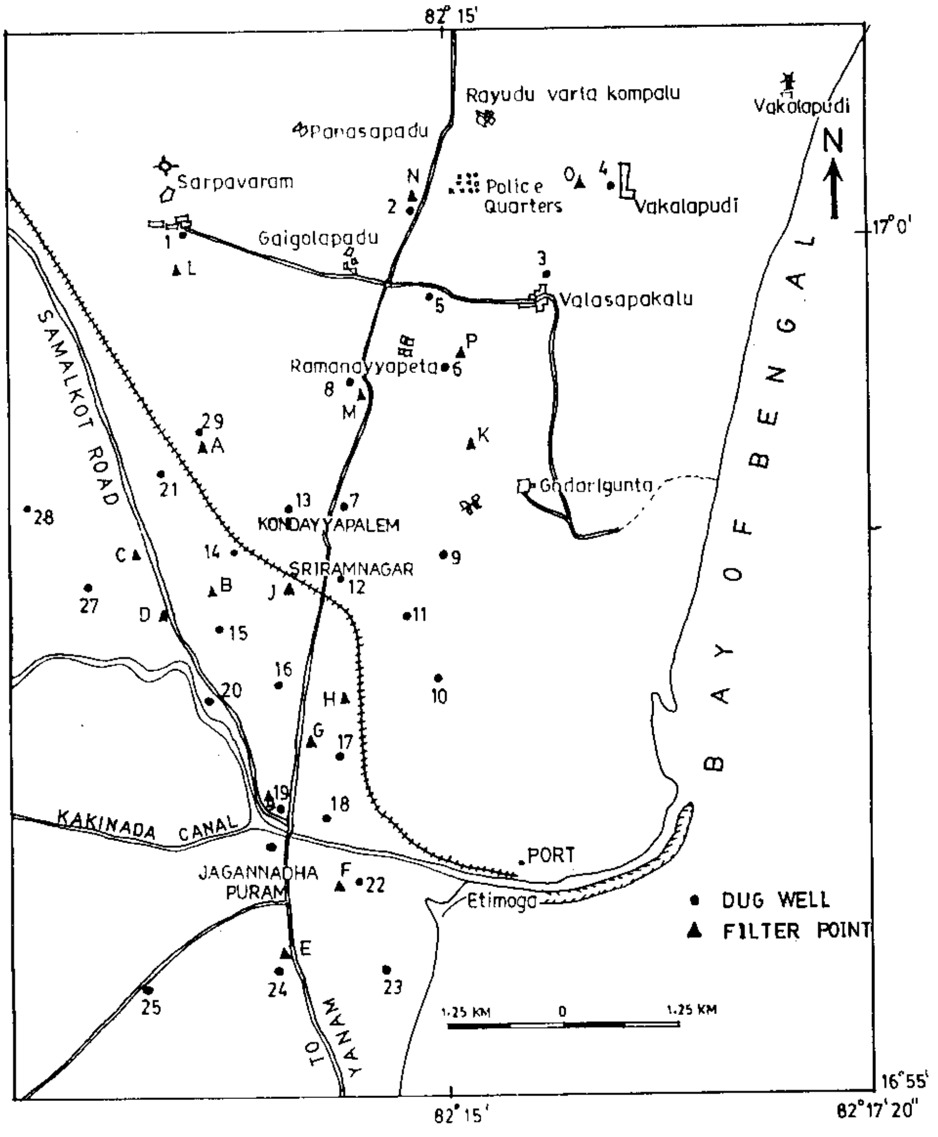


Fig. 4 Location of Observation wells (Dug wells + Filterpoints)

chilled storage. All analysis was carried out according to the procedures recommended by NIH, Roorkee (UM 26).

The laboratory analysis was carried out at Deltaic Regional Centre of NIH, Kakinada. The ion balance error was calculated for each well and observed to be in the range. However, a major parameter Nitrate could not be analysed, hence the ion balance error is more in few wells. All samples were accompanied by sample sheets with the appropriate sample label. The turn-around time in the laboratory was typically between four to six weeks.

3.2 Preparation of Landuse/cover map

The landuse/cover map of the study area is prepared using the satellite imageries. The details of satellite data is as follows.

Satellite	Sensor	Row/Path	Date of Pass	Product	Scale
IRS 1B	LISS II, A2	22/56	26.2.93	GC Std. FCC	1:50,000

The Satellite imagery is registered with base map of the study area which is prepared from Survey of India toposheets on 1: 50 000 scale. The following classification is adopted for the preparation of land use/cover map. Water bodies(W), Built-up land(B), Crop land(C), Current fallow land(CF), Marshy land(M), Sand(S), Salt affected land (SA) and Unused land (WL). These features have been demarcated on the basis of color, texture, pattern on the satellite imagery(NRSA, Landuse/cover Manual). The location of all observation wells are superimposed on the landuse/cover map(Fig. 2). Thus, the surrounding landuse/cover of each observation well is identified. The well location, its depth and its surrounding landuse are given in Table 2.

Table No.2

Details of Observation wells in the Study Area

Sl. No.	Well Label	Location	Type of well	Well depth from G.L. (mts.)	Land use nearby well
1	1	Sarpavaram	Dug Well	3.67	Crop area
2	2	Balaji Nagar	Dug Well	3.45	Built up area
3	3	Valasapakalu	Dug Well	3.14	Plantation
4	4	Vakalapudi	Dug Well	3.40	Plantation
5	5	Ramanayya Peta	Dug Well	4.12	Water body
6	6	R.R.Nagar	Dug Well	3.58	Built up area
7	7	Madhav Patnam	Dug Well	3.27	Built up area
8	8	Nagamallithota	Dug Well	3.40	Built up area
9	9	Godarigunta	Dug Well	3.21	Built up area
10	10	Sambamurthynagar	Dug Well	2.82	Current fallow land
11	11	Santhi Nagar	Dug Well	2.56	Built up area
12	12	Perraju Peta	Dug Well	2.69	Built up area
13	13	Kondayya Palem	Dug Well	3.63	Built up area
14	14	Gandhi Nagar	Dug Well	3.44	Built up area
15	15	Rama Rao peta	Dug Well	3.44	Built up area
16	16	Surya rao Peta	Dug Well	3.51	Built up area
17	17	Suryanarayana Puram	Dug Well	3.30	Current fallow land
18	18	Budam peta	Dug Well	3.65	Built up area
19	19	Temple street	Dug Well	2.53	Water body
20	20	Frazer Peta	Dug Well	2.57	Built up area
21	21	Pratap nagar	Dug Well	3.55	Built up area
22	22	Jagannadha puram	Dug Well	2.45	Built up area
23	23	Gogudanayya peta	Dug Well	1.91	Marshy area
24	24	M.S.N Charties	Dug Well	3.48	Built up area
25	25	Turangi	Dug Well	3.52	Built up area
26	26	Paradesamma peta	Dug Well	2.92	Water body
27	27	Indrapalem	Dug Well	4.00	Water body
28	28	Chidiga	Dug Well	4.98	Water body
29	29	Madhura Nagar	Dug Well	3.42	Built up area
30	A	Madhura Nagar	Filter Point	6.00	Built up area
31	B	Gandhi Nagar	Filter Point	6.70	Built up area
32	C	Indra Palem	Filter Point	6.10	Water body
33	D	Surya rao Peta	Filter Point	6.10	Built up area
34	E	M.S.N.Charties	Filter Point	6.10	Built up area
35	F	Jagannadha Puram	Filter Point	6.30	Built up area
36	G	Suryanarayana puram	Filter Point	6.40	Current fallow land
37	H	Sambamurthynagar	Filter Point	6.00	Current fallow land
38	I	Bhanugudi	Filter Point	6.35	Built up area
39	J	Town Rly.Station	Filter Point	6.80	Built up area
40	K	Godarigunta	Filter Point	6.90	Built up area
41	L	Sarpavaram	Filter Point	6.10	Crop area
42	M	Nagamalli thota	Filter Point	6.50	Built up area
43	N	Balaji Nagar	Filter Point	6.80	Built up area
44	O	Vakalapudi	Filter Point	6.50	Vegetation
45	P	R.R.Nagar	Filter Point	6.30	Built up area

To evaluate hydrochemistry of dug wells and filter points in the study area the following hydrochemical investigations are attempted.

i. The average of physical and chemical parameter of dug well samples collected during the month of Feb. 97, May 97, Aug. 97 and Nov. 97 are compared with filter point samples collected in same months.

ii. All samples were classified according to Stiff, Piper and U.S. Salinity Laboratory classification and compared for its seasonal changes. Thus the mixing/recharge zones are identified in the study area.

iii. Impact of Fertiliser use/land use on groundwater quality was assessed using SO_4/Cl ratios

iv. Suitability of groundwater for drinking water standards

v. Variations in SAR and % Na values in the study area

vi. Comparison of TDS values between dug well and filter point located at same place

4.0 RESULTS AND DISCUSSIONS

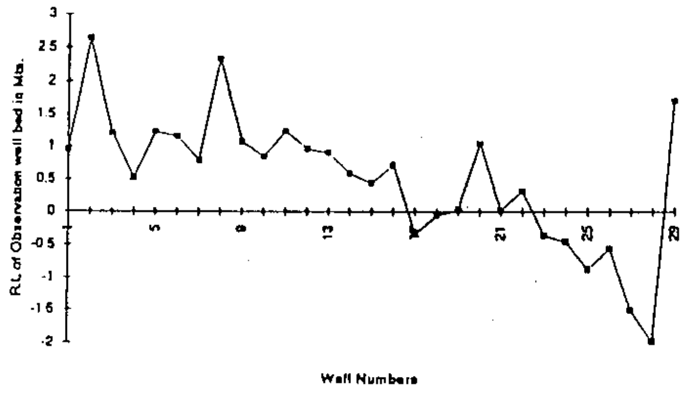
4.1 Groundwater level Measurements

The reduced level of each observation well depth in the study area is plotted to identify whether the well depth is above or below the Mean Sea Level. The monthly R.L of groundwater levels are compared with well depths and shown in Fig. 5.

