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A BASE LINE SURVEY OF GROUNDWATER QUALITY IN COASTAL AQUIFER, ANDHRA PRADESH

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PREFACE

Water as a resource is under relentless pressure due to population growth, rapid urbanisation, large-scale industrialization and environmental demands. Due to the contamination of surface water and groundwater, the net availability of fresh water has been decreasing. Water quality issues are gaining recognition as groundwater depletion worsens. The level of natural contamination such as fluoride, arsenic and chemical pollutants (pesticides and insecticides) is high and rising. However, man made pollutants of septic tanks, sewage disposal and dumping of waste products especially in coastal towns make threat to limited freshwater potential zones of coastal areas. The lack of reliable data, however, makes it difficult to appreciate the magnitude and impact of the problem. In order to establish and assess the data on groundwater quality of coastal aquifer, the Kakinada town is selected as a pilot study. Monitoring of groundwater levels and quality had been started by Deltaic Regional Centre of NIH, Kakinada since 1994. In this report the detailed analysis of groundwater quality within the hydrologic boundaries is presented for the year 1999.

The study entitled **'A baseline survey of groundwater quality in coastal aquifer, Andhra Pradesh'** is undertaken by Sri Y. Ramji Satyaji Rao, Scientist 'C', and assisted by Sri T. Vijaya, Sr. R.A and D. Mohan Rangan,Tech Gr –II. The study is under the work program of Deltaic Regional Centre, Kakinada for the year 1999-2000.

(DIRECTOR)

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ABSTRACT

The study provides analysis of groundwater quality to identify probable pollution or contamination in the coastal aquifer of Kakinada. Sampling surveys have been conducted in the months of May 99, Aug. 99 and Nov. 99 and collected for about 186 samples which includes shallow wells, filter points, canal water and rainwater. The spatial and temporal variations of water quality parameters are presented in the report. High Nitrate concentrations upto 300 mg/lt. are observed in the study area. However, the maximum permissible limit of Nitrate in drinking water is 45 mg/lt. The spatial distribution of SO_4/Cl ratio also confirms the high concentration of Nitrate in the study area. The correlation between water quality parameters during different seasons in the study area is calculated. The samples collected in the study area are classified according to Chadha (1999) and observed its seasonal changes. The main hydrochemical facies observed in the study area is NaCl. The groundwater level fluctuations in few observation wells (w.r.t msl) are also analysed.

Detailed studies are necessary to find out the sources of Nitrate pollution and its transport process in the coastal aquifer of Kakinada. High concentrations of Nitrates may cause the health hazards if it is used for drinking water purposes especially for infants.

1.0 INTRODUCTION

Increase in population, rapid urbanisation, large-scale industrialisation resulting water quality deterioration and affecting the net availability of fresh water potentials. Sectoral availability of water may decline significantly in future if the limited water resources are not managed properly (VISION 2050). The water crisis could precipitate faster than expected, unless integrated land-water use strategies were implemented, and suitable water storage and conservation practices were adopted.

In addition to promoting innovative water management techniques including scientific rainwater harvesting, watershed management, revival of traditional wisdom of water storage and conservation practices, as well as promoting active community participation in the water management process, the empowerment of users and their associations, especially farmer's cooperatives is critically important by way of decentralisation of water management activities. In short, the success of water development activities would depend on, how effectively can the development and management strategies be evolved, strengthened and integrated to sustain water planning and development process aimed at rationalising the availability of water for different uses. In fact, increasing efficiency in the water related activities has to be the watchword to overcome water crisis.

Today especially water quality issues are gaining recognition as groundwater depletion worsens. The level of natural contaminants such as fluoride and arsenic, and chemical pollutants such as pesticides and insecticides, is high and rising. The lack of reliable data, however, makes it difficult to appreciate the magnitude and impact of the problem. Waterquality aspects have serious implications for the supply of rural drinking water and are important determinates of public health. Change in groundwater quality is observed in major agriculture, industrial belts and urban complexes. This may be due to over use of fertilizers, pesticides/insecticides in agriculture and haphazard disposal of untreated urban and industrial wastes.

In order to establish and assess data on groundwater quality of coastal aquifer, the Kakinada town is selected as a pilot study. It is always better to have an evaluation of groundwater quality w.r.t. groundwater level in coastal aquifer within the hydrologic boundaries. It will help in understanding the groundwater flow and hydrochemical processes in the aquifer and their changes.

1.1 Non-point pollution of groundwater in urban areas

Groundwater pollution in urban areas occurs, first of all due to the insufficient extent of urban sewerage systems and due to industry and local stockyards etc. Groundwater in domestic wells in the suburban areas is mostly polluted chemically and biologically. Unsuitably located stockyards, especially older ones, ignorance of stockyard management, incorrect tipping of toxically waste etc., are causes of the groundwater pollution upto hundreds of meters from stockyard field.

In the future, urban area can exceptionally only be considered as sanitarily irreproachable for groundwater captation for drinking purposes. But it is necessary to solve groundwater protection even beyond this area, in the environs of towns, which act as nonpoint pollution sources with enormous qualitative and quantitative heterogeneity. Underground wells and other underground artificial barriers and drains, and open drains etc., as technical works of an active and passive groundwater protection, will be desirable to protect groundwater sources in the proximity of towns.

The location of towns and water resources can't be for technical and natural reasons changed. Securing their co-existence and with regard to the complexity of the influence of urbanisation on groundwater quality inside and outside the urban area, is a highly demanding task and requires our full attention (Vrba, 1981).

With the establishment of direct relationship between concentration of Nitrate in drinking water with incidence of Methemoglobinemia, which may prove fatal for infants. Therefore study of Nitrate in domestic supply has become vitally essential. During bacterial degradation, Nitrogen is converted into Ammonia or Ammonium ions, which on oxidation yield Nitrite and eventually Nitrate. Ammonium ions (NH_4^+) being positively charged get attached with clay particles and clay humus, which are negatively charged. Nitrate ions are free to move, leach and enter the groundwater body. Some sources of Nitrate connected with agriculture include fertilisers, barnyards, silo waste, disposal of crop residue and application of herbicides and insecticides. Though fertilisers play a vital role in increasing agricultural production, indiscriminate use of fertilisers is not only harmful but also unutilised Nitrogen causes high concentration of Nitrate in groundwater. Kakar (1981) had studied the Nitrate pollution of groundwater in southern and southwestern Haryana, India and concluded that the occurrence of high Nitrate (500mg/lt.) in natural waters at shallow levels is likely to be caused by local pollution. No conspicuous pattern regarding areal distribution of Nitrate has been observed along direction of groundwater movement and also suggested ameliorative measures to prevent high concentrations of Nitrate in groundwater to safeguard public health.

Walter et al. (1975) have indicated that immobilization, Ammonification and nitrification interacted significantly to effect Nitrogen leaching.

Mathur, et al. (1998) had studied N-Fertilizer impact on Nitrate concentrations in shallow aquifers of Ganjam district, Orissa and concluded that drainage of fertilizer along with waterfront should be minimised by using modern techniques. It has been reported that 0.1% polymex AG when mixed with inorganic fertilizer minimises drainage and maximises its utilisation by plants. Quantity of N-Fertilizer to be used should be evaluated as per the crop species, type of soil, and supporting crop to be provided.

Schot et al. (1992) had studied the relations between groundwater composition, land use, soil conditions and flow patterns on a regional scale in the Netherlands. They have applied R-mode factor analysis and Q-mode analysis to a set of 1349 groundwater samples to determine the factors controlling groundwater composition and corresponding water types. Increased solute concentrations in shallow groundwater, especially Nitrate, Sulphate and Potassium, indicate increased pollution resulting from urbanisation and increasing intensive agricultural activity over the past decades.

Bouwer (1987) had studied the effect of irrigated agriculture on groundwater and concluded that the time it takes for deep percolation from irrigated fields to reach underlying groundwater increases with decreasing particle size of the vadose zone material and increasing depth to groundwater. And also mentioned that the large area of irrigated land in the world has been effected by groundwater pollution, more research is necessary on downward movement of water and chemicals in the Vodose zone.

Subbarao and Satyanarayana (1988) have studied the conductivity variations in coastal alluvium by collecting groundwater samples from coastal aquifers of Andhra Pradesh near the Bay of Bengal. They have concluded that the variation of conductivity values could be related to Chloride concentration and soil influence in the coastal aquifer.

Jain et al. (1994) have evaluated groundwater quality in Kakinada and recommended monitoring groundwater quality regularly to find out the sources of pollution in the study area.

Satyaji Rao et al. (1995; 1996; 1997 and 1998) have evaluated groundwater quality in Kakinada town and found high concentrations of total hardness, Sulphate and Nitrate. The spatial distribution maps of major anion and cations were prepared for the study area. The comparison of groundwater chemistry between dug wells (depth < 3m) and filter points ($3m >$ depth ≤ 6m) indicated that the tapping of groundwater for drinking water purposes is recommended through filter points in the study area. They have also recommended to find out the reasons for high Nitrate content in the study area and its preventive measures.

1.2 Scope and objectives

The purpose of the study is to provide groundwater quality data for quality assessment and to create database required for evaluation of probable pollution or contamination in the coastal aquifer of Kakinada. Probable pollution includes Nitrate and other chemical concentrations. The objectives of the study are as follows:

i. Describe the groundwater quality between Gorrekhandi stream, Eleru river, Bikkavolu drain and Bay of Bengal (hydrologic boundaries).

ii. Analysis of water quality parameters of Dug wells, Filter points, canal water, rainwater and seawater.

iii. Describe the variations of water quality parameters in the study area.

iv. Classification of water samples according to modified Piper's trilinear diagrams (Chadha, 1999) and comparison with Piper's (1953) classification.

v. Describe correlation between water quality parameters of dug wells in the study area and its seasonal changes.

vi. Evaluate the spatial distribution of water quality parameters in the study area.

vii. Evaluation of high Nitrate using SO_4/Cl ratio.

viii. Analysis of groundwater table fluctuation (w.r.t. M.S.L).

ix. Identification of possible pollution or contamination parameters and their intensity in the study area.

2.0 STUDY AREA

The study area includes the Kakinada coastal aquifer and a part of Godavari river Eastern Delta system. The study area lies between the hydrological boundaries of Gorrekhandi stream, Eleru river, Bikkavolu drain and Bay of Bengal. The study area is bounded by $16^0$55'0" to $17^0$10'0" N latitude and $82^0$10'0" to $82^0$21'41" E longitude. The location of the study area is shown Fig. 1. The total area under study is approximately 393 km^2 and it has coast length for about 24 kms. The main geology of the study area is coastal alluvium. The groundwater table is under unconfined conditions. The average watertable fluctuation from pre monsoon to post monsoon period is 2m above MSL. The main landuse in the study area is a combination of built-up, agriculture and marshy lands. The Hope Island that is naturally formed in the Bay of Bengal is about 6 kms from the Kakinada coast. The general groundwater quality varies potable to slightly saline. The main drinking water source for Kakinada Municipality is from Godavari river. However, most of the people depend on groundwater source in the study area due to limited supply of Municipal water. The maximum temperature is 40^0C between April to June and minimum temperature is 20^0C during December to January. The maximum normal rainfall 238 mm is in the month of October and minimum of 8 mm in the month of January. The average relative humidity varies between 75% to 95% in the study area.

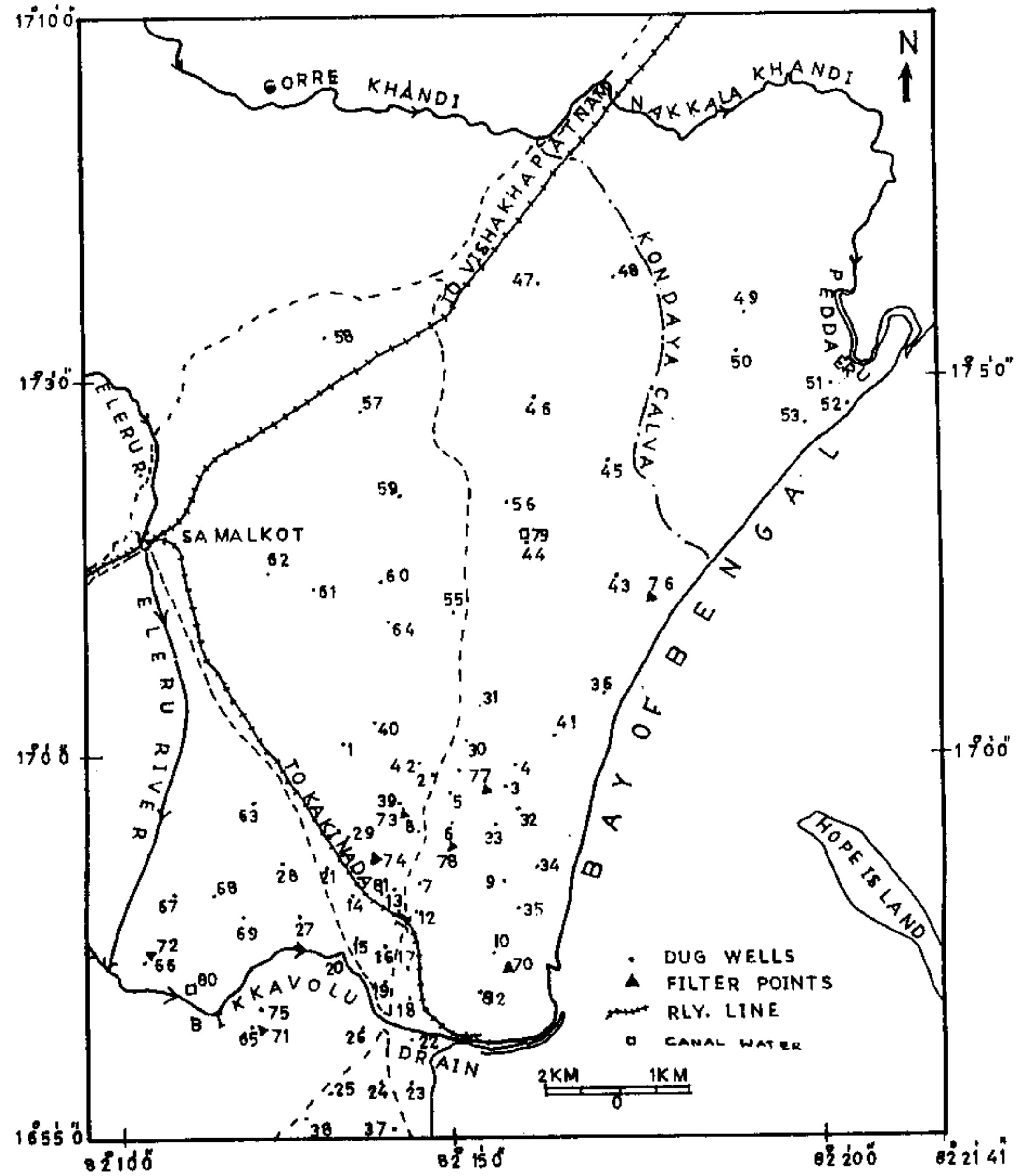

Fig. 1 Location of the study area

3.0 METHODOLOGY

To assess the quality of groundwater in the study area, three field surveys have been conducted in the month of May-1999, August-1999 and November- 1999. In the months of May-99 and August-99, total 82 groundwater samples were collected. However, in the month of November 1999 total 85 samples have been collected which includes dugwells, filter points, 'canalwater and rainwater. The monthly groundwater levels data are also used to assess seasonal fluctuations in the study area.