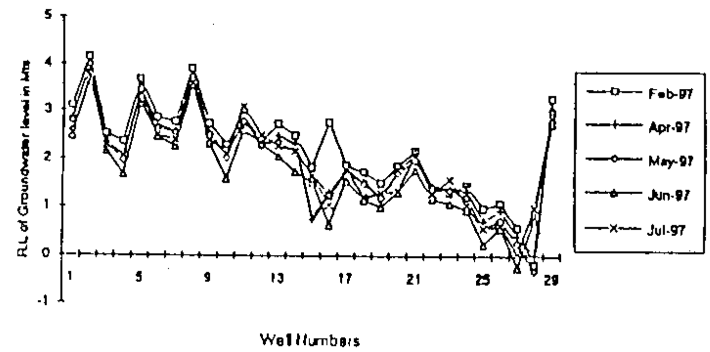
From the Fig.5 it is observed that the depth of few wells (Nos. 17,18, 23, 24, 25, 26, 27 and 28) are below M.S.L. The groundwater level fluctuations in these wells are different from wells above M.S.L. The influence of water bodies, salt creek, canal etc., may be more on wells located below MSL. The groundwater table contours during pre monsoon (April 97) and post monsoon (Oct. 97) periods were drawn and shown in Fig 6 and 7 respectively. The approximate flow directions have been demarcated on these contour maps. The flow direction observed to be towards wells located below M.S.L and sea coast. The average groundwater table in the study area during pre monsoon and post monsoon periods are 1.65 and 2.65 Mts.(above MSL) respectively. It is necessary for increasing the observation well network especially parallel to sea coast and upstream of well No.1 for demarcation of actual groundwater flow direction in the regional scale. The comparison between average groundwater table and monthly rainfall in the study area is shown in Fig.8. From this it is observed that the influence of rainfall during the months of July 97 and Sep. 97 was clearly observed on average groundwater table conditions in the study area. Due to the shallow groundwater table conditions and the unsaturated zone (a mix of sand and clay) of the aquifer, the rainfall recharge is reaching to the groundwater storage at faster rate in the study area. Monitoring of average groundwater table fluctuation is very much necessary to arrest the seawater intrusion/up coning, if any in the study area.

4.2 Hydrochemistry of dug wells

The physical and chemical analysis results of samples collected from dug wells during the month of Feb. 97, May 97, Aug. 97 and Nov. 97 are given in Table 3, 4, 5 and 6 respectively.



Comparison of Groundwater levels in Observation Wells



Comparison of Groundwater levels in observation wells

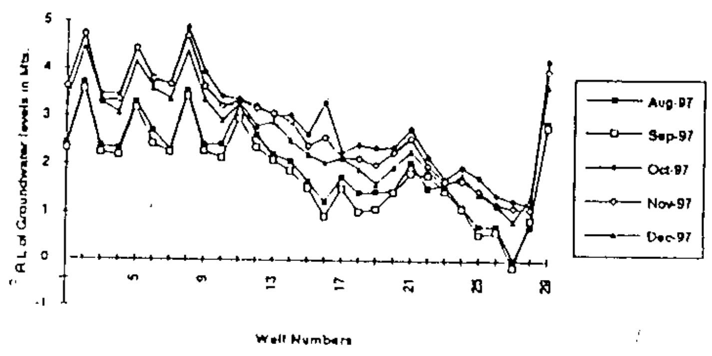


Fig. 5 Monthly groundwater levels and RL of well bed level

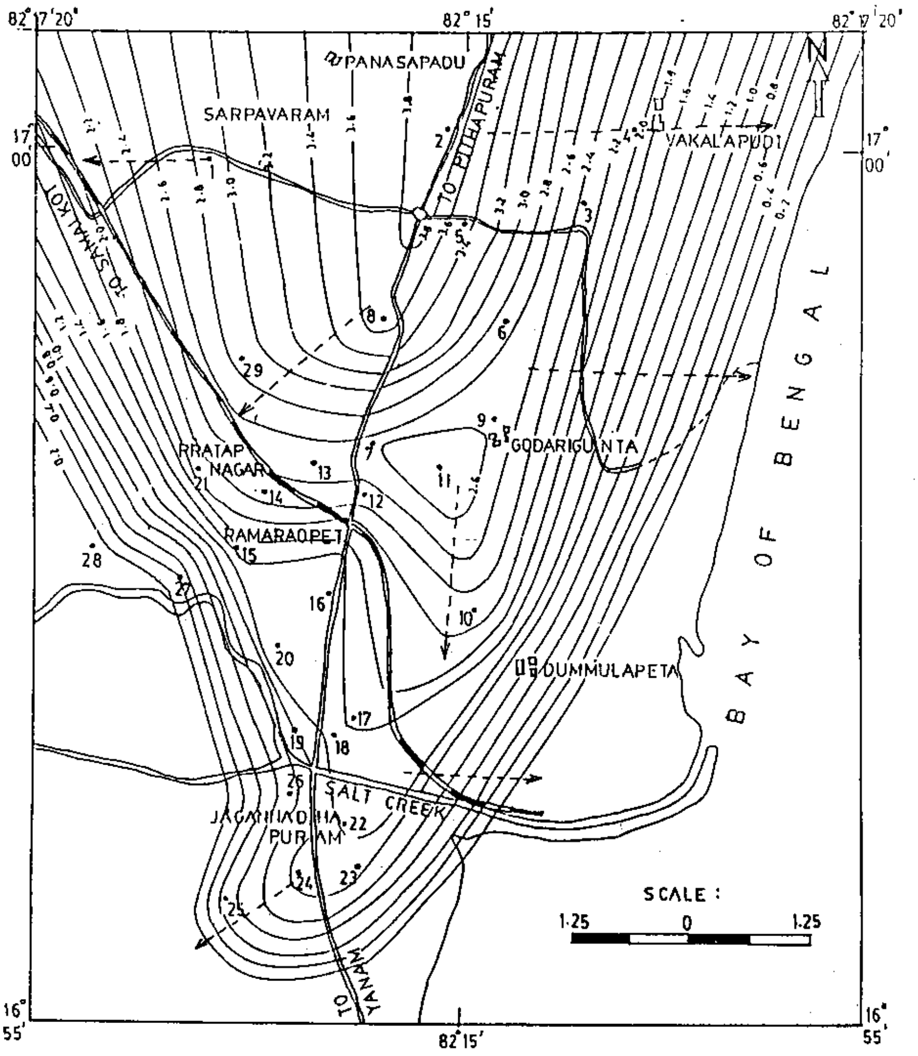


Fig. 6 Groundwater table contours during pre monsoon period, (April 1997)

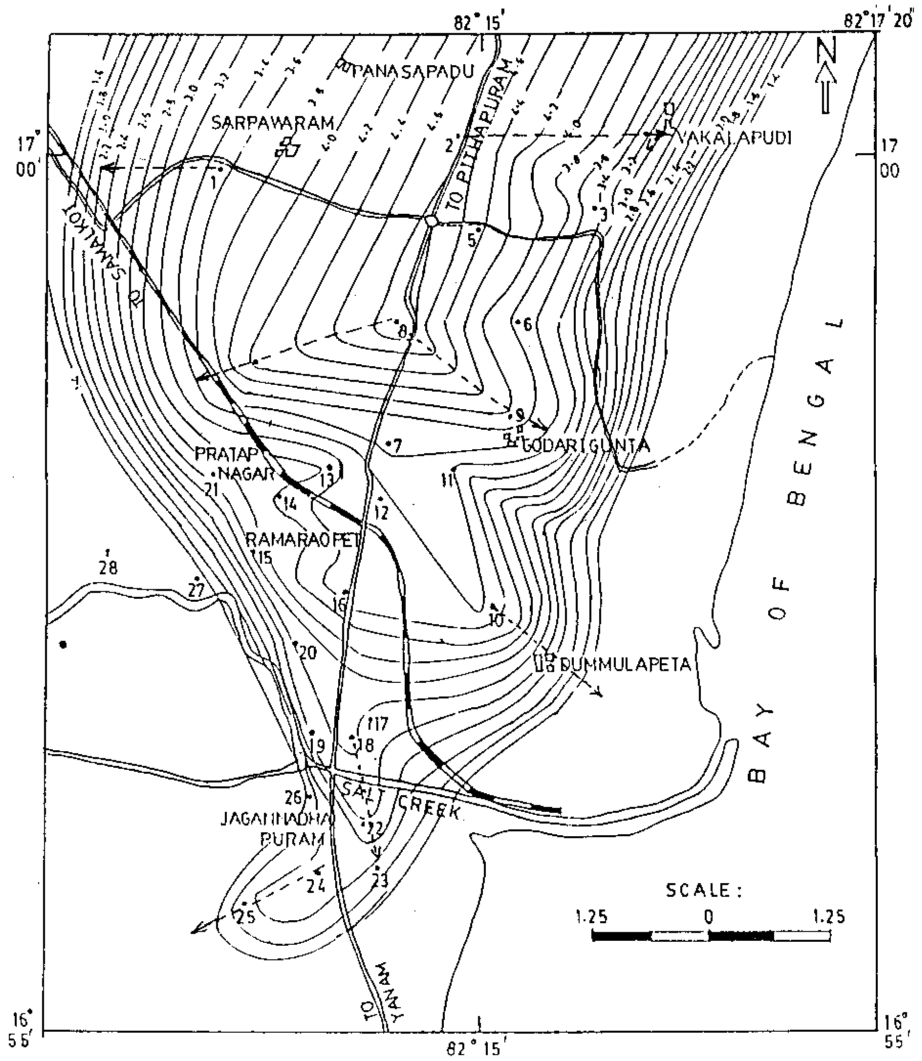
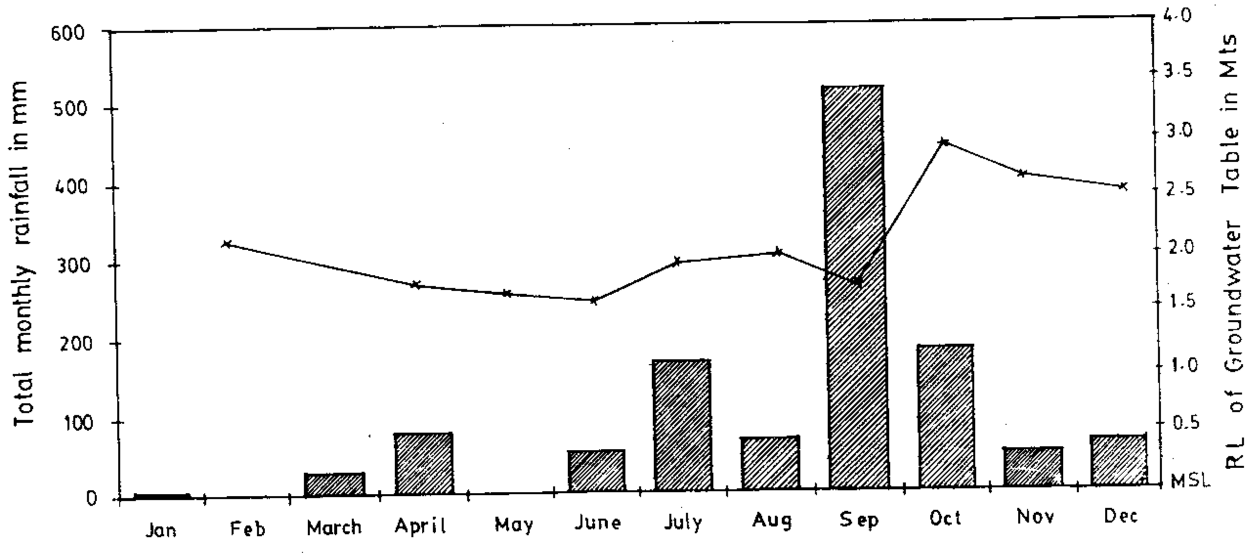


Fig. 7 Groundwater table contours during post monsoon period (October 1997)

Comparison of RL of Groundwater table and rainfall



Months (Jan 97 Dec 97)

Fig 8 Comparison between average groundwater table and monthly rainfall

TABLE NO.3.

Chemical analysis of Groundwater samples collected in Kakinada Town (Dug Wells) during the month of Feb '97.

Well ID.	Temp °C	pH	EC (μmhos/cm) at 25°C	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^{-3} (ppm)
1	26	7.3	1480	947	410	100.3	38.9	100	80.0	292	188	115.0	1.5
2	27	7.1	1070	685	274	81.8	17.0	120	30.0	320	144	28.5	0.8
3	26	6.4	3500	2240	654	120.3	86.0	375	210.0	730	454	267.0	1.0
4	26	7.5	1930	1235	423	98.0	43.3	230	30.0	544	286	60.0	1.3
5	28	6.8	1260	806	360	87.4	34.5	70	80.0	316	98	96.0	7.5
6	27	7.1	1110	710	392	76.2	49.1	85	5.8	388	132	37.5	1.2
7	26	6.9	810	518	232	60.2	19.9	70	18.0	302	54	33.0	0.9
8	26	7.1	400	256	200	56.9	14.1	75	9.8	210	88	84.0	0.9
9	27	7.4	1750	1120	334	88.2	27.7	185	75.0	346	264	54.0	1.0
10	27	7.5	1060	678	288	68.2	28.7	90	30.0	422	28	60.0	1.1
11	27	7.8	250	160	128	40.1	6.8	20	3.2	174	10	15.0	0.8
12	26	7.1	1970	1261	374	88.1	37.3	245	45.0	524	234	177.0	1.5
13	28	7.2	1480	947	270	60.2	29.2	125	120.0	292	164	99.0	1.9
14	28	7.2	1150	736	294	65.8	31.6	110	35.0	374	108	64.5	1.4
15	28	6.9	1200	768	340	83.4	32.1	105	60.0	388	104	54.0	3.0
16	27	7.3	2450	1568	474	91.4	59.8	310	145.0	832	254	150.0	2.4
17	26	7.1	3810	2438	440	120.3	34.0	510	160.0	882	614	117.0	1.1
18	27	7.2	2530	1619	757	200.5	62.2	170	120.0	600	294	202.0	1.4
19	27	7.2	3100	1984	823	240.6	53.9	295	85.0	718	384	440.0	2.6
20	26	6.9	1320	845	360	80.2	38.9	80	75.0	382	124	47.0	2.6
21	26	7.3	350	224	150	28.1	19.4	15	25.0	180	12	19.5	0.8
22	27	7.1	2580	1651	512	124.3	49.1	370	35.0	800	304	138.0	1.4
23	28	7.9	1800	1152	346	81.8	34.5	250	25.0	614	184	126.0	0.7
24	28	7.3	600	384	150	32.1	17.0	60	50.0	200	64	45.0	3.1
25	26	7.2	2690	1721	588	120.3	70.0	315	20.0	360	500	212.0	2.5
26	27	6.7	2490	1593	440	81.0	57.8	315	120.0	724	264	135.0	1.9
27	27	6.8	1750	1120	338	76.2	36.0	215	85.0	460	214	127.0	2.6
28	27	6.8	1250	800	324	91.4	23.3	80	12.0	170	162	102.0	3.8
29	26	7.2	400	256	226	62.6	17.0	20	8.0	206	32	24.0	1.9

T.H. - Total Hardness.

TABLE NO.4.

Chemical analysis of Groundwater samples collected in Kakinada Town (Dug Wells) during the month of May '97.

Well ID.	Temp °C	pH	EC (μmhos/cm) at 25°C	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^{-3} (ppm)
1	31	7.1	1700	1088	585	168.4	40.0	120	50	318	248	106.0	1.0
2	30	6.9	820	525	208	60.2	14.0	125	15	240	166	28.5	0.4
3	32	7.2	2930	1875	448	121.0	35.5	390	195	662	388	220.0	0.8
4	30	7.1	1830	1171	440	96.2	48.6	280	33	540	290	55.5	0.8
5	31	7.2	1300	832	248	96.2	2.0	125	82	336	122	82.5	1.3
6	31	7.3	1600	1024	420	128.3	24.3	100	8	408	238	70.5	0.8
7	30	7.3	670	429	252	44.9	34.0	35	15	248	54	33.0	0.9
8	32	7.4	410	263	280	56.1	34.0	120	8	240	128	74.5	1.4
9	30	7.3	1660	1062	368	64.2	50.5	175	44	348	342	42.0	0.9
10	31	7.1	1180	755	328	70.6	37.0	120	7	558	48	85.5	1.1
11	31	7.2	406	260	100	20.9	11.7	25	3	146	12	4.5	0.2
12	31	7.2	3170	2029	504	89.9	68.0	415	34	628	536	190.0	2.6
13	32	7.2	1950	1248	372	96.2	32.0	160	120	308	200	121.0	2.1
14	30	7.1	1200	768	320	78.6	30.1	140	31	424	132	66.0	2.1
15	31	7.3	1070	685	304	70.6	31.0	100	32	390	84	27.0	3.2
16	30	7.5	2590	1657	452	81.8	60.3	320	136	846	256	114.0	2.4
17	30	7.4	3890	2489	296	69.0	30.1	475	130	808	612	94.5	0.8
18	30	7.2	3300	2112	749	197.3	62.2	240	134	572	328	172.0	2.5
19	31	7.1	2300	1472	772	142.8	101.1	215	90	576	260	365.0	2.6
20	31	7.3	1470	941	412	86.0	48.0	90	72	404	112	48.0	2.6
21	31	7.1	600	384	280	65.8	28.2	20	17	252	32	13.5	1.0
22	31	7.2	1730	1107	308	81.8	25.3	285	20	676	196	66.0	2.1
23	31	7.1	1580	1011	260	57.7	28.2	185	18	448	190	69.0	2.6
24	31	7.5	630	403	120	22.5	15.5	55	25	216	48	18.0	1.1
25	30	7.2	2890	1849	513	176.4	17.5	275	9	360	520	120.0	1.4
26	30	7.4	2970	1901	369	88.3	36.0	375	94	752	400	144.0	2.9
27	30	7.2	1100	704	152	51.3	5.8	190	62	372	144	82.5	0.6
28	30	7.1	1460	934	286	80.2	20.9	105	14	188	142	60.0	0.8
29	32	7.2	700	448	200	48.1	19.4	15	4	240	36	16.5	0.5

T.H. - Total Hardness.

TABLE NO.5.

Chemical analysis of Groundwater samples collected in Kakinada Town (Dug Wells) during the month of Aug '97.

Well NO.	Temp °C	pH	EC (µmhos/cm) at 25°C	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^{-3} (ppm)
1	29	7.1	1400	899	643	169	54	145	41	330	232	124.0	2.3
2	29	7.0	750	481	186	48	16	95	11	226	116	7.5	2.3
3	30	7.5	2550	1637	485	82	68	410	135	736	452	172.0	2.3
4	30	7.4	1950	1252	564	160	40	315	21	652	380	115.0	0.9
5	30	7.2	1100	706	343	88	30	135	65	326	124	84.0	4.3
6	29	7.6	1100	706	370	92	34	170	7	424	192	48.0	0.9
7	29	7.2	750	481	219	58	18	100	18	282	76	36.0	1.5
8	29	7.5	415	266	218	55	20	19	11	256	36	7.5	0.8
9	30	7.6	1700	1091	440	92	51	230	56	394	396	48.0	0.8
10	29	7.3	1000	642	377	128	14	135	11	548	68	76.5	1.5
11	29	7.3	305	196	81	21	7	10	3	86	20	30.0	1.1
12	30	7.5	2550	1637	595	184	33	490	32	708	572	195.0	0.8
13	30	7.3	1650	1059	488	108	53	210	115	350	220	136.0	5.0
14	30	7.2	1250	802	408	96	41	175	36	530	168	76.5	3.2
15	29	7.3	1000	642	312	87	23	90	39	382	112	36.0	4.8
16	30	7.7	1800	1155	381	128	15	305	101	874	224	105.0	7.5
17	29	7.4	2350	1509	369	90	35	390	122	818	464	96.0	6.4
18	30	7.4	2200	1412	832	226	65	225	133	678	348	145.0	7.5
19	29	7.3	2900	1862	864	257	54	395	125	874	512	520.0	8.3
20	29	7.2	1150	738	400	101	36	80	55	420	120	48.0	4.8
21	30	7.1	550	353	239	66	18	60	12	244	52	42.0	1.5
22	30	7.6	2100	1348	599	131	66	315	29	848	260	108.0	7.7
23	30	7.1	2600	1669	139	31	15	14	4	108	32	25.5	3.4
24	29	7.8	700	449	200	42	23	80	32	264	104	55.5	1.8
25	30	7.3	4150	2664	1362	369	107	480	20	458	1076	144.0	5.2
26	29	7.4	1850	1187	459	80	63	290	86	768	280	145.0	5.5
27	30	7.2	1750	1123	459	90	57	200	72	496	292	165.0	13.1
28	30	6.9	1400	899	490	122	45	140	16	182	264	151.0	13.1
29	30	7.4	465	298	232	42	31	29	5	232	36	6.0	10.7

T.H. - Total Hardness.

TABLE NO.6.

Chemical analysis of Groundwater samples collected in Kakinada Town (Dug Wells) during the month of Nov.'97.