All the samples are analysed for physical parameters (Temp, pH, EC), major anions (HCO_3, Cl, SO_4, NO_3) and major cations (Ca, Mg, Na, K). The physical parameters are measured in the field and chemical parameters are analysed in the Water Quality Laboratory of Deltaic Regional Centre of NIH, Kakinada using standard methods (Jain and Bhatia, 1989). The control chart of Ion balance error for all samples is prepared. The statistical analysis (Min., Max., Mean and Standard Deviation) of water quality parameters is carried out for different seasons. The chemical analysis data of all the samples are classified according to Chadha (1999) and Pipers (1953).

3.1 Chadha's Hydrogeochemical Classification

In the Piper diagram (1953) the milliequivalent percentages of the major cations and anions (percentage reacting values) are plotted in each triangle and the type of water is determined on the basis of position of the data plot in the respective cationic and anionic triangular fields and extended further into the central diamond field, which provides the overall character of the water.

In the Chadha (1999) diagram the difference in milliequivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium) expressed as percentage reacting values is plotted on the X-axis and the difference in millequivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate) is plotted on Y-axis. The resulting field of study is a square or rectangle. Depending upon the size of the scales, choose X and Y coordinates. The milliequivalent percentage differences between alkaline earths and alkali metals and between weak acidic anions and strong acidic anions, would plot in one of the four possible sub fields of the proposed diagram. The main advantage of the proposed diagram is that it can be made simply on most spreadsheet software packages. The square or rectangular field describes the overall character of the water.

Samples collected from dugwells, filterpoints, canal water, rainwater are classified according to this diagram. Further, all these samples are also plotted on Pipers (1953) trilinear diagram and compared each other. The correlation coefficient between water quality parameters is calculated using SYSTAT software and the plots of these relations are also prepared for the month of May-99 and August-99 and November-99.

The network of observation wells has been increased from 41 to 82 during the sampling month of Nov-99 to cover entire study area. Using increased network of observation wells the spatial distribution of water quality maps have been prepared for the study area using SURFER software.

The ratio of sulphate to Chloride is a useful tool for assessing the impact of landuse on groundwater quality (Hirscuberg, 1984 and 1990; Pionke et. al. 1990) particularly in assessing the impact of fertiliser use. The ratio of SO_4 /Cl is calculated for samples collected (Dug wells) in the month of Nov-99 and prepared the spatial distribution map of the ratio. Significant deviation of the SO_4/Cl ratio from a value of 0.25 generally indicates that groundwater has been affected by fertilizer use and high values of the ratio may be accompained by high Nitrate or Ammonium concentrations. The SO_4/Cl 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.

The changes in groundwater levels in few observation wells are studied in the month of May-99, August-99 and November-99 to observe the freshwater head w.r.t MSL. In coastal areas it is always better to monitor groundwater levels during non-monsoon period, because if the groundwater table is below MSL, thus creates severe impact on the freshwater potential available in the coastal aquifier.

4.0 RESULTS AND DISCUSSIONS

The sample numbers, types of sample, location, depth of observation wells in the study area are shown in Table No.1. The location of these samples is shown in Fig. 1. Total 41 dug well samples were collected during the month of May-99 and August-99 respectively. However in the month of November-99 total 85 water samples were collected which includes 71 dugwells, 9 filter points, 2 canal samples and 3 rainwater samples. All these samples were analysed for physical and chemical parameters. The control chart of IBE for each sample (1 to 41) collected in the month of May-99, Aug-99 and November-99 is shown in Figure 2. Similarly IBE control chart of samples (1 to 85) collected in the month of November-99 is shown in Figure 3. The Figures 2 & 3 shows that the ion balance error lies between ± 10% of 90% samples in the study area.

To compare the seasonal variations in water quality parameters, total 41 samples (1 to 41) are chosen in the month of May-99, August-99 and November-99 respectively. The variation of physical parameters (Temp, pH and EC) in these samples are shown Figure 4. The range of temperature, pH, and EC during the study period is 28^0C to 32^0C, 6.6 to 7.9 and 390 to 8,222 μmho/cm respectively. High EC values have been observed in sample Nos. 36 to 38, which are located near seacoast and in marshy lands. Similarly the variations in major anions (Chloride, Bi-carbonate, Sulphate and Nitrate) and major cations (Calcium, Magnesium, Sodium and Potassium) in these samples are shown in Figure 5 and 6 respectively. There is no much Phosphate content (<5ppm) observed in the study area (Satyaji Rao et. al.

Table No.1 Details of samples collected in the study area

Sample Nos.	Location	Type of Sample	Depth of Well (mts.)	Land use
1	Sarpavaram	Dug Well	4.4	Agriculture
2	Balaji nagar	Dug Well	4.1	Urban
3	Valasapakalu	Dug Well	3.98	Agriculture
4	Vakalapudi	Dug Well	3.9	Agriculture
5	Ramanayya peta	Dug Well	5	Urban
6	R.R Nagar	Dug Well	4.24	Urban
7	Madhav Nagar	Dug Well	3.82	Urban
8	Lal Bahadur Nagar	Dug Well	3.91	Urban
9	Godarigunta	Dug Well	4.03	Urban
10	Sambamurthy nagar	Dug Well	3.15	Urban
11	Shanti nagar	Dug Well	3.38	Urban
12	Bhanugudi	Dug Well	3.38	Urban
13	Kondayya palem	Dug Well	4.43	Urban
14	Gandhi nagar	Dug Well	4.43	Urban
15	Ramarao Peta	Dug Well	4.17	Urban
16	Surya Rao Peta	Dug Well	4.37	Urban
17	Surya Narayana Puram	Dug Well	3.84	Urban
18	Budam Peta	Dug Well	4.5	Urban
19	Temple Street	Dug Well	3.2	Urban
20	Frazer Peta	Dug Well	3.14	Urban
21	Pratap Nagar	Dug Well	4.29	Urban
22	Jagannadha puram(Church)	Dug Well	3.05	Urban
23	Gogudanayya peta(Gollu peta)	Dug Well	2.64	Urban
24	M.S.N Charties Street	Dug Well	4.03	Urban
25	Ravindra nagar (Turangi)	Dug Well	4.26	Urban
26	Paradesamma peta	Dug Well	3.63	Urban
27	Indra palem	Dug Well	4.77	Urban
28	Chidiga	Dug Well	5.6	Agriculture
29	Madhura Nagar	Dug Well	4.23	Urban
30	Rayudu Palem	Dug Well	4.63	Agriculture
31	Penumarthy (ADB Road)	Dug Well	4.47	Agriculture
32	V.pakalu-NFCL Road	Dug Well	4.3	Agriculture
33	Suresh Nagar (NFCL Road)	Dug Well	3.37	Urban
34	Santhanpuri colony	Dug Well	3.5	Agriculture
35	Sita ram Nagar	Dug Well	3	Urban
36	Chinna Vakalapudi (Light House	Dug Well	3.45	Agriculture
37	Raghavendra Puram (Yanam Rd)	Dug Well	3.92	Agriculture
38	Velamala Turangi	Dug Well	3.03	Agriculture
39	Rajendra Nagar	Dug Well	4.7	Urban
40	Panasa padu Road	Dug Well	2.95	Agriculture
41	Peda Vakalapudi	Dug Well	4.59	Agriculture
42	Anjaneya Nagar	Dug Well	3.5	Urban
43	Elwyn Peta (Nemam)	Dug Well	4.7	Agriculture
44	Panduru	Dug Well	4.25	Agriculture
45	Gorasa	Dug Well	5.42	Agriculture
46	Nagam Peta	Dug Well	7.2	Agriculture
47	Nava Kandarada	Dug Well	4.55	Agriculture
48	Kondevaram	Dug Well	5.6	Agriculture
49	Endapalli Jn.	Dug Well	5.83	Agriculture
50	U.Kothapally	Dug Well	5.55	Agriculture
51	Uppada (opp. Govt.School)	Dug Well	4.1	Agriculture
52	Uppada (Farm House)	Dug Well	3.8	Agriculture
53	Subbam Peta	Dug Well	3.76	Agriculture

54	Atcham Peta (ADB Road)	Dug Well	4.3	Agriculture
55	Timma Puram	Dug Well	3.62	Agriculture
56	Venkata puram	Dug Well	3.5	Agriculture
57	Chandram Palem	Dug Well	6.2	Agriculture
58	Kandarada	Dug Well	4.55	Agriculture
59	Navara	Dug Well	4.6	Agriculture
60	Gonchala	Dug Well	5.25	Agriculture
61	Brahmananda Puram	Dug Well	4.88	Agriculture
62	Unduru	Dug Well	4.48	Agriculture
63	Madhav Patnam	Dug Well	4.5	Agriculture
64	Turangi Main Road	Dug Well	4.7	Agriculture
65	Kovvuru	Dug Well	4.6	Agriculture
66	Atchyutapura trayam	Dug Well	5.1	Agriculture
67	Rameswaram	Dug Well	4.52	Agriculture
68	Karakuduru	Dug Well	4.3	Agriculture
69	Kovvada	Dug Well	4.1	Agriculture
70	Dummula peta	Fiter point	6	Agriculture
71	Kovvuru	Filter point	4.1	Agriculture
72	Atchyutapura trayam	Filter point	5.1	Agriculture
73	Chaitanya Nagar	Filter point	11.1	Urban
74	Govt. Polytechnic for Women	Filter point	6	Urban
75	Kovvuru (Diamond Soap Factory)	Filter point	36	Agriculture
76	Nemam	Filter point	31	Agriculture
77	Vigneswar Nagar	Filter point	5	Agriculture
78	DRC,NIH, Kakinda	Filter point	5	Urban
79	Panduru	Canal	...	Agriculture
80	Aratlakatta	Canal	...	Agriculture
81	Military Road (Kondayya palem)	Dug Well	3.71	Urban
82	Jalari peta	Dug Well	3.55	Urban
83	Kakinada Bay	Sea water	0.3 from surface	Bay of Bengal
84	DRC,NIH, Kakinda	Rain water	Roof	Urban
85	DRC,NIH, Kakinada	Rain water	Roof	Urban
86	DRC,NIH, Kakinada	Rain water	Roof	Urban

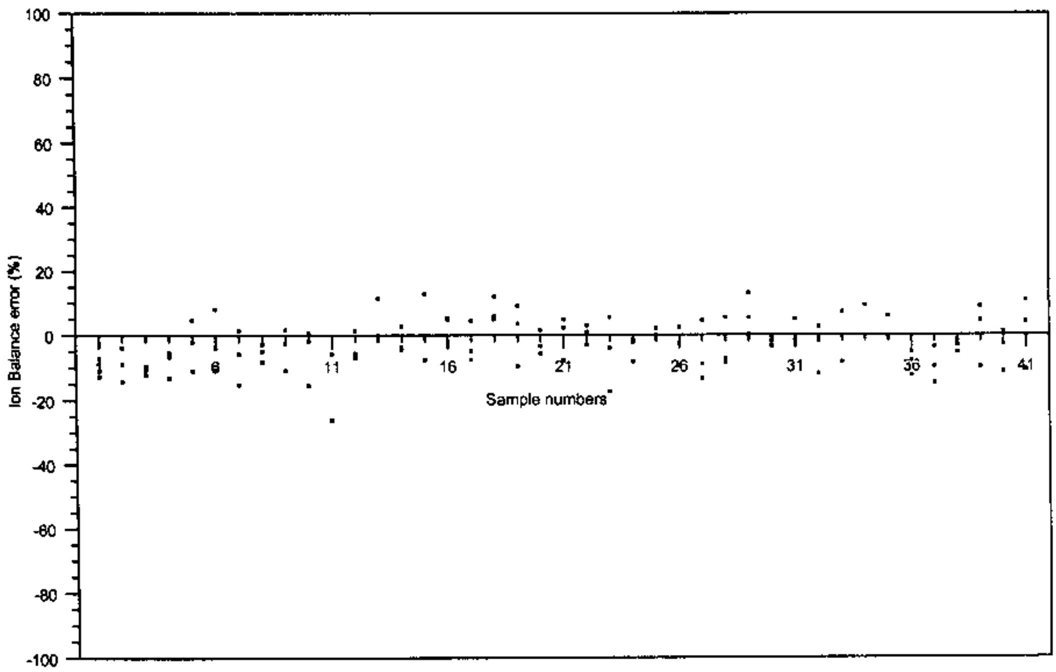

Fig.2. Control chart of IBE of water quality of samples (1 to 41)
collected during May 99, Aug. 99 and Nov.99.