Well ID.	Temp ^{0}C	pH	EC (μmhos/cm) at $25^{0}C$	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^{-3} (ppm)
1	27	7.1	2050	1316	767	144	99	150	125	410	332	217	2.8
2	28	6.9	850	545	298	75	27	125	22	270	160	217	1.0
3	27	7.3	2850	1829	686	120	94	460	245	734	576	225	0.4
4	27	7.2	1950	1252	556	114	66	440	43	575	400	112	0.0
5	27	7.2	900	578	327	83	29	140	79	286	128	75	1.0
6	27	7.4	500	321	202	53	17	75	10	228	48	30	0.4
7	26	7.2	800	513	311	70	33	125	19	340	76	48	2.1
8	28	7.5	420	269	186	48	16	70	11	292	24	22	0.5
9	28	7.5	1150	738	301	66	33	210	52	272	260	43	3.1
10	27	7.3	750	449	286	75	24	60	12	332	52	45	1.1
11	27	7.7	285	183	120	25	14	35	4	136	24	27	0.0
12	27	7.2	1950	1252	537	192	14	250	45	524	372	160	1.6
13	27	7.5	1750	1123	483	98	58	115	105	324	224	93	1.8
14	27	7.3	1250	802	464	125	37	125	44	394	176	72	1.2
15	27	7.4	1100	706	336	85	30	110	53	282	128	81	0.9
16	26	7.8	1550	995	340	80	34	195	155	616	172	93	1.8
17	28	7.4	2500	1605	512	78	77	500	215	756	536	96	1.1
18	27	7.2	2950	1894	710	169	70	270	175	564	448	180	0.9
19	27	7.2	2700	1733	1079	221	128	285	125	504	532	330	2.8
20	27	7.4	1100	706	388	83	44	70	80	386	132	61	2.4
21	27	7.3	750	482	371	86	38	75	16	356	48	52	1.0
22	27	7.3	1600	1027	507	109	57	170	27	544	240	118	4.5
23	28	7.5	325	209	166	27	24	25	4	152	28	22	2.5
24	27	7.7	850	546	299	54	40	105	59	278	176	69	1.7
25	27	7.2	3600	2311	862	215	79	520	32	356	932	165	3.5
26	27	7.5	2150	1380	443	95	50	350	150	650	292	135	1.8
27	28	7.2	1650	1059	484	95	60	250	100	546	272	133	2.8
28	28	7.6	750	481	247	48	31	65	96	186	112	72	4.1
29	27	7.2	500	321	267	56	31	20	9	160	44	52	2.4

T.H. - Total Hardness.

4.2.1 Physical parameters

pH:

Due to the similar hydrogeological environment of the observation wells, the values for pH were not varying considerably during the study period. Most pH readings were higher than 7 in the study area and are probably due to the buffer effect of high concentrations of bicarbonate ions in these areas. Values of pH below 6 were uncommon in the area.

EC:

Measurements of Electrical Conductivity (EC) in observation wells varied considerably even in similar hydrogeological conditions. The variations in EC values may be due to number of chemical processes controlling EC in groundwater in the region, including the oxidation and reduction of iron and sulphur species. The range of EC values observed in the month of Feb.97, May 97, Aug. 97 and Nov. 97 was 350-3810, 410-3890, 305-4150, 285-3600 μ mhos/cm respectively. The minimum and maximum values of EC during the study period were observed in well No. (285 μmhos/cm) and well No. 25 (4150 μmhos/cm) respectively.

Temperature:

There is no much temp. variation in observation wells. The seasonal change in temperature is also observed in groundwater samples collected from dug wells. The average temperature of groundwater samples collected from dug wells during the month of Feb.97, May 97, Aug. 97 and Nov.97 are 26.8^{0}C, 24.5^{0}C, 29.3^{0}C and 27^{0}C respectively.

4.2.2 Major cations

Calcium:

The range of calcium in the study area during the month of Feb. 97, May 97, Aug. 97 and Nov. 97 was 28-240, 21-197, 21-369 and 25-221 ppm respectively. High concentration of calcium was observed in well Nos.18, 19 and 25. These wells are located nearby salt creek and Cheediga (Fig.4). The average values of calcium during pre monsoon (May 97), mönsoon (Aug. 97) and Post monsoon (Nov. 97) periods are 87, 112, and 96 ppm respectively. There is not much significance seasonal variation in calcium content in the study area.

Magnesium:

The range of Magnesium in the study area during the month of Feb. 97, May 97, Aug.97 and Nov.97 was 6.8-86, 2-101, 7-107, 14-128 ppm respectively. High concentration of Magnesium was observed in well Nos.3, 19 and 25. These wells are located near sea and salt creek (Fig.4).

Sodium and Potassium:

The Sodium content in every sample was greater than the potassium content during the study period. The range of sodium during the month of Feb.97, May 97, Aug.97 and Nov.97 was 20-510, 15-475, 14-490 and 20-520 ppm respectively. Similarly the potassium range was 8-210, 3-195, 4-135 and 4-245 ppm respectively. High sodium content was observed always in well No.3 which is located near marshy land and near to the sea coast.

Among all major cations most dominated cation is sodium and few wells showed calcium. The lowest content of cation observed in the study area was Magnesium. The variation of major cations in each observation well during different seasons are plotted and shown in Fig.9. The concentrations of cations are increasing from pre monsoon (May 97) to post monsoon period (Nov.97) which is not in general in other areas. However, this phenomena quite often observed in coastal areas. The reason may be due to the residual solids on the ground surface which are accumulated during pre monsoon period through evaporation. During the monsoon period the rainfall recharge carries the salts accumulated on soil surface to the groundwater. Further, it is necessary to analyse the soil samples for its chemical constituents in the study area to confirm this phenomena.

4.2.3 Major Anions:

Bicarbonate:

It is a major anion in the study area. The range of bicarbonate during the month of Feb. 97, May 97, Aug.97 and Nov.97 was 170-800, 146-846, 86-874 and 136-756 ppm respectively. High bicarbonate content was observed in well Nos.16, 17 and 22.

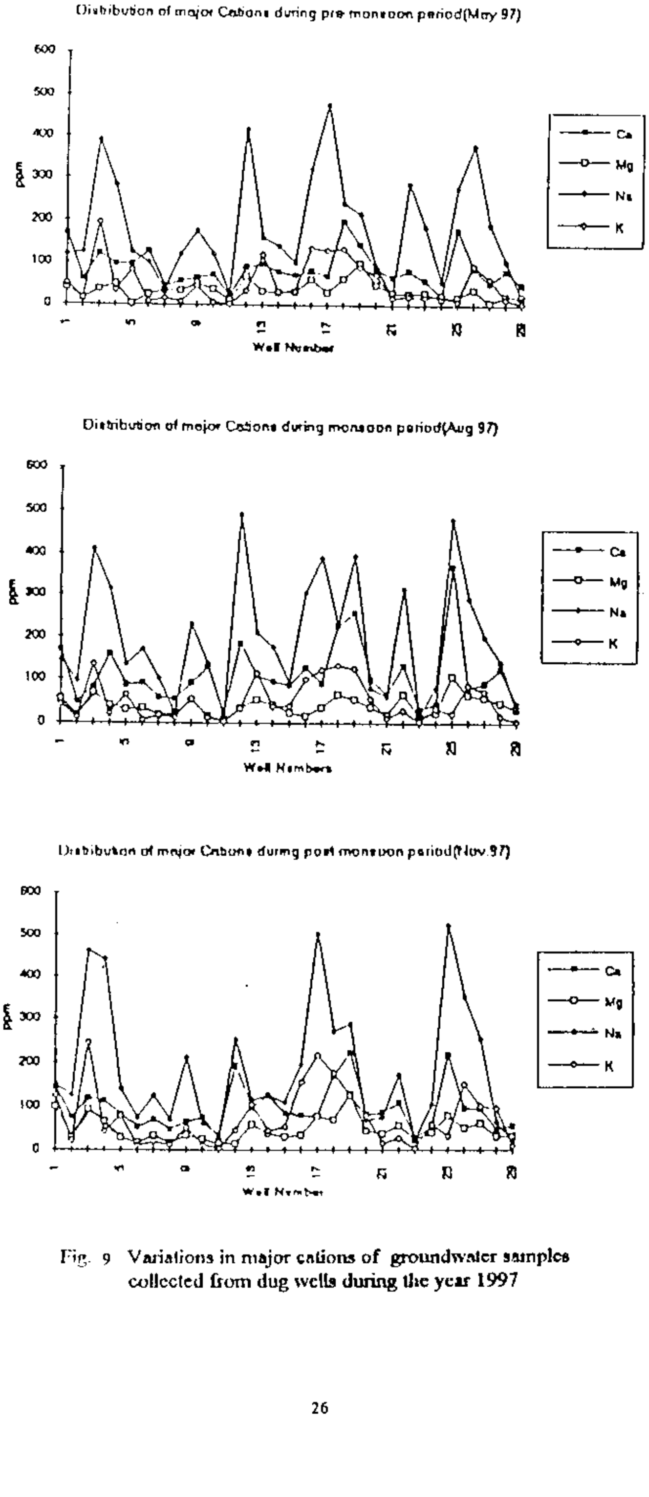


Fig. 9 Variations in major cations of groundwater samples collected from dug wells during the year 1997

Chlorides:

The range of chloride content during the month of Feb.97, May 97, Aug.97 and Nov 97 was 10-614, 12-612, 20-464 and 24-536 ppm respectively. High concentration of chloride content was observed in wells located below M.S.L, salt creek and nearby sea coast.

Sulfate and Phosphate:

The range of sulfate content during the month of Feb. 97, May 97, Aug. 97 and Nov. 97 was 20-440, 5-365, 6-520 and 22-330 ppm respectively. Well No.19 showed high concentration of sulfate among all observation wells during the study period.

The phosphate content in all observation wells was observed to be less than 13 ppm during the study period. The distribution of all major anions during the study period is shown in Fig.10 The average concentration of anions (HCO_3, Cl and SO_4) was observed to be high in monsoon period (Aug. 97) than in pre and post monsoon periods. The reason may be due to the recharge of rainwater which carries various salts from the surface and joins into the shallow water table.

4.3 Hydrochemistry of Filter Points

Total sixteen filter points located in and around Kakinada were selected for assessing groundwater quality. The location of these filter points are shown in Fig.4. The details of filter points are given in Table 2. Groundwater samples from these filter points were collected during the month of May 97, Aug. 97 and Nov. 97, and analysed for its physical and chemical parameters. The analysis results are given in Table 7 & 8 and 9 respectively.

4.3.1 Physical Parameters

The temperature of groundwater samples collected from different filter points are observed to be same in each survey conducted during the month of May 97, Aug. 97 and Nov. 97. The average temperature of filter points during these months are 24.5^0 C, 29^0 C and 27^0 C respectively. The range of electrical conductivity in the month of May 97, Aug. 97 and Nov. 97 was 470-1090, 255-3450 and 330-2900 μmhos/cm respectively. The pH values varied in between 7 to 8 during the study period.