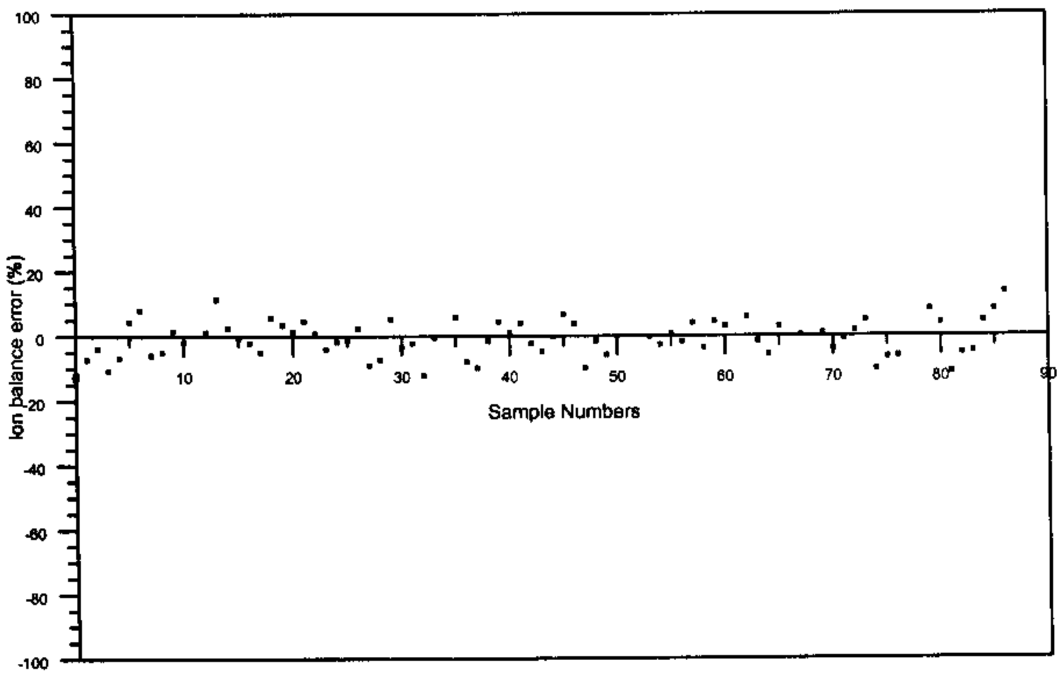

Fig.3. Control chart of IBE of water quality data of samples (1-86)
collected during Nov.99

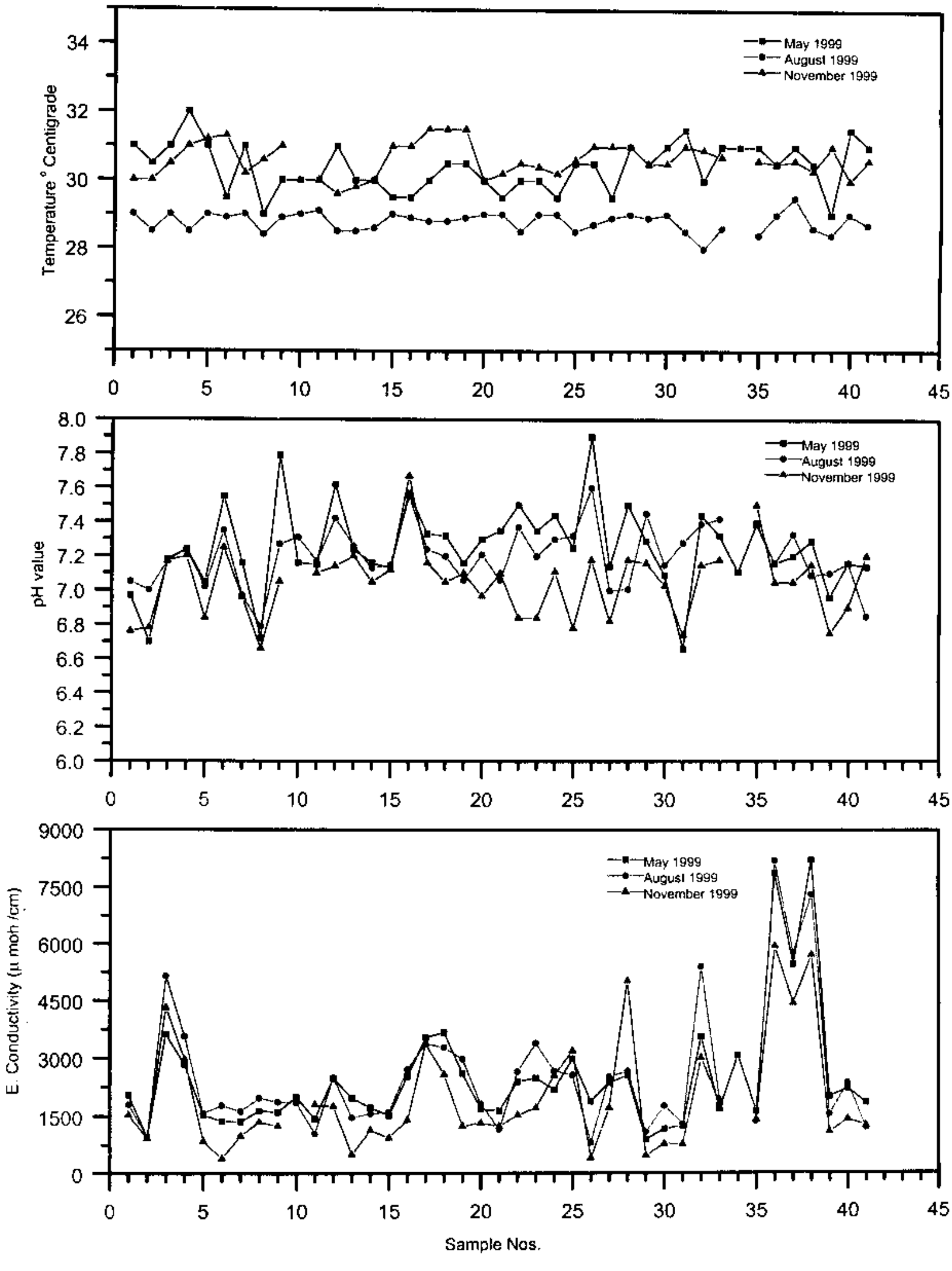

Fig.4. Seasonal variation of physical parameters in the study area.

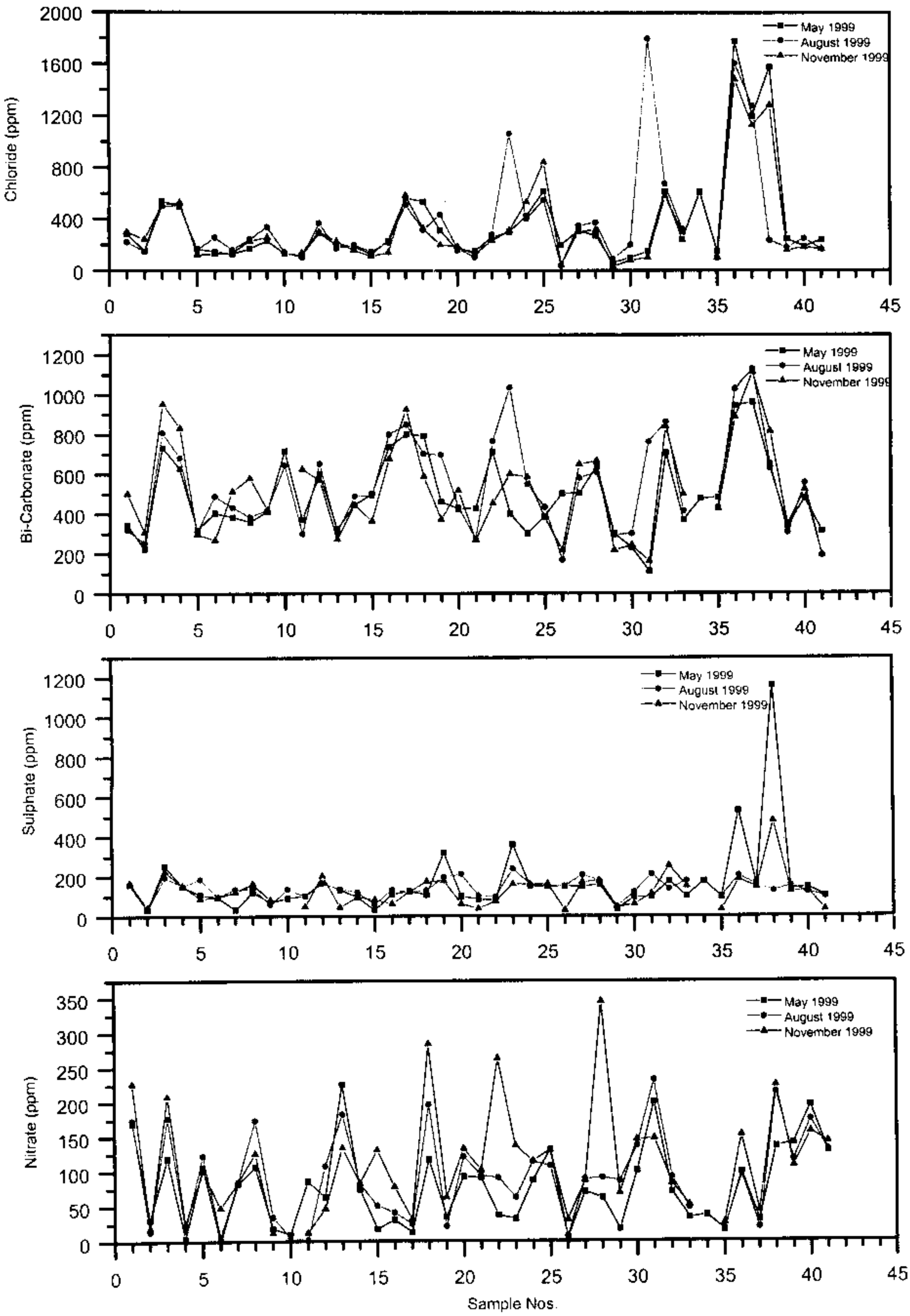

Fig.5. Seasonal variation of Anions in the study area.

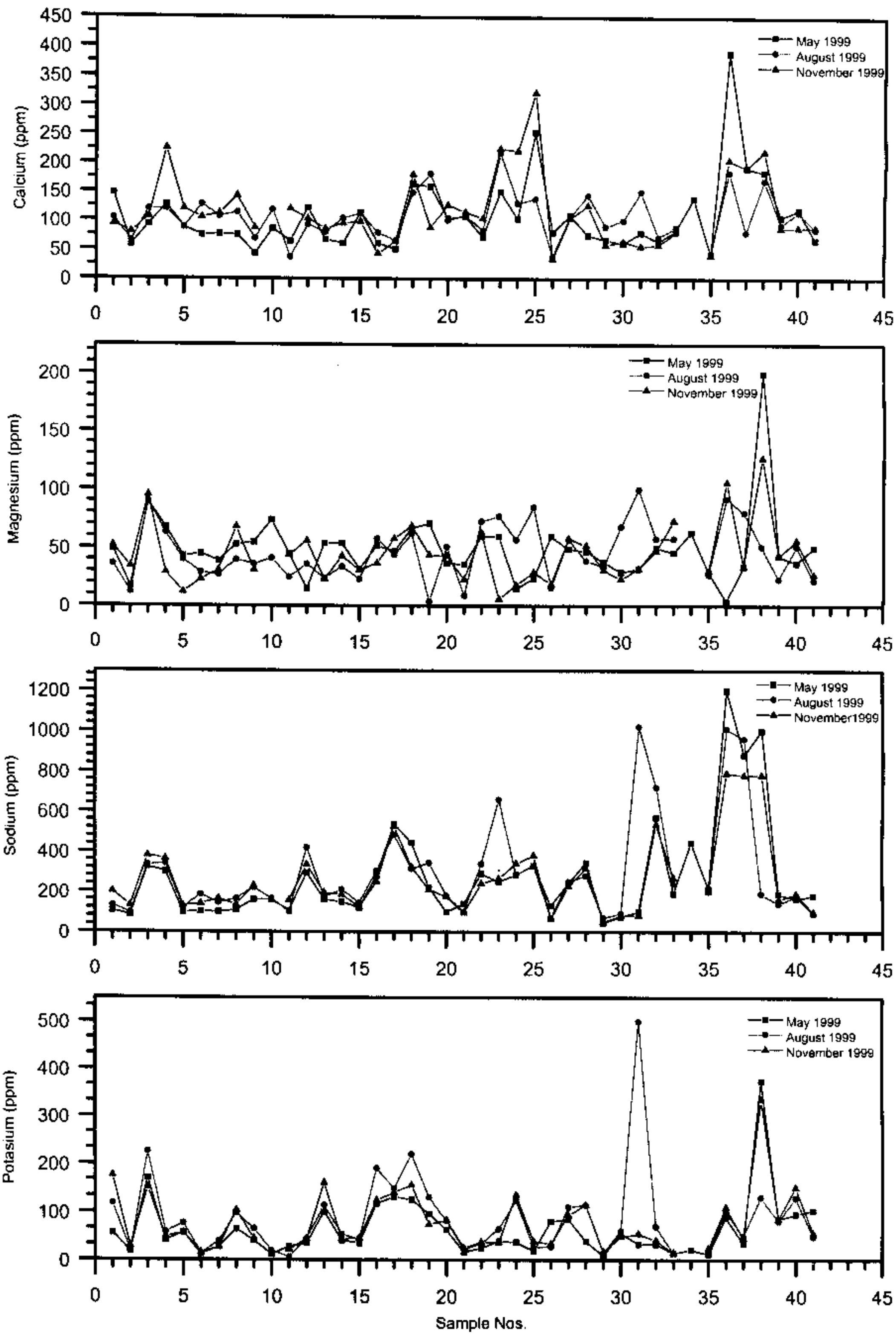

Fig.6. Seasonal variation of Cations in the study area

1996). From the Figure 5, it is observed that the range of Cl, HCO_3, SO_4 and NO_3 is 32 to 1800 ppm, 112 to 1128 ppm, 28 to 1168 ppm and 0 to 345 ppm respectively. The range of Ca, Mg, Na and K (Fig. 6) is observed as 34 to 390 ppm, 4 to 200 ppm, 45 to 1200 ppm and 6 to 500 ppm respectively. It is also observed that the maximum concentrations of anions and cations are observed in the sample Nos. 36 to 38 except Nitrate content. High Nitrate content is observed in the middle of the town than in seacoast. It may be due to dumping of waste materials in the town or due to intensive septic tanks. The gaps in the graphs (Fig. 4, 5 and 6) indicate non-availability of sample in that period.

The statistical analysis (Minimum, Maximum, Mean, Standard Deviation) of physical and chemical parameters of the samples collected during the study period is given in the Table No.2. The Table No. 2 indicated that the standard deviation of EC, Cl, Mg, Na and SO_4 from their mean has been decreased from pre monsoon (May 1999) to post monsoon period (Nov. 1999). This is mainly due to the seasonal changes in groundwater quality. Further, the average concentrations of these parameters are reduced from pre monsoon to post monsoon period. However, the standard deviation of Bicarbonate and Nitrate from their mean has been increased from pre monsoon to post monsoon period. This is mainly due to the recharge of groundwater (recharge water may contains more HCO_3 and NO_3 contents in the study area). The average concentrations of HCO_3 and NO_3 have been increased from pre monsoon to post monsoon period unlike other parameters. It is also observed that the concentration of average water quality parameter is high during monsoon period (Aug. 1999). This may be due to the immediate

Table.2.Statistical analysis of groundwater quality parameters in the study area.

	May 1999 (No. of samples 41)				August 1999 (No. of samples 40)				November 1999 (No. of samples 39)			
	Min.	Max.	Mean	S.D.	Min.	Max.	Mean	S.D.	Min.	Max.	Mean	S.D.
Temperature ° C	29.0	32.0	30.0	0.70	28.0	29.0	28.7	0.28	29.6	31.0	30.6	0.49
pH	6.6	7.9	7.2	0.25	6.9	7.6	7.2	0.25	6.7	7.6	7.1	0.21
E.C. (μ mho /cm)	891.0	8222.0	2476.0	1554.00	809.0	8200.0	2553.0	1626.00	390.0	5940.0	1950.0	1446.00
Calcium (ppm)	42.0	390.0	107.0	64.00	37.0	218.0	107.0	39.00	34.0	321.0	117.0	63.00
Magnesium (ppm)	4.0	200.0	49.0	30.00	4.0	100.0	46.0	24.00	6.0	127.0	44.0	25.00
Sodium (ppm)	45.0	1200.0	273.0	250.00	70.0	1020.0	295.0	248.00	50.0	790.0	263.0	190.00
Potassium (ppm)	9.0	375.0	62.0	63.00	6.0	500.0	87.0	87.00	15.0	335.0	78.0	64.00
Chloride (ppm)	60.0	1780.0	362.0	370.00	40.0	1800.0	384.0	393.00	32.0	1484.0	336.0	332.00
Bi-Carbonate (ppm)	112.0	960.0	492.0	196.00	168.0	1128.0	544.0	242.00	160.0	1112.0	514.0	236.00
Sulphate (ppm)	30.0	1160.0	162.0	183.00	34.0	237.0	139.0	46.00	28.0	479.0	125.0	83.00
Nitrate (ppm)	0.0	225.0	76.0	58.00	2.0	232.0	91.0	64.00	12.0	345.0	112.0	78.00
T.D.S. (ppm)	570.0	5262.0	1584.0	994.00	518.0	5248.0	1634.0	1073.00	249.0	3801.0	1248.0	925.00
Total Hardness (ppm)	214.0	1282.0	468.0	200.00	163.0	861.0	457.0	164.00	163.0	1072.0	473.0	200.00

dilution of salts accumulated on ground surface and it joins groundwater immediately. Further these parameters are diluted if sufficient recharge is occurred and few parameters may increase due to the presence of those parameters in the recharge water (HCO_3 and NO_3). The average seasonal variations of groundwater quality parameters are shown in the form of bar charts (Fig. 7).

The variations in electrical conductivity, major anions and cations in the samples collected during the month of November-99 are shown Fig. 8. Sample Nos. 1 to 69, 81 and 82 are dug wells, 70 to 78 are filter points, 79 and 80 are canal water, 83 is seawater and 84 to 86 are rainwater samples. The quantitative difference in water quality parameters between these samples is clearly seen in the Figure.8. The seawater sample analysis is not shown in the graph because the concentration of chemical parameters is 10 times more than the samples collected from the study area. The gaps in Figure 8 indicate non-availability of samples. The average physical and chemical parameters of these samples are given in Table No.3 and the same is shown in the form bar chart in Figure 9. Due to high values of seawater the sea sample is not included in the bar chart. The bar chart indicates that there is no much significant difference between Dugwell and Filter points chemistry because the sample depths are almost from the shallow aquifer only. However, during the post monsoon period (Nov-99), the dug wells are showing less chemical concentrations than Filter points especially Cl, SO_4 and NO_3. Interesting phenomena is also observed that the Nitrate content in rainfall is slightly more than the canal water. Therefore, it is suggested that more studies on air pollution in the study area may be initiated and it may be

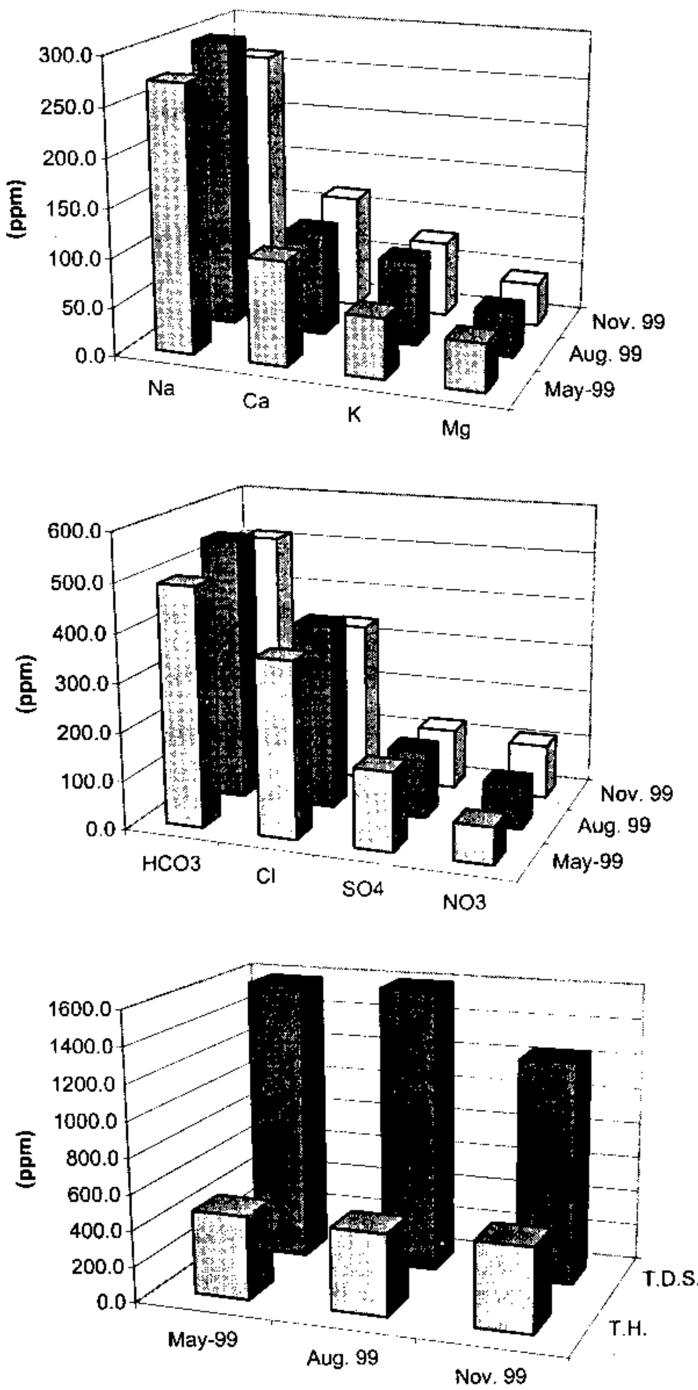

Fig. 7. Average seasonal variation of ground water quality parameters of samples (1-41)

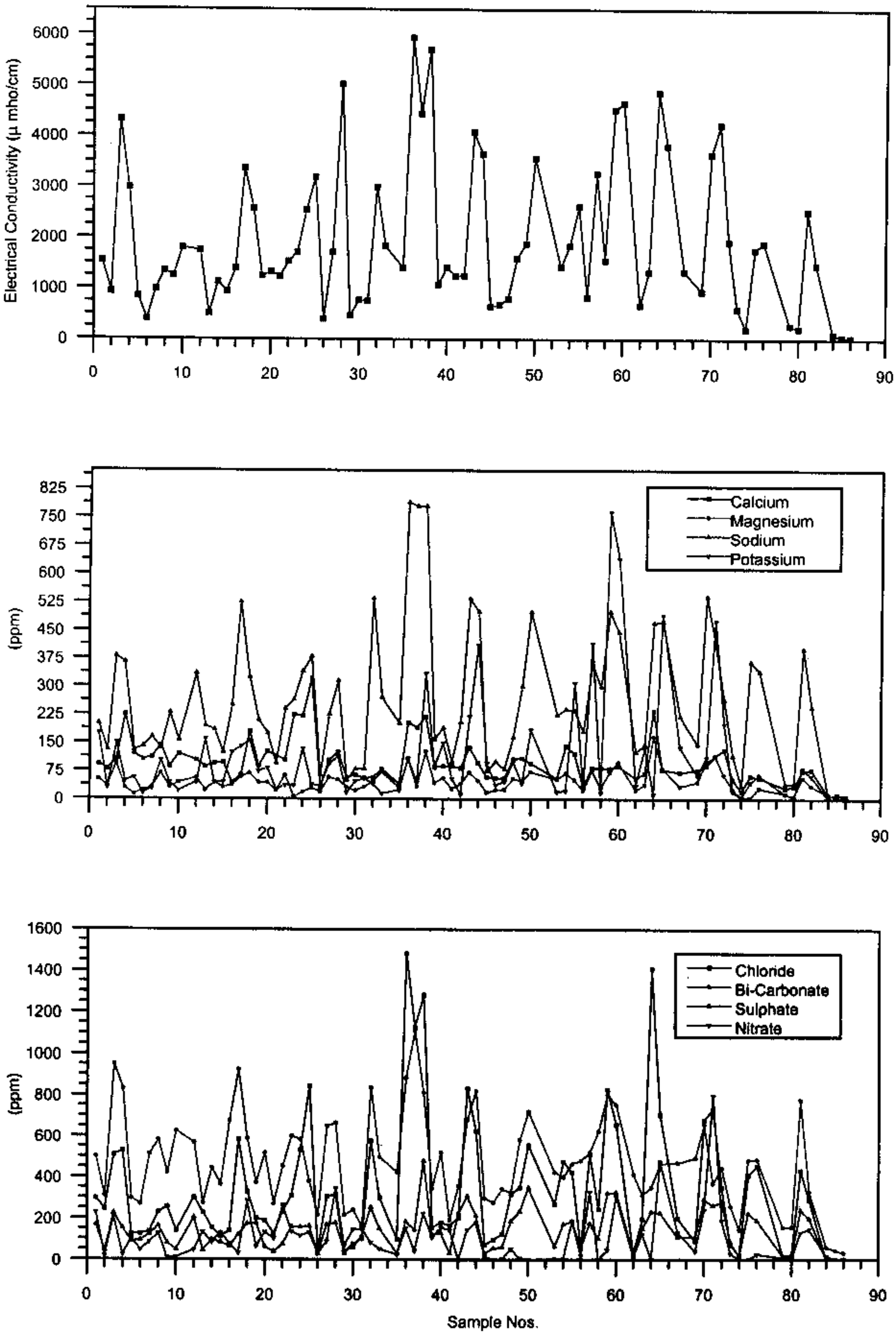

Fig.8. Variation of EC and chemical parameters of samples collected in the month of Nov.99.