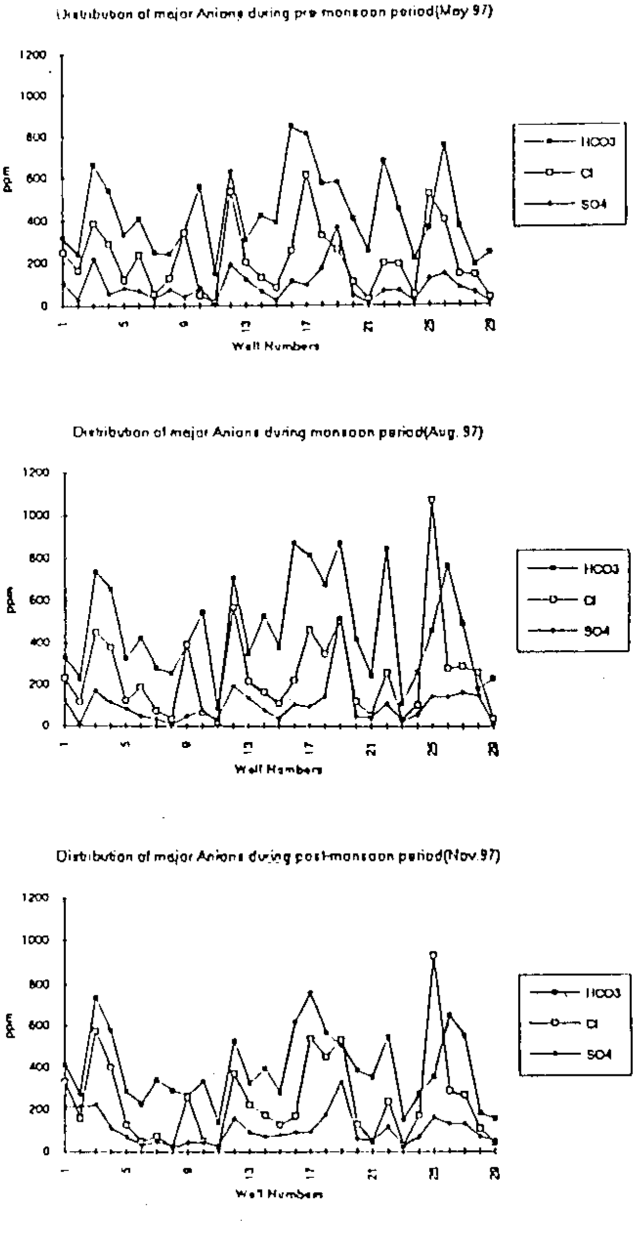


Fig. 10 Variations in major anions of groundwater samples collected from dug wells during the year 1997

TABLE NO.7.

Chemical analysis of Groundwater samples collected in Kakinada Town (Filter Points) during the month of May.'97.

Well ID.	Temp °C	pH	EC (μmhos/cm) at 25°C	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^{-3} (ppm)
A	24.5	7.6	1484	950	504	101.1	61.2	150	4	340	180	153.0	0.8
B	24.5	7.2	1138	728	277	63.0	29.2	90	27	236	100	79.5	2.6
C	24.5	6.9	1121	717	280	77.0	21.4	75	11	240	108	45.0	0.5
D	24.5	7.2	1745	1117	332	67.4	39.9	260	23	336	236	135.0	3.0
E	24.5	7.6	846	541	240	49.7	28.2	85	26	280	44	79.5	0.3
F	24.5	7.2	1890	1209	624	121.9	77.8	55	105	648	120	50.0	0.2
G	24.5	7.3	1000	640	504	80.2	73.9	595	76	660	700	153.0	0.2
H	24.5	7.4	1000	640	412	88.2	46.7	615	26	624	692	108.0	0.2
I	24.5	7.2	1000	640	496	118.7	48.6	265	59	376	404	105.0	0.8
J	24.5	7.2	1683	1078	447	107.0	43.7	160	76	384	204	90.0	1.2
K	24.5	7.3	1000	640	428	81.8	54.4	360	22	568	388	79.5	0.8
L	24.5	7.1	595	381	192	54.5	13.6	60	7	188	50	45.0	0.5
M	24.5	7.4	639	409	212	57.7	16.5	45	0	212	36	30.0	0.4
N	24.5	6.9	470	301	80	22.5	5.8	95	4	168	68	12.0	0.6
O	24.5	7.3	1005	643	168	45.0	13.6	140	4	300	124	22.5	1.2
P	24.5	7.4	1258	805	280	80.2	19.4	175	2	348	168	41.0	0.8

T.H. - Total Hardness.

TABLE NO.8.

Chemical analysis of Groundwater samples collected in Kakinada Town (Filter Points) during the month of Aug '97.

Well No.	Temp ^0C	pH	EC (μmhos/cm) at 25^0C	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^{-3} (ppm)
A	29	7.7	1050	674	483	93	61	130	6	152	192	178.0	1.8
B	30	7.1	900	578	285	63	31	95	25	244	80	68.0	2.5
C	29	6.8	1200	770	282	65	29	150	15	242	180	51.0	3.5
D	29	7.3	1400	899	395	74	51	305	23	360	252	142.0	11.7
E	29	7.6	700	449	218	43	27	110	24	292	48	57.0	2.7
F	30	7.1	255	164	89	24	7	11	2	78	20	30.0	1.1
G	30	7.4	2700	1733	424	66	63	560	67	686	640	195.0	4.1
H	30	7.6	3450	2215	453	71	67	730	20	774	960	142.0	5.8
I	30	7.3	1750	1123	489	107	54	265	48	406	324	127.0	5.2
J	29	7.5	1150	738	410	90	45	165	59	406	160	97.5	5.0
K	29	7.2	1300	834	341	64	44	275	29	632	140	48.0	1.7
L	29	7.3	480	308	177	43	17	30	7	184	44	34.5	1.1
M	29	7.6	410	263	198	43	22	43	1	224	36	6.0	1.8
N	29	7.1	500	321	145	30	17	84	6	212	60	6.0	1.5
O	29	7.6	750	481	169	43	15	145	5	320	92	3.0	12.4
P	29	7.6	1250	802	421	88	49	190	6	448	224	45.0	4.1

T.H. - Total Hardness.

TABLE NO.9.

Chemical analysis of Groundwater samples collected in Kakinada Town (Filter Points) during the month of Nov.'97.

Well ID.	Temp °C	pH	EC (µmhos/cm) at 25°C	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^{-3} (ppm)
A	27	7.6	1350	867	630	109	87	120	7	396	240	139	1.2
B	27	7.2	750	482	267	56	31	80	22	242	76	67	2.4
C	27	7.0	800	514	291	64	32	70	18	210	120	39	2.1
D	27	7.4	1600	1027	459	85	60	265	36	322	296	135	7.0
E	27	7.8	440	282	178	40	19	65	15	194	48	54	2.6
F	27	7.8	330	212	168	26	25	40	4	252	16	7	1.1
G	27	7.5	2900	1862	402	62	60	520	88	574	744	115	3.2
H	26	7.3	2700	1733	423	82	53	530	31	596	752	180	5.8
I	28	7.2	1600	1027	445	94	51	245	64	364	360	138	5.2
J	27	7.3	1350	866	491	106	55	160	90	392	200	117	4.0
K	27	7.3	1200	770	348	72	41	195	57	270	252	110	3.0
L	27	7.0	700	449	211	53	19	75	11	194	68	57	3.0
M	27	7.6	490	315	208	42	25	35	2	208	32	39	2.0
N	27	7.0	550	353	174	40	18	70	7	154	84	33	1.5
O	27	7.4	800	513	199	50	18	90	7	152	120	15	8.9
P	27	7.5	1050	647	369	72	46	100	6	260	172	67	2.0

T.H. - Total Hardness.

4.3.2 Major Cations

The concentration of Ca, Mg, Na and K in filter points in the month of May 97, Aug. 97 and Nov. 97 are shown in Fig.11. The major cation observed was sodium during the study period. The concentrations of major cations are reduced from pre monsoon to post monsoon period.

4.3.3 Major Anions

The concentration of HCO_3 , Cl, and SO_4 in filter points in the month of May 97, Aug. 97 and Nov. 97 are shown in Fig.12. The major anion in the study area was bicarbonate except few filter points (G and H) which are near to salt creek. They showed Chloride was a major anion.

4.4 Classification of groundwater samples and its seasonal changes

4.4.1 Stiff Classification

The major cations and anions in each sample collected during pre monsoon and post monsoon periods are given in Table 10. Most of the wells are under $NaHCO_3$ type of water. The seasonal change is observed only in major cations (Ca and Na). The anion change is very limited in the study area except in well No.19 and I. The dominant cation and anion change (Table 10) indicates the mixing phenomenon of groundwater in few places in the study area.

4.4.2 Piper's Trilinear Classification

The chemical analysis data of groundwater samples collected from dugwells and filter points during pre monsoon and post monsoon periods were plotted on Piper's trilinear diagrams to infer hydrochemical facies in the study area. The hydrochemical facies inferred from these diagrams are given in the Table 11. Mainly three facies of $Ca(HCO_3)_2$, NaCl and Mixed $CaNaHCO_3$ were observed in the study area. The seasonal change of hydrochemical facies in dugwells and filter points observed to be in mixed $CaNaHCO_3$ facies. If any facies is changing into Mixed $CaNaHCO_3$ from pre monsoon to post monsoon period, it may indicate the recharge area. Similarly if the mixed $CaNaHCO_3$ is changing into NaCl, it may indicates the discharge area. The seasonal changes of hydrochemical facies in dug wells and filter points are shown in Table 11.