Table 3. Average Water quality parameters (ppm) of samples collected in the month of Nov.99

Type of Sample (Nos)	Temp °C	pH	EC (μmho/cm)	Ca	Mg	Na	K	Cl	HCO_3	SO_4	NO_3	TDS	TH
Dug Wells (63)	31	7.07	2017	104	46	270	118	344	511	143	107	1291	450
Deep Wells (7)	31	7.08	2038	75	59	296	121	387	404	191	183	1304	433
Canal Water (2)	31	7.59	244	32	11	40	10	18	156	13	4.5	156	125
Rain Water (3)	30	6.21	64	10	7	1.5	1.03	0	45	0	7	41	54
Sea Water (1)	NA	7.7	68600	416	1109	11400	600	18720	2254	5412	NA	48900	5660

Source: Sea water analysis data (Murali Krishna et al, 1997)

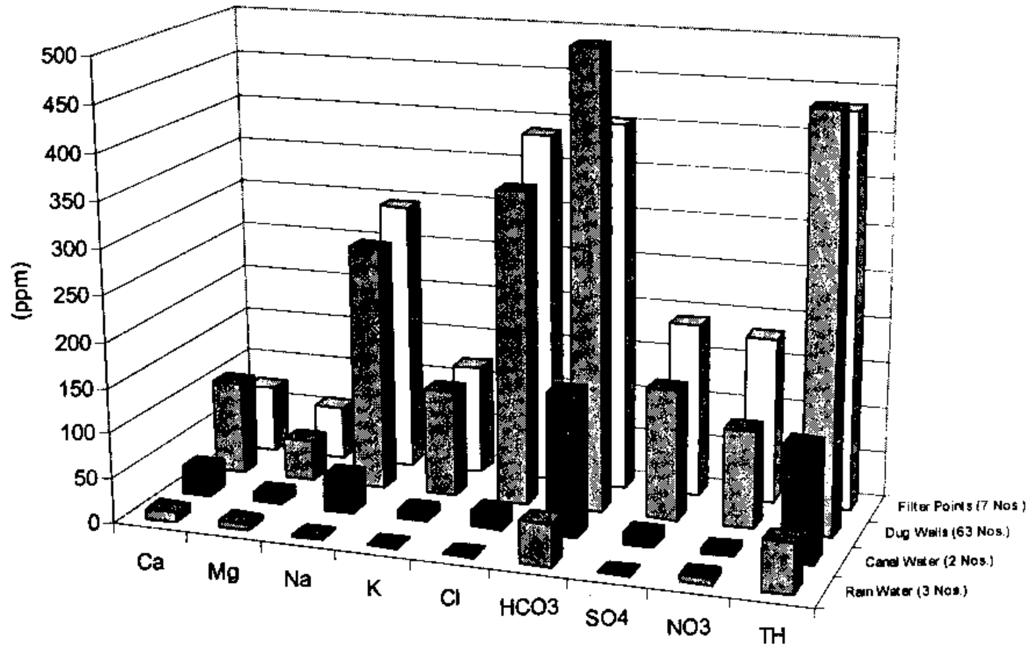

Fig.9. Average water quality parameters of different sources of water in the study area (Nov.99)

noted that the rain samples, which are collected from the study area are nearer to fertilizer factories.

The water samples collected during the study period is classified according to Chadha (1999) diagram to infer the hydrogeochemical facies and their seasonal changes in the study area. The classification of samples Nos.1 to 41 in the month of May-99, August-99 and November-99 is shown in Fig. 10, 11 and 12 respectively. The changes in samples location on the diagrams indicates that the seasonal mixing process in the shallow groundwater. All the samples that are plotted on diagrams are collected from dugwells (1 to 41).

Similarly, samples collected in the month of November-99 are plotted Chadha's diagram and the same is shown in Figure 13. The distinct location of samples of rainwater, canal water and seawater is clearly seen in the diagram. Among 77 samples collected in the month of November-99, indicates that 49% of samples is NaCl type, 23% is $CaCl_2$ type, 21% is $CaHCO_3$ and 7% is $NaHCO_3$ type in the study area. The wells, which are falling under $CaHCO_3$, may indicate recharge zone of water (except rain and canal water samples). The location of sample nos. 6, 7, 10, 15, 21 and 29 may be considered as recharge zones in the study area. The recharge may be due to rainwater, canal water or local aquifer conditions. The samples collected in the month of Nov. 1999 (77 Nos.) are also plotted on Pipers (1953) trilinear diagrams and the same is shown in Fig. 13(a). The classification made according to Chadhas diagram is same as Pipers classification. It indicates that the Chadhas diagram could be used, as alternative for Pipers classification and the plotting of water quality data is easy in Chadha's diagram.

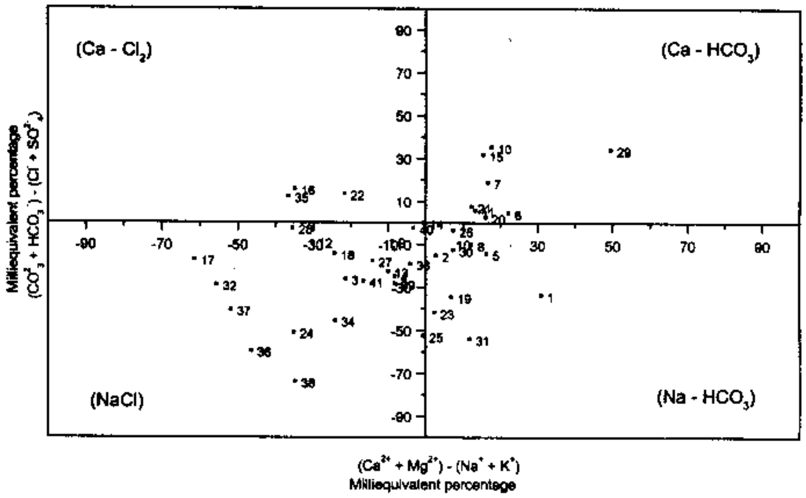

Fig.10. Geochemical classification of Groundwater samples (1-41) during May 1999

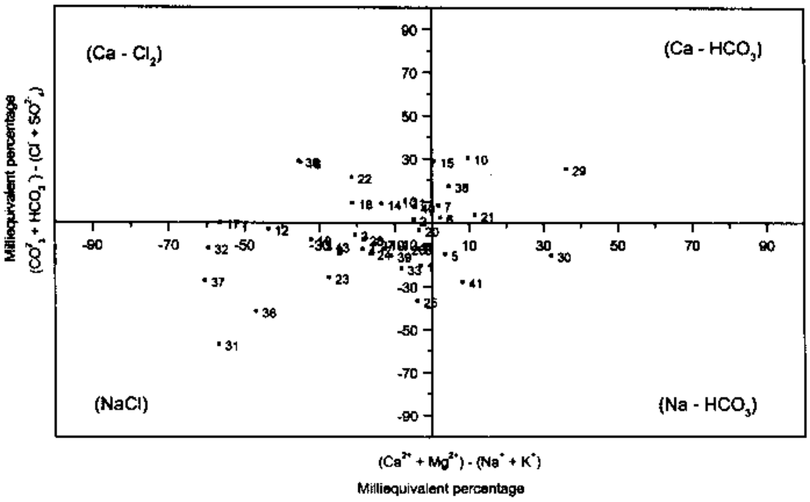

Fig.11. Geochemical classification of Groundwater samples (1-41) during Aug. 1999

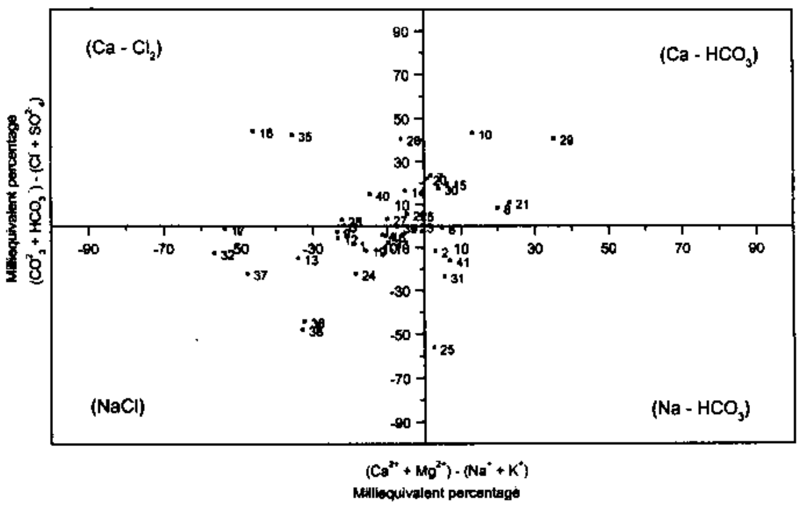

Fig.12. Geochemical classification of Groundwater samples (1-41) during Nov. 1999

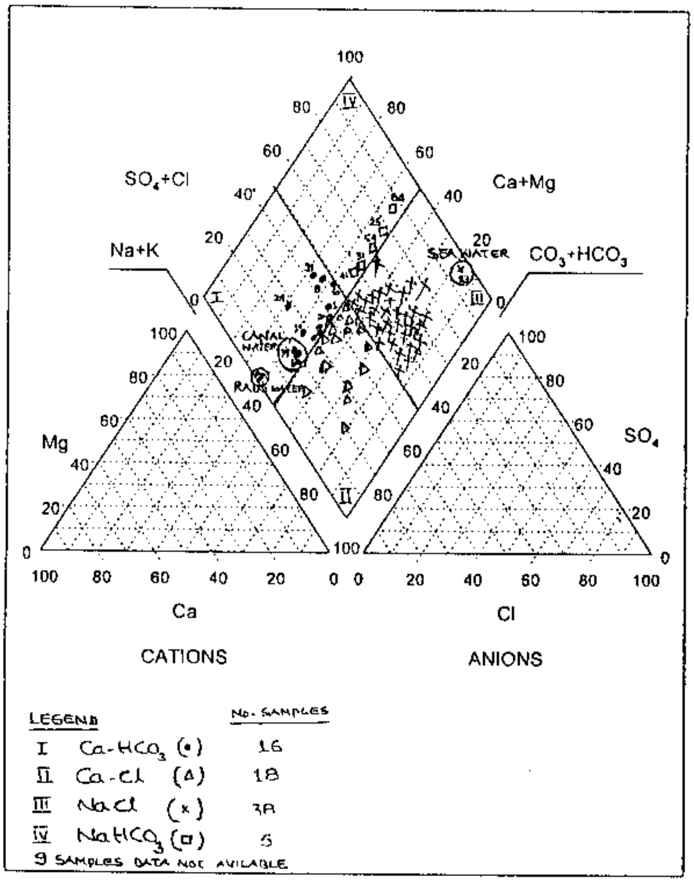

Fig. 13(a). Geochemical classification of different sources of samples (1to 86) during Nov. 1999, Pipers (1953)

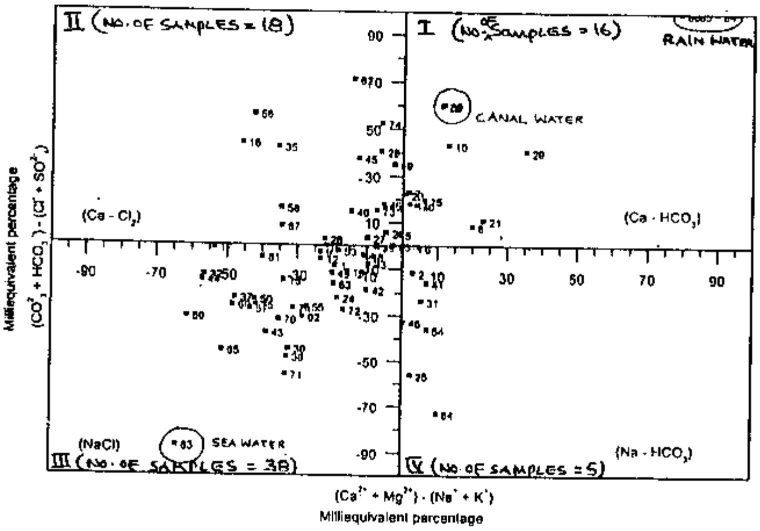

Fig.13. Geochemical classification of different sources of samples (1 to 86) during Nov. 1999, CHADHA(99)

To identify correlation between water quality parameters in the study area the samples Nos. 1 to 41 have been considered. The correlation coefficient between water quality parameters in the month of May-99 and August-99 and November-99 are given in Table nos.4, 5 and 6 respectively and their corresponding correlation plots are shown in Figure Nos.14, 15 and 16. These tables indicated that there is a seasonal variation between water quality parameters in the study area. However, the high correlations of EC with Cl, Na, HCO_3 and Total Hardness with Ca, Mg, SO_4, Cl are observed. Jain et al. (1998) have used the high correlation between EC with Cl, Na and HCO_3 , and developed regression model for EC in the study area. A good relation of total hardness with Ca, Mg, SO_4 and Cl indicates that the hardness in groundwater is mainly due to dissolved Sulphates of calcium, Magnesium and Chloride. The correlation between HCO_3 and Sodium indicates that HCO_3 in the region is mainly due to the presence of Sodium Bicarbonate. The general groundwater quality in the study area is hard to very hard (150 to 300 ppm or more).

Based on the samples collected from Dugwells in the month of November-99 the spatial distribution of few water quality parameters of Cl, HCO_3, Na, SO_4, TDS and NO_3 are prepared and the same are shown Fig Nos.17, 18, 19, 20, 21, and 22 respectively. It is observed that the present network of observation wells are not uniformly distributed in the study area. The extrapolation contours have been drawn wherever the observation wells are not present. Dense network of Observatory wells is observed in the middle of town. Few more wells are to be established above the railway track towards Visakhapatnam (Fig. 1).