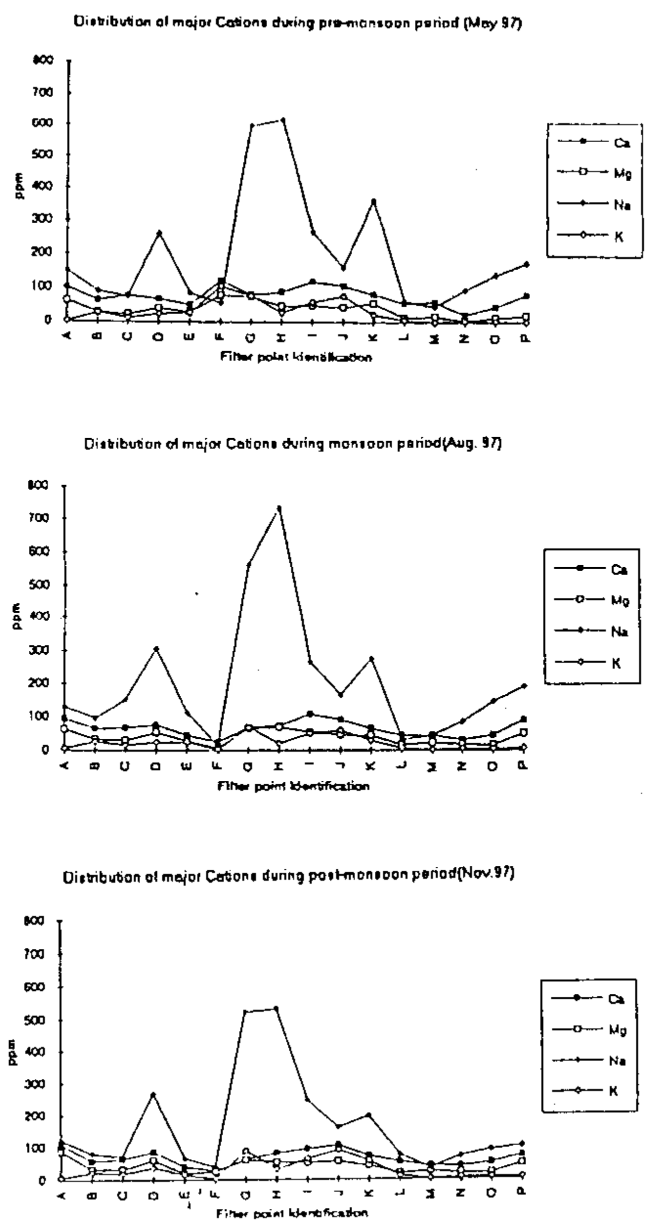
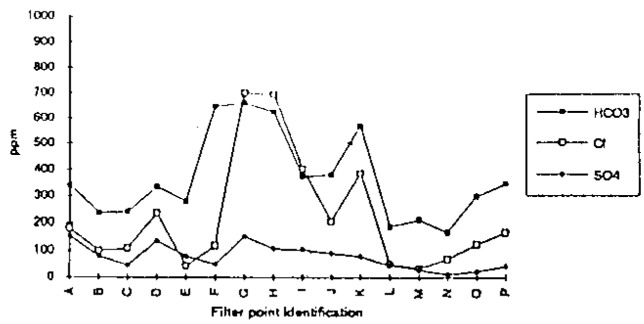
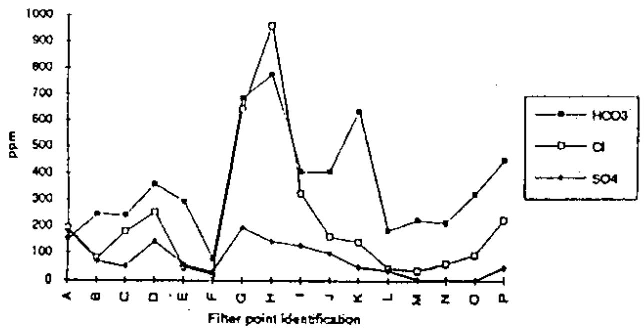


Fig. 11 Variations in major cations of groundwater samples collected from filter points during the year 1997

Distribution of major Anions during pre-monsoon period(May 97)



Distribution of Major Anions during monsoon period(Aug 97)



Distribution of major Anions during post-monsoon period(Nov.97)

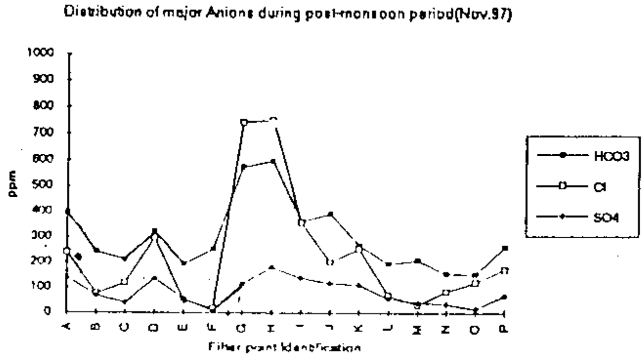


Fig. 12 Variations in major anions of groundwater samples collected from filter points during the year 1997

Table No. 10

Stiff classification of groundwater samples collected from Dug wells(29 Nos.) and Filter points(16 Nos.) during the year 1997

Well No. (Dug wells)	Pre-monsoon (May 97)	Post-monsoon (Nov. 97)	Well label (Filter Points)	Pre-monsoon (May 97)	Post-monsoon (Nov. 97)
1	$CaHCO_3$	$NaHCO_3^*$	A	$NaHCO_3$	$NaHCO_3$
2	$NaHCO_3$	$NaHCO_3$	B	$NaHCO_3$	$NaHCO_3$
3	$NaHCO_3$	$NaHCO_3$	C	$CaHCO_3$	$NaHCO_3^*$
4	$NaHCO_3$	$NaHCO_3$	D	$NaHCO_3$	$NaHCO_3$
5	$NaHCO_3$	$NaHCO_3$	E	$NaHCO_3$	$NaHCO_3$
6	$CaHCO_3$	$NaHCO_3^*$	F	$CaHCO_3$	$NaHCO_3^*$
7	$CaHCO_3$	$NaHCO_3^*$	G	NaCl	NaCl
8	$NaHCO_3$	$NaHCO_3$	H	NaCl	NaCl
9	$NaHCO_3$	$NaHCO_3$	I	NaCl	$NaHCO_3^*$
10	$NaHCO_3$	$CaHCO_3^*$	J	$NaHCO_3$	$NaHCO_3$
11	$NaHCO_3$	$NaHCO_3$	K	$NaHCO_3$	$NaHCO_3$
12	$NaHCO_3$	$NaHCO_3$	L	$NaHCO_3$	$NaHCO_3$
13	$NaHCO_3$	$NaHCO_3$	M	$CaHCO_3$	$CaHCO_3$
14	$NaHCO_3$	$NaHCO_3$	N	$NaHCO_3$	$NaHCO_3$
15	$NaHCO_3$	$NaHCO_3$	O	$NaHCO_3$	$NaHCO_3$
16	$NaHCO_3$	$NaHCO_3$	P	$NaHCO_3$	$NaHCO_3$
17	$NaHCO_3$	$NaHCO_3$			
18	$NaHCO_3$	$NaHCO_3$			
19	$NaHCO_3$	$NaCl^*$			
20	$NaHCO_3$	$CaHCO_3^*$			
21	$CaHCO_3$	$CaHCO_3$			
22	$NaHCO_3$	$NaHCO_3$			
23	$NaHCO_3$	$CaHCO_3^*$			
24	$NaHCO_3$	$NaHCO_3$			
25	NaCl	NaCl			
26	$NaHCO_3$	$NaHCO_3$			
27	$NaHCO_3$	$NaHCO_3$			
28	$NaHCO_3$	$NaHCO_3$			
29	$CaHCO_3$	$NaHCO_3^*$			

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

Table No. 11

Piper's Trilinear classification of groundwater samples collected form Dug wells and Filter points during the year 1997

Well No. (Dug wells)	Pre-monsoon (May 97)	Post-monsoon (Nov. 97)	Well label (Filter Points)	Pre-monsoon (May 97)	Post-monsoon (Nov. 97)
1	II	II	A	I	I
2	III	II*	B	III	III
3	II	II	C	I	I
4	III	III	D	II	II
5	III	III	E	III	III
6	I	III*	F	I	I
7	I	III*	G	II	II
8	III	III	H	II	II
9	II	III*	I	II	II
10	III	I*	J	III	III
11	I	I	K	III	II*
12	II	II	L	I	III*
13	II	III*	M	I	I
14	III	III	N	I	III*
15	III	III	O	III	II*
16	III	III	P	III	I*
17	III	III			
18	III	II*			
19	II	II			
20	III	III			
21	I	I			
22	II	III*			
23	III	I*			
24	III	III			
25	II	II			
26	III	III			
27	III	III			
28	II	III*			
29	I	I			

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

I = $Ca(HCO_3)_2$, II = $NaCl$, III = Mixed Ca Na HCO_3

4.4.3 U.S.Salinity Laboratory Classification

The chemical analysis of samples collected from dug wells and filter points during pre monsoon and post monsoon periods are plotted on Wilcox diagrams. The classifications inferred from each diagram are given in Table 12. The types of C1-S1, C2-S1, C3-S1 and C4-S1 are good water for irrigation and C4-S2 is moderate for irrigation water. According to US salinity laboratory classification the quality of groundwater in the study area is suitable for irrigation purposes. However, seasonal change was observed in few wells (Table No.12) located nearby salt creek and Kakinada lock.

4.4.4 SAR and % Na ratios

The SAR and %Na values in dug wells and filter points are shown in Table 13 and 14 respectively. The range of SAR in dug wells and filter points during study period was 0.5 to 12 and 0.5 to 15 respectively. Similarly the percentage of Sodium varies 16 to 75% and 27 to 78% respectively. Based on SAR values the study area falls under the medium hazard of Sodium (2 to 18).

4.5 Comparison of Hydrochemical analysis of Dug wells and Filter points

The average physical and chemical parameters of samples collected from Dug wells (29 Nos) and Filter points (16 Nos) during the month of Feb.97, May 97, August 97. and Nov.97 are given in Table 15. The comparison showed that the concentration of major cations and anions are more in dug wells than in filter points. Thus, the general groundwater quality in filter point samples are better than dug well samples.

4.6 Comparison of Groundwater quality parameters with Drinking water Standards

The water quality parameters of samples collected from dug wells and filter points are compared with ISI Max. permissible drinking water standards. The comparison is shown in Table 16. The TDS and HCO_3 contents have exceeded the ISI maximum permissible limits in few wells(Table No.16). However, most of the filter points samples are within the limits. It is always advisable to tap groundwater through filter points in the study area, especially for drinking water purposes.