Table 4: Correlation Coefficient between Water Quality Parameters during Pre monsoon (May 99)

	EC	Ca	Mg	Na	K	Cl	HCO_3	SO_4	NO_3	TDS	TH
EC	1.000										
Ca	0.725	1.000									
Mg	0.448	-0.006	1.000								
Na	0.968	0.693	0.286	1.000							
K	0.640	0.212	0.772	0.484	1.000						
Cl	0.976	0.771	0.329	0.971	0.530	1.000					
HCO_3	0.699	0.404	0.209	0.732	0.283	0.622	1.000				
SO_4	0.813	0.523	0.709	0.693	0.790	0.756	0.293	1.000			
NO_3	0.094	0.177	0.055	-0.004	0.336	0.078	-0.305	0.180	1.000		
TH	0.850	0.792	0.606	0.726	0.640	0.814	0.450	0.848	0.174	0.850	1.000

No. of Observations : 41(dug wells)

Table 5: Correlation Coefficient between Water Quality Parameters during Monsoon (Aug. 99)

	EC	Ca	Mg	Na	K	Cl	HCO_3	SO_4	NO_3	TDS	TH
EC	1.000										
Ca	0.454	1.000									
Mg	0.562	0.393	1.000								
Na	0.626	0.376	0.686	1.000							
K	0.177	0.346	0.470	0.466	1.000						
Cl	0.549	0.481	0.713	0.956	0.531	1.000					
HCO_3	0.753	0.470	0.659	0.829	0.358	0.720	1.000				
SO_4	0.344	0.521	0.492	0.480	0.414	0.517	0.440	1.000			
NO_3	0.157	0.342	0.339	0.066	0.593	0.151	-0.038	0.264	1.000		
TH	0.609	0.832	0.837	0.638	0.489	0.716	0.677	0.607	0.408	0.609	1.000

No. of Observations: 40(dug wells)

Table 6:Correlation Coefficient between Water Quality Parameters during Post Monsoon (Nov. 99)

	EC	Ca	Mg	Na	K	Cl	HCO_3	SO_4	NO_3	TDS	TH
EC	1.000										
Ca	0.555	1.000									
Mg	0.664	0.151	1.000								
Na	0.893	0.514	0.589	1.000							
K	0.489	0.215	0.615	0.437	1.000						
Cl	0.878	0.647	0.580	0.945	0.438	1.000					
HCO_3	0.800	0.374	0.545	0.827	0.377	0.698	1.000				
SO_4	0.699	0.464	0.693	0.691	0.644	0.664	0.579	1.000			
NO_3	0.375	0.242	0.406	0.129	0.540	0.158	0.085	0.367	1.000		
TH	0.777	0.860	0.635	0.706	0.486	0.805	0.574	0.721	0.399	0.777	1.000

No. of Observations: 39(dug wells)

TDS = Total Dissolved Solids T.H = Total Hardness (as $CaCO_3$)

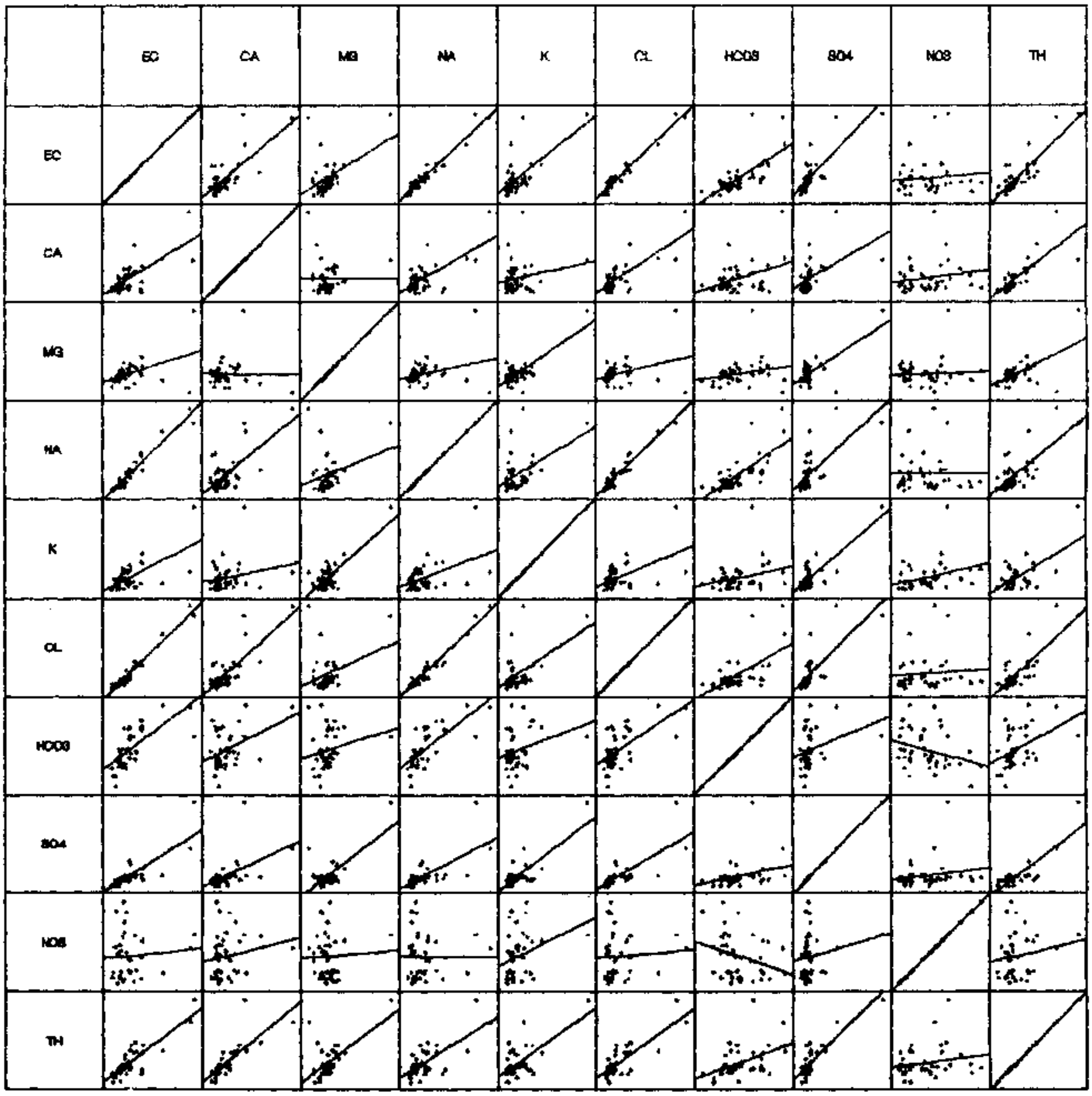

Fig.14. Correlation coefficient plots of water quality parameters of samples (1-41) during pre-monsoon (May 1999) period.

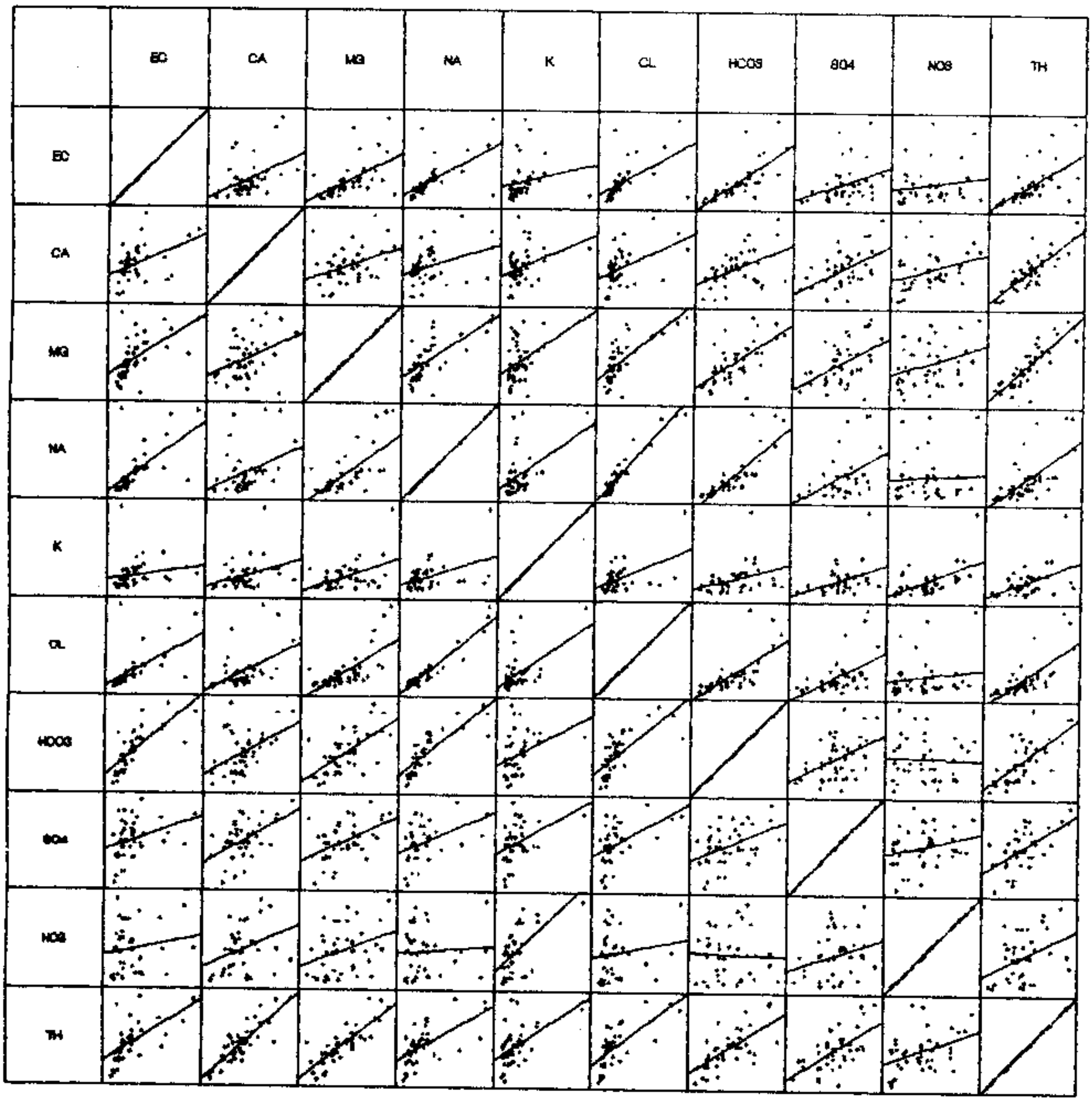

Fig.15. Correlation coefficient plots of water quality parameters of samples (1-41) during -monsoon (Aug. 1999) period.

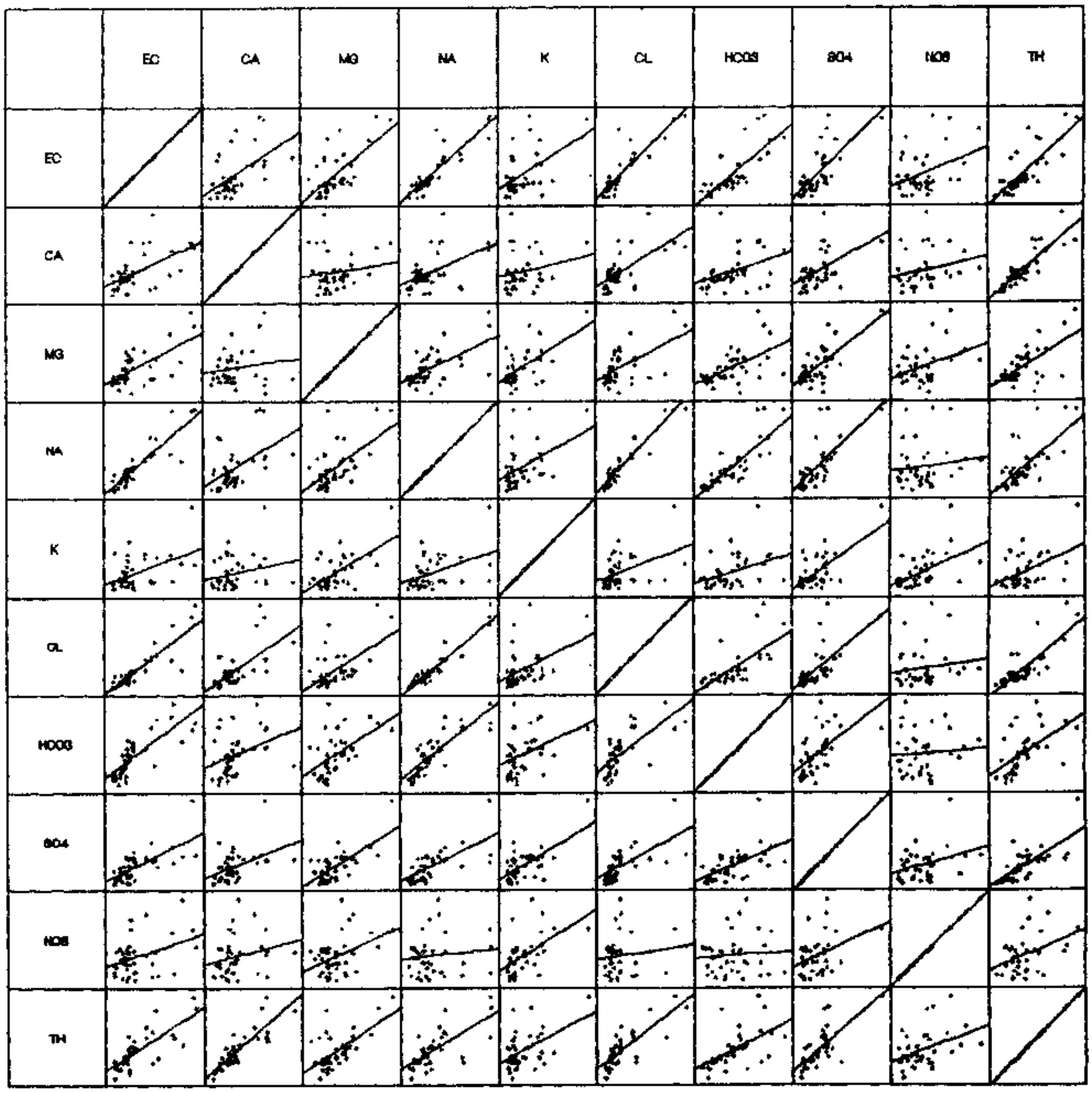

Fig.16. Correlation coefficient plots of water quality parameters of samples (1-41) during post-monsoon (Nov. 1999) period.