Table No. 12

U S Salinity Laboratory Classification of groundwater samples collected from Dug wells (29 Nos.) and Filter Points (16 Nos.) during the year 1997

Well No. (Dug wells)	Pre-monsoon (May 97)	Post-monsoon (Nov. 97)	Well label (Filter Points)	Pre-monsoon (May 97)	Post-monsoon (Nov. 97)
1	C3-S1	C3-S1	A	C3-S1	C3-S1
2	C3-S1	C3-S1	B	C3-S1	C3-S1
3	C4-S1	C4-S1	C	C3-S1	C3-S1
4	C3-S1	C3-S1	D	C3-S1	C3-S1
5	C3-S1	C3-S1	E	C3-S1	C2-S1*
6	C3-S1	C2-S1*	F	C3-S1	C2-S1*
7	C2-S1	C3-S1*	G	C3-S2	C4-S2*
8	C2-S1	C2-S1	H	C3-S2	C4-S2*
9	C3-S1	C3-S1	I	C3-S1	C3-S1
10	C3-S1	C2-S1*	J	C3-S1	C3-S1
11	C2-S1	C2-S1	K	C3-S1	C2-S1*
12	C4-S1	C3-S1*	L	C2-S1	C2-S1
13	C3-S1	C3-S1	M	C2-S1	C2-S1
14	C3-S1	C3-S1	N	C2-S1	C3-S1*
15	C3-S1	C3-S1	O	C3-S1	C3-S1
16	C4-S1	C3-S1*	P	C3-S1	C3-S1
17	C4-S2	C4-S1*			
18	C4-S2	C4-S1*			
19	C4-S1	C4-S1			
20	C3-S1	C3-S1			
21	C2-S1	C2-S1			
22	C3-S1	C3-S1			
23	C3-S1	C2-S1*			
24	C2-S1	C3-S1*			
25	C4-S1	C4-S1			
26	C4-S1	C3-S1*			
27	C3-S1	C3-S1			
28	C3-S1	C3-S1			
29	C2-S1	C2-S1			

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

Table No. 13

Variations in Sodium Absorption Ratio and percentage of Sodium in Dug wells collected during the year 1997

Well No.	Feb. 97 SAR	Feb. 97 %Na	May 97 SAR	May 97 %Na	Aug. 97 SAR	Aug. 97 %Na	Nov. 97 SAR	Nov. 97 %Na
1	2.1	44	2.1	36	2.5	36	2.3	39
2	3.2	52	3.7	58	3.1	54	3.1	50
3	6.4	62	8.0	71	8.1	69	7.6	66
4	4.8	56	5.8	59	5.7	56	8.1	64
5	1.6	41	3.4	60	3.2	52	3.4	55
6	1.8	33	2.1	35	3.8	51	2.3	46
7	1.9	43	0.9	27	2.9	52	3.1	49
8	2.3	47	3.1	49	0.6	20	2.2	47
9	4.4	60	3.9	54	4.7	56	5.2	63
10	2.3	45	2.9	45	3.0	45	1.5	34
11	0.8	27	1.1	37	0.5	23	1.4	40
12	5.5	61	8.1	65	8.7	65	4.7	53
13	3.3	61	3.6	57	4.1	55	2.3	44
14	2.8	49	3.4	52	3.7	51	2.5	41
15	2.5	47	2.5	46	2.2	44	2.6	48
16	6.2	64	6.5	66	6.8	67	4.6	65
17	10.5	75	12.0	80	8.8	73	9.6	72
18	2.7	41	3.8	48	3.4	44	4.4	53
19	4.5	48	3.4	43	5.8	54	3.7	42
20	1.8	43	1.9	41	1.7	38	1.5	39
21	0.5	30	0.5	19	1.7	38	1.7	33
22	7.1	62	7.1	68	5.6	54	3.3	44
23	5.8	62	4.9	62	0.5	20	0.8	26
24	2.1	56	2.2	56	2.5	52	2.6	50
25	5.6	55	5.2	54	5.6	44	7.7	57
26	6.5	66	8.5	72	5.9	62	7.2	68
27	5.1	63	6.7	76	4.0	53	4.9	58
28	1.9	37	2.7	46	2.7	40	1.8	52
29	0.6	19	0.5	16	0.8	23	0.5	17

Table No. 14

Variations in Sodium Absorption Ratio and percentage of Sodium in Filter Points collected during the year 1997

	May 97		Aug. 97		Nov. 97	
Well Label	SAR	%Na	SAR	%Na	SAR	%Na
A	2.9	39	2.5	37	2.1	30
B	2.3	45	2.4	45	2.1	43
C	1.9	38	3.8	55	1.8	37
D	6.2	64	6.6	63	5.3	57
E	2.4	47	3.2	55	2.1	47
F	0.9	29	0.5	23	1.3	35
G	11.5	73	11.8	75	11.3	75
H	13.1	77	14.9	78	11.2	73
I	5.1	57	5.2	56	5.1	58
J	5.3	50	3.5	51	3.1	48
K	7.5	65	6.5	65	4.5	59
L	1.8	42	1.0	29	2.2	46
M	1.3	31	1.3	32	1.0	27
N	4.6	72	3.1	56	2.3	48
O	4.7	65	4.8	65	2.8	51
P	4.5	57	4.1	50	2.3	38

Table No. 15

Comparison of Hydrochemical analysis of groundwater samples collected from Dug wells and Filter points during the year 1997

Month & Type of Well	Temp. °C	pH	EC (μmoh/cm)	TDS	TH	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{-2}	PO_4^{-3}
				Average values in ppm									
Feb. 97 &	...Not available...												
Dug Wells (29 Nos.)	26.8	7.3	1639	1049	376	90	37	173	62	440	199	108	2
May 97 & Dug Wells (29 Nos.)	30.6	7.2	1693	1083	357	87	34	182	52	431	216	89	1.5
Filter points (16 Nos.)	24.5	7.3	1117	715	343	76	37	202	30	369	226	77	0.9
Aug. 97 & Dug Wells (29 Nos.)	29.5	7.3	1567	1005	440	112	39	198	49	465	249	102	4.4
Filter points (16 Nos.)	29.3	7.3	1203	772	311	63	37	205	22	354	216	77	4.1
Nov. 97 & Dug Wells (29 Nos.)	27.0	7.3	1430	918	432	96	47	186	73	395	239	105	1.0
Filter points (16 Nos.)	27.0	7.2	1163	746	329	66	40	166	29	299	224	82	3.4

Table No. 16

Comparison of chemical parameters of Dug well and Filter point samples with WHO (1984) and ISI(1983) drinking water standards during the year 1997

Parameters	Range in the study area	WHO(1984)	ISI(1983) Highest desirable	ISI(1983) Maximum Permissible	Well Nos. exceeded the ISI Maximum Pemissible Limits
EC (μ mohs/cm)	250 - 3890	1400	-	-	-
pH	6.1 - 8.3	6.5 - 8.5	7.0 - 8.5	6.5 - 9.2	-
Temparature(^{0} C)	20 - 27	-	-	-	-
TDS	160 - 2500	1000	500	1500	3, 12, 16, 17, 18, 19, 22, 23 25, 26, G, H
Ca^{2+}	24 - 216	500	75	200	18, 19, 25
Mg^{2+}	10 - 140	-	30	100	19, 25
Na^+	34 - 525	200	-	-	-
K^+	3 - 313	-	-	-	-
HCO^-_3	80 - 872	-	300	600	3, 4, 12, 16, 17, 18, 19, 22, 23, 24, 26
SO^{2-}_4	0 - 325	400	150	400	19
PO^{3-}_4	0 - 12	-	-	-	-
Cl^-	10 - 726	250	250	1000	25

Units = mgl^{-1}

4.7 Comparison of TDS between dug wells and filter points

Few dug wells and filter points located adjacent at various places in the study area were chosen for comparison of average TDS during the study period. The details are as follows :

Dug well No./Filter point label	4/O	2/N	6/P	8/M	16/D	17/G	24/E	1/L
Average TDS values during the study period in ppm	1227	559	690	301	1482	2234	584	1062
	545	325	760	329	1014	1412	424	379

The spatial distribution of average TDS in dug wells and filter points is shown in Fig 13. Most of the dug wells have showed high TDS values than filter points. Detailed investigations are necessary to study the groundwater quality variations at different depths within the unconfined conditions.

4.8 Sulfate/Chloride Ratios

The ratio of sulfate to chloride is a useful tool for assessing the impact of landuse on groundwater quality (Hirschberg, 1984, 1990, Pionke et al 1990), particularly in assessing the impact of fertiliser use. The detailed landuse/cover map of the study area is prepared from Satellite imageries and the location of each well is marked on the map (Fig.3.). The ratio of SO_4/Cl is calculated for all samples collected during the study period. Significant deviation of the sulfate/chloride ratio has a value of 0.25 generally indicates that groundwater has been affected by fertiliser use, and high values of the ratio may be accompanied by high Nitrate or ammonium concentrations. The sulfate/chloride ratio may be a more sensitive indicator of contamination than ammonia or nitrate concentrations, as it will be relatively unaffected by chemical processes that can remove nitrogen compounds from groundwater.