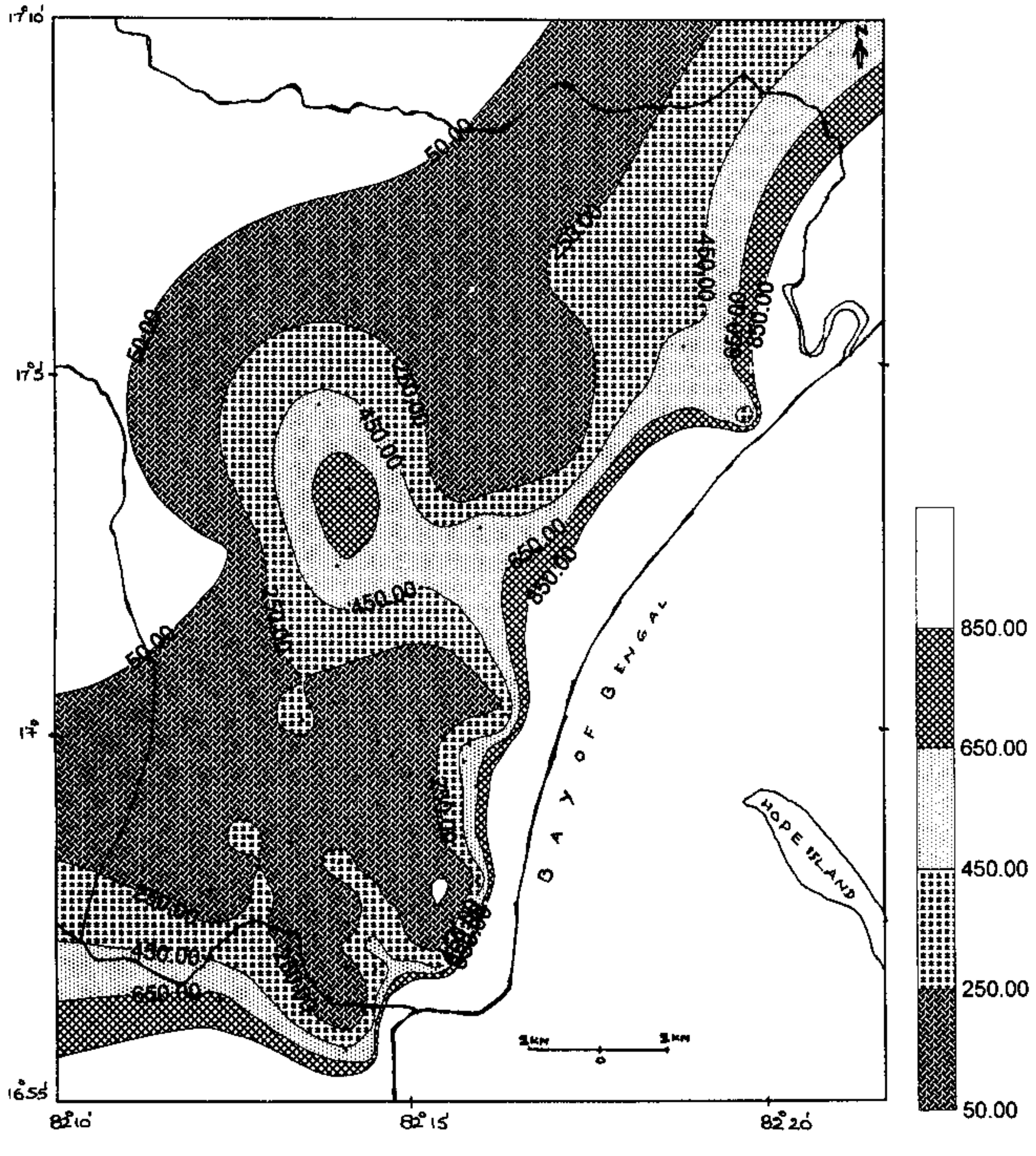

Fig.17. Spatial distribution of Chloride (ppm) in the study area (Nov.99)

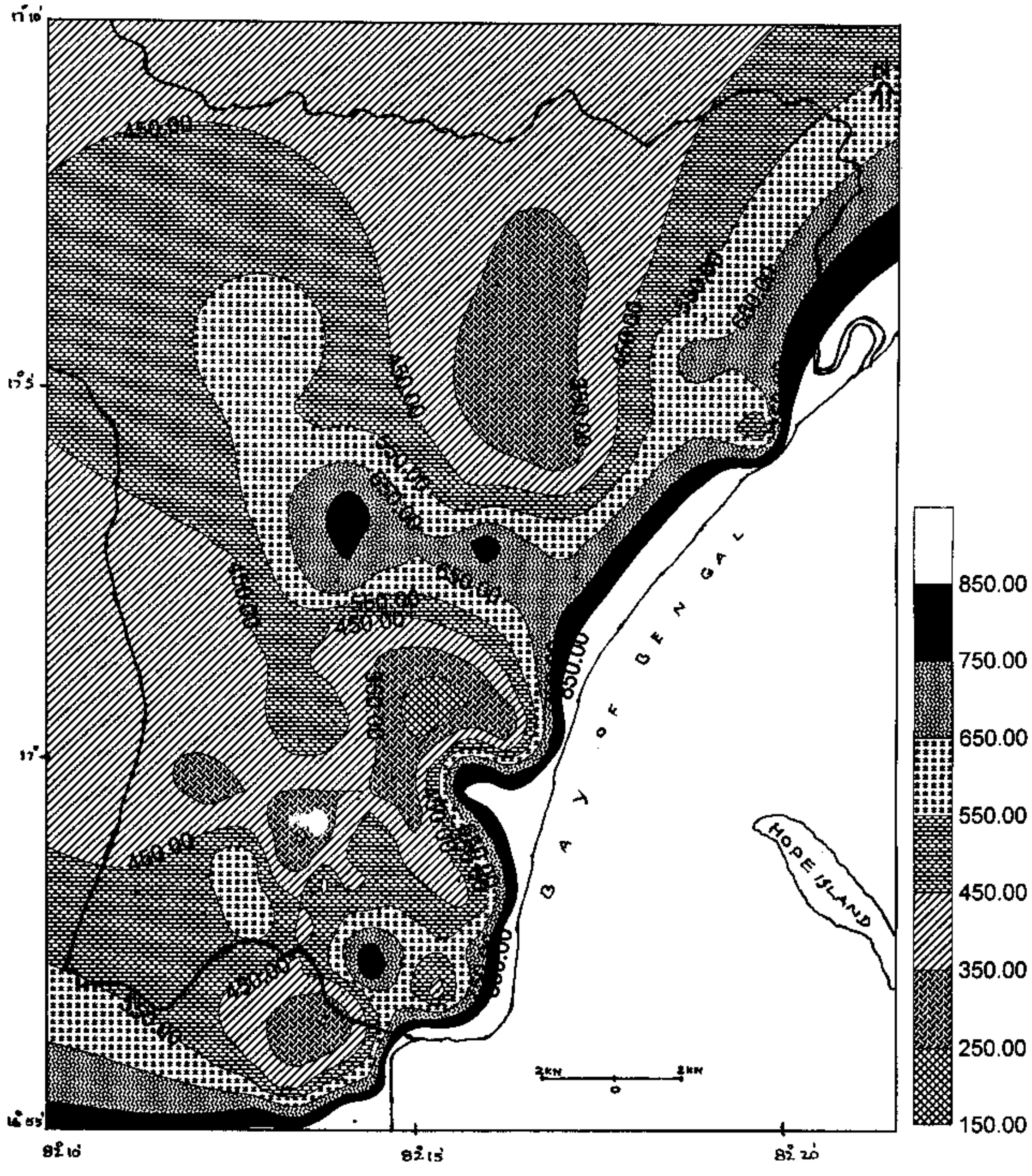

Fig.18. Spatial distribution of Bicarbonate (ppm) in the study area (Nov.99)

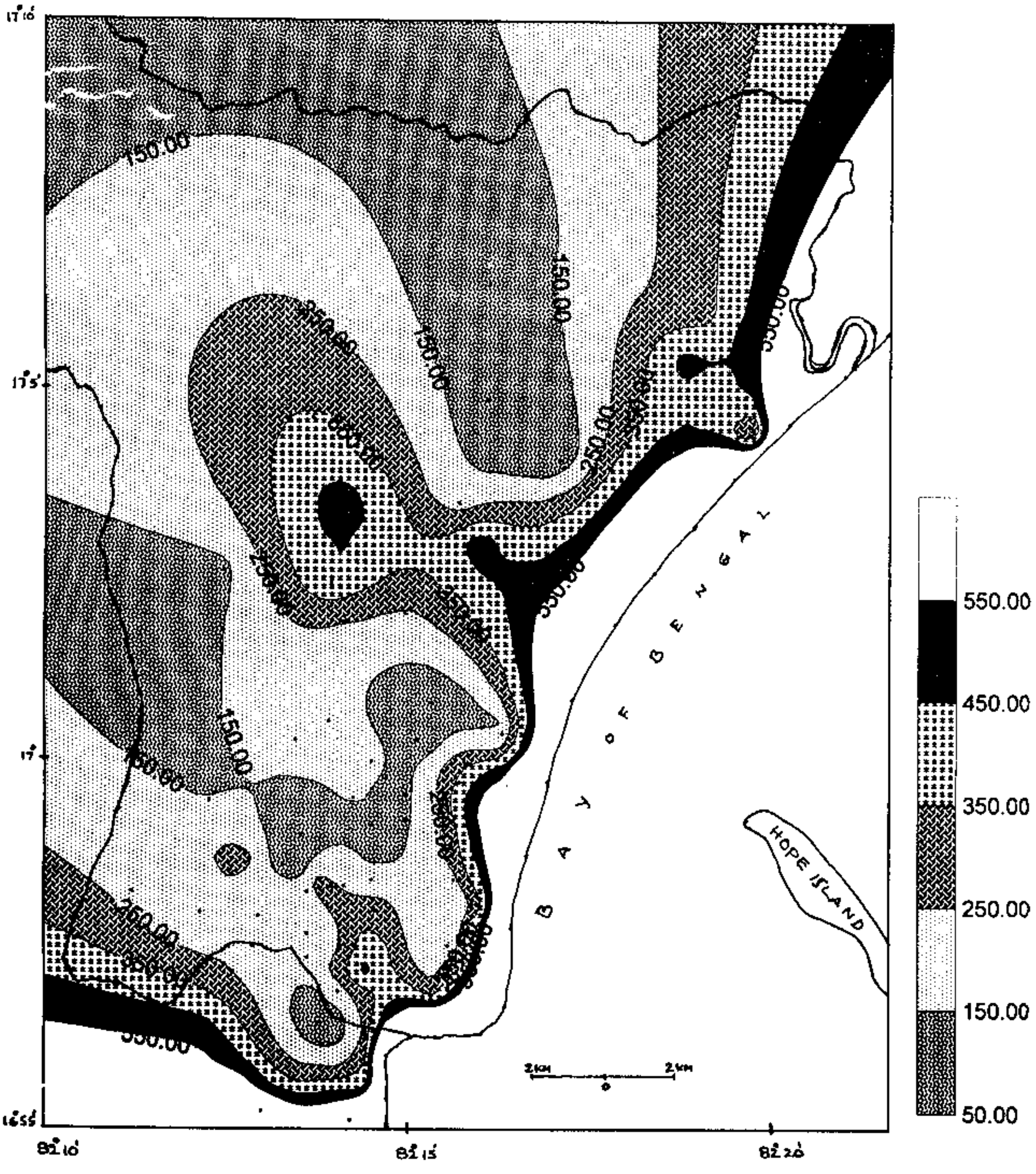

Fig.19. Spatial distribution of Sodium (ppm) in the study area (Nov. 99)

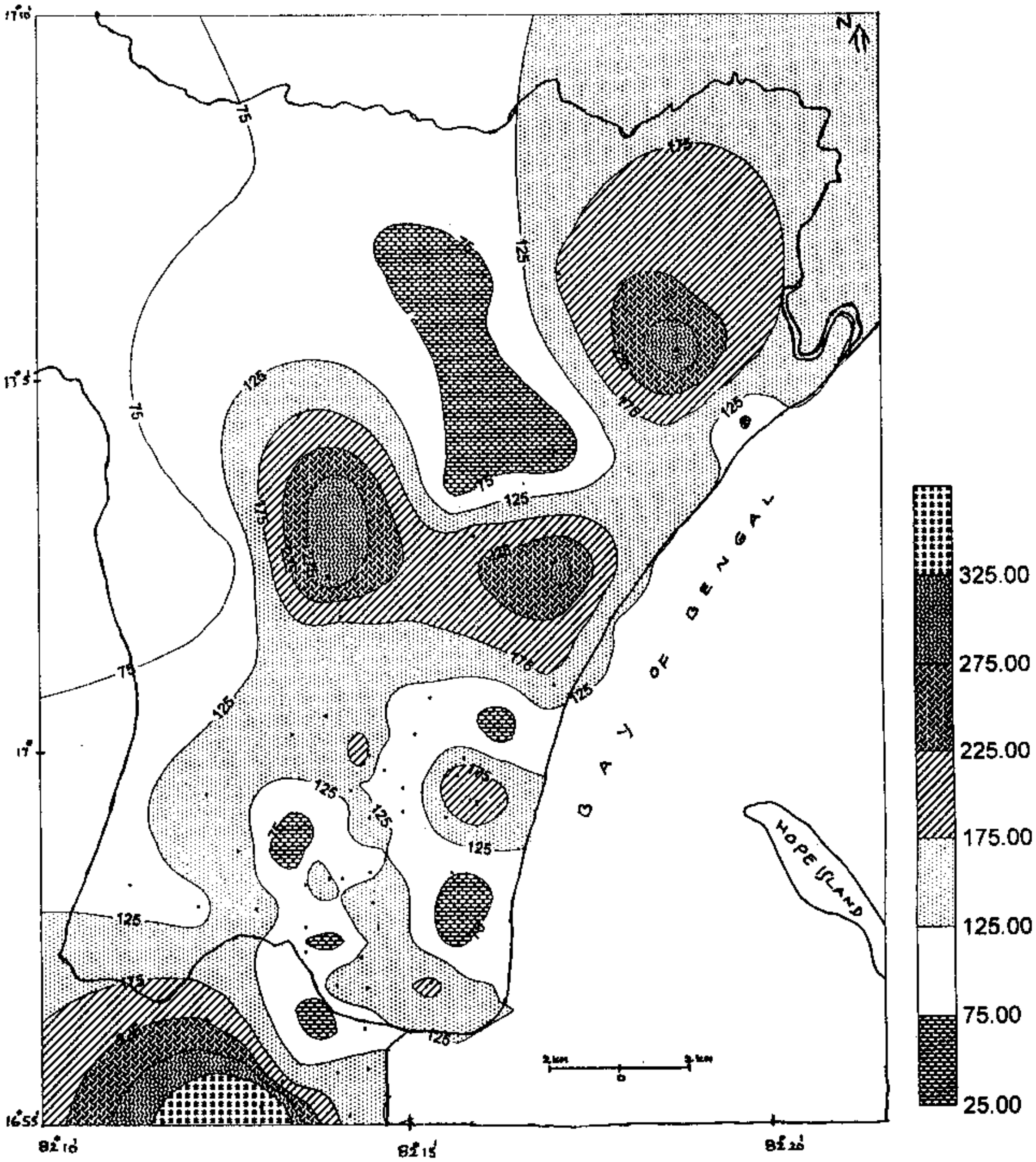

Fig.20. Spatial distribution of sulphate (ppm) in the study area (Nov.99)