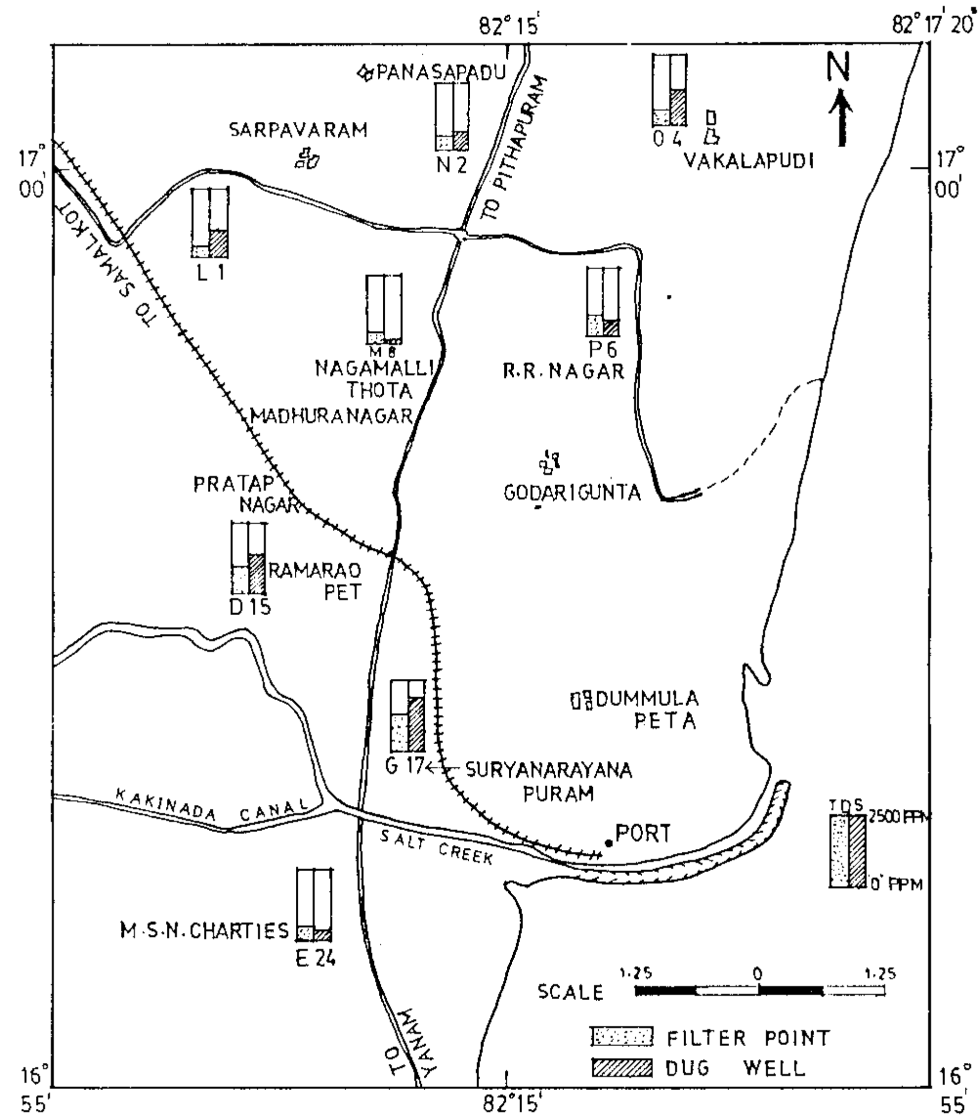


Fig 13 TDS comparison between Dug wells and filter points

Plots of the distribution of sulfate/chloride ratios in dug wells and filter points are shown in Fig Nos.14 and 15 respectively. The distribution of SO_4/Cl ratio in dug wells shows that the groundwater is being affected by fertiliser use in the study area except at Rayudu pakalu,(well No.2.), Vakalapudi (well No. 4) , Godarigunta (well No.9) and Suryanarayana puram (well No.17). During the study period the concentration of Nitrate could not be analysed. However, Jain,C.K et al (1994) have analysed shallow groundwater samples collected from Kakinada aquifer and quoted high nitrate contents in the study area. The evaluation of nitrate concentration in the study area is necessary and thus the sources can be identified.

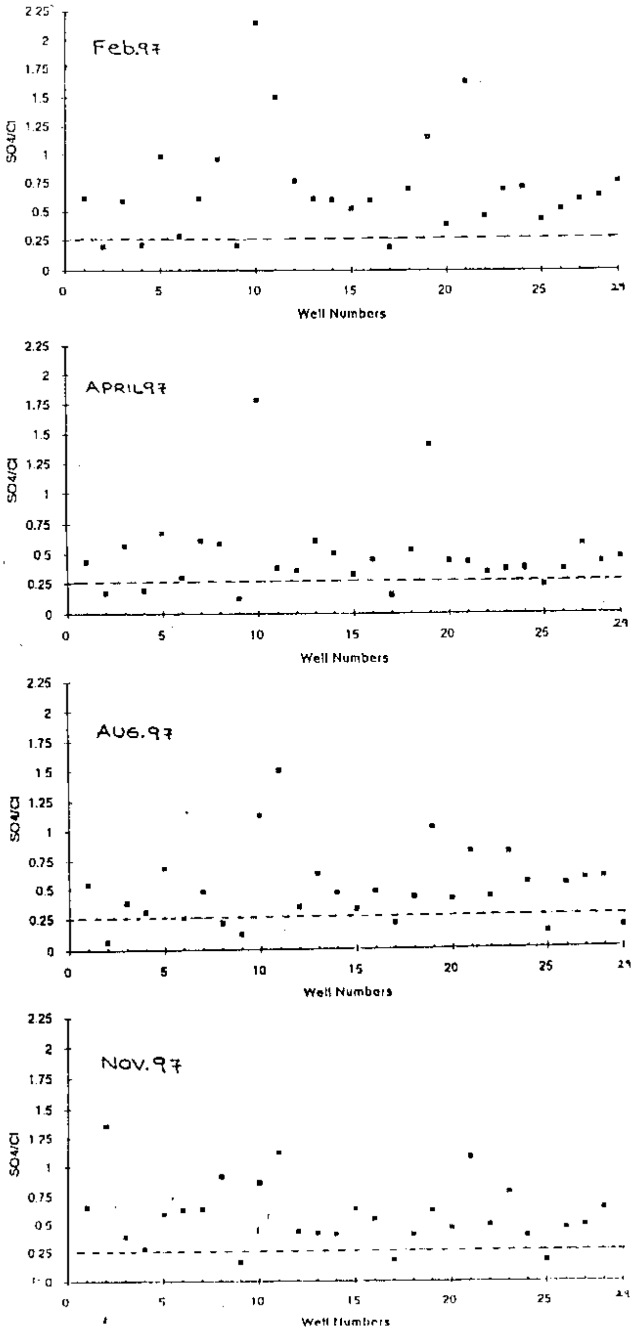


Fig. 14 Distribution of SO_4/Cl ratios of Dug wells during the year 1997

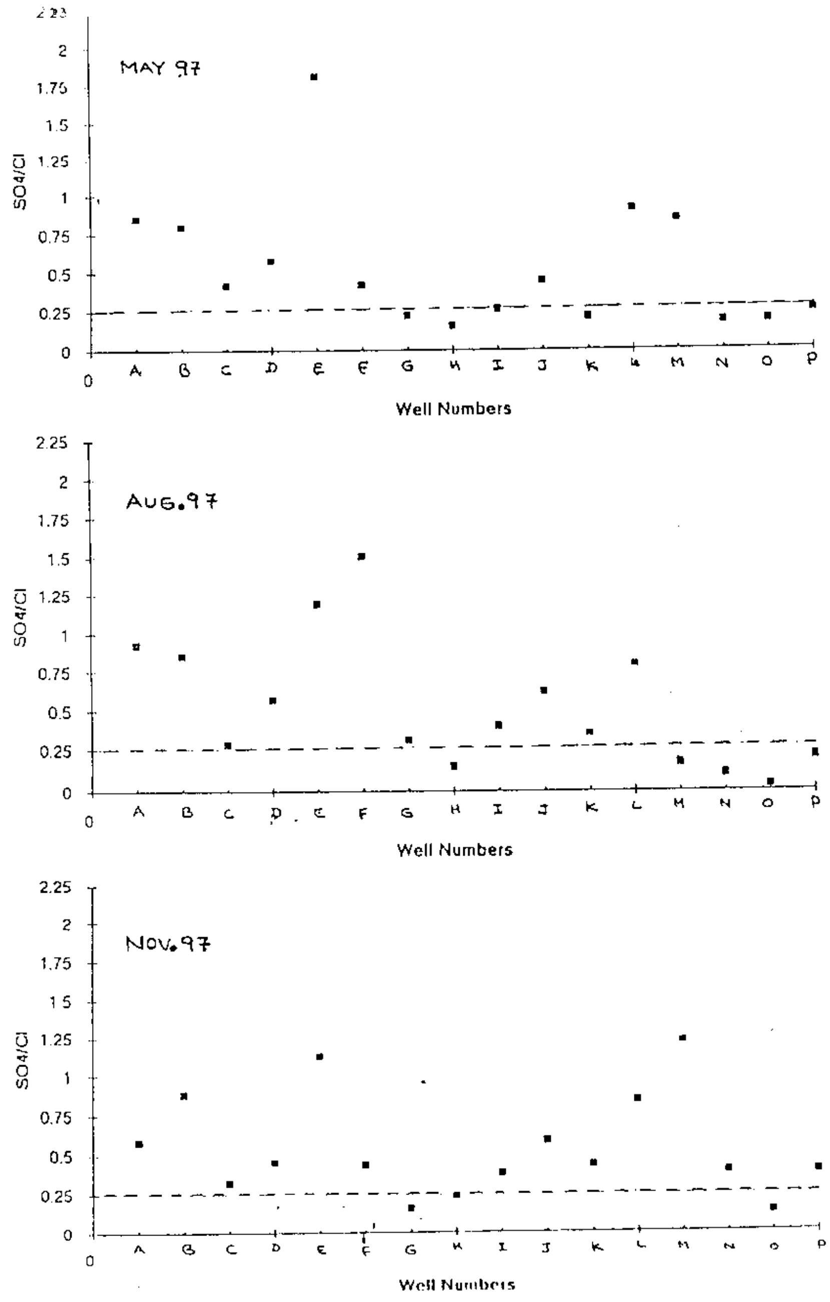


Fig. 15 Distribution of SO_4/Cl ratios of Filter points during the year 1997

5.0 CONCLUSIONS

Total 45 wells were selected for assessing groundwater hydrochemistry of the study area. Among which 29 are dug wells and 16 are filter points. The monthly groundwater levels were measured only in dug wells. The groundwater level fluctuations are different from wells located above MSL to the wells located below MSL. The spatial distribution of groundwater levels during pre monsoon (April 97) and post monsoon (Oct.97) periods are prepared and thus the approximate groundwater flow directions were demarcated in the study area. The comparison of monthly rainfall and average groundwater table shows that the groundwater recharge in the study area is mainly due to the monsoon rainfall. The rise of average groundwater table in the study area from pre monsoon to post monsoon period was 1.0 Mt.

Total 164 groundwater samples were collected during the month of Feb.97, May 97, Aug. 97 and Nov. 97. These samples were analysed for its physical and chemical parameters at DRC water quality laboratory.

Stiff classification shows that most of the samples (dug wells and filter points) are under $NaHCO_3$ type of water. The seasonal changes were observed in only major cations (Ca and Mg).

Pipers trilinear classification shows that only three hydrochemical facies were observed in the study area. They are $Ca(HCO_3)_2$, NaCl and Mixed $CaNaHCO_3$. The change in hydrochemical facies in well Nos. 6, 7, 9, 22 and 28 indicated that these wells are located in recharge area.

US Salinity laboratory classification shows that the quality of groundwater in the study area is suitable for irrigation purposes except wells located near saltcreek..

More seasonal changes in chemical parameters are observed in dug wells than in filter points

Based on SAR and %Na values the study area falls under medium hazard of sodium.

The comparison of Hydrochemical analysis between dug wells and filter points shows that the general groundwater quality in filter points is better than in dug wells.

The comparison of water quality parameters with ISI maximum permissible drinking water standards gives an indication that it is always advisable to tap groundwater through filter points in the study area, especially for drinking water purposes. The TDS and HCO_3 contents have exceeded the ISI maximum permissible limits in the study area.

The spatial distribution of TDS values in the study area shows that dug wells are having high TDS values than filter points.

The impact of fertilizer use/landuse on groundwater quality was assessed through SO_4/Cl ratios and it was observed that the groundwater is being affected by fertilizer use. The landuse/cover map of the study area was prepared from IRS 1B, LISS II FCC imageries on 1:50 000 scale.

Detailed investigations are necessary to study the groundwater quality variations at different depths within the unconfined conditions.

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