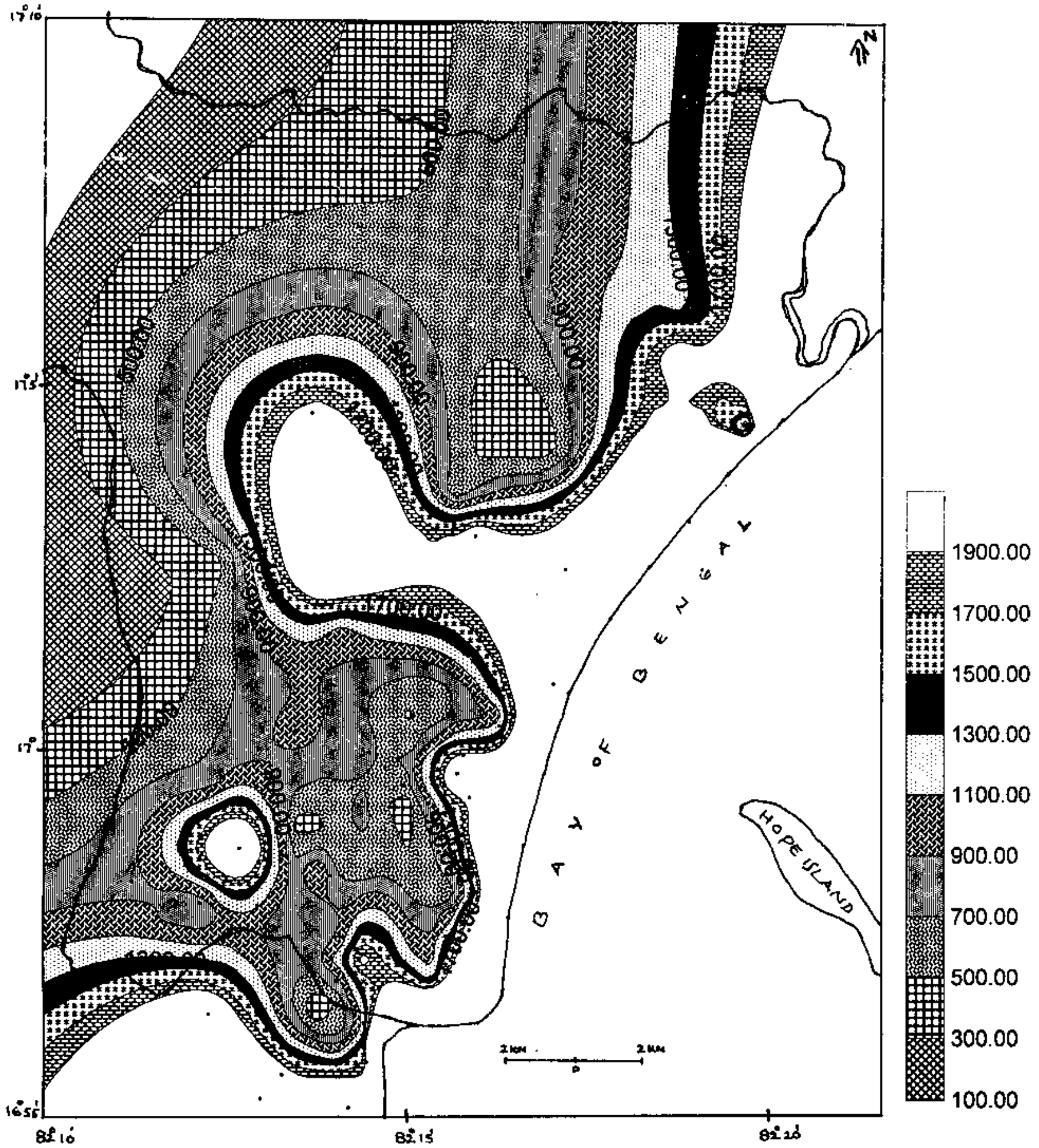

Fig.21. Spatial distribution of TDS (ppm) in the study area (Nov.99)

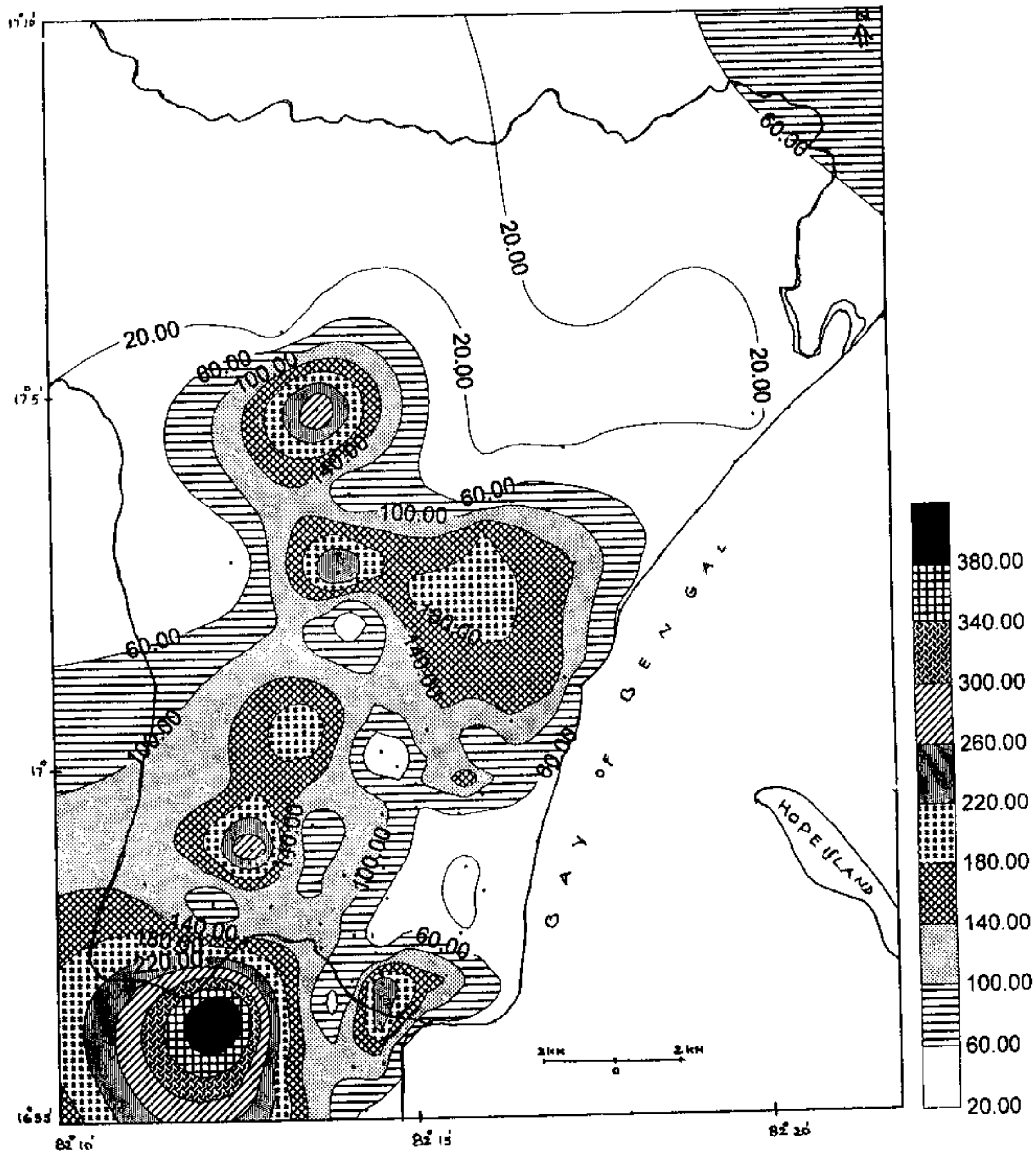

Fig.22. Spatial distribution of Nitrate (ppm) in the study area (Nov.99)

The highest values of Cl, HCO_3, SO_4, Na, TDS have been observed at the seacoast, in sample no. 59 (Navara) & nearby samples and also near Bikkavolu drain. These areas are the probable places of high concentrations of pollution in the study area. The reasons for high concentrations are to be studied. The distribution of high Nitrate is observed not only from above places but also some places in the city. This may be due to the local dumping of waste material in the town and also may be due to septic tanks. Almost 85% of the study area is exceeding the permissible limits of Nitrate in groundwater (<45 ppm). It is therefore, suggested that the intensive studies may be initiated to find out sources of Nitrate pollution in the study area. An attempt is made to study the spatial distribution of Sulphate/Chloride ratio in the study area. The spatial distribution map is shown in Figure 23. More deviation from the ratio of 0.25 indicates high Nitrate concentrations in the study area. The sources for high Nitrate in the study area aretobe studied in detail.

The groundwater levels (w.r.t MSL) in some of the dugwells are shown in the Figure 24. The average ground water table in the study area is always above MSL. Thus indicates that there is no flow from sea to shallow aquifer except at well no. 27 (nearer to salt creek). The quality of water is also poor in the well. The studies on water levels incombination with water quality leads to better understanding of hydrogeochemical process or identification of pollution sources in the study area.

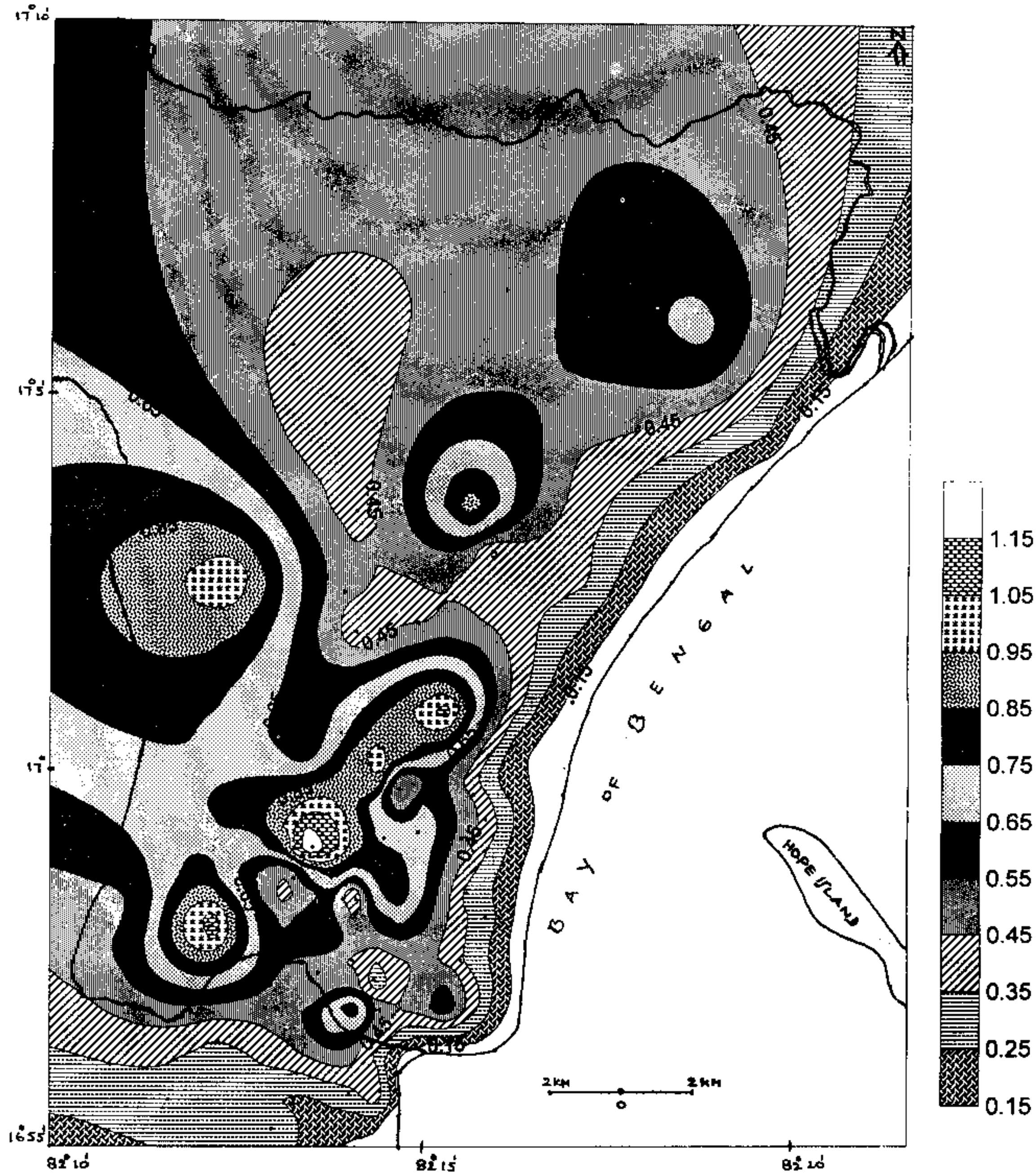

Fig.23. Spatial distribution of Sulphate/Chloride ratio in the study area (Nov. 99)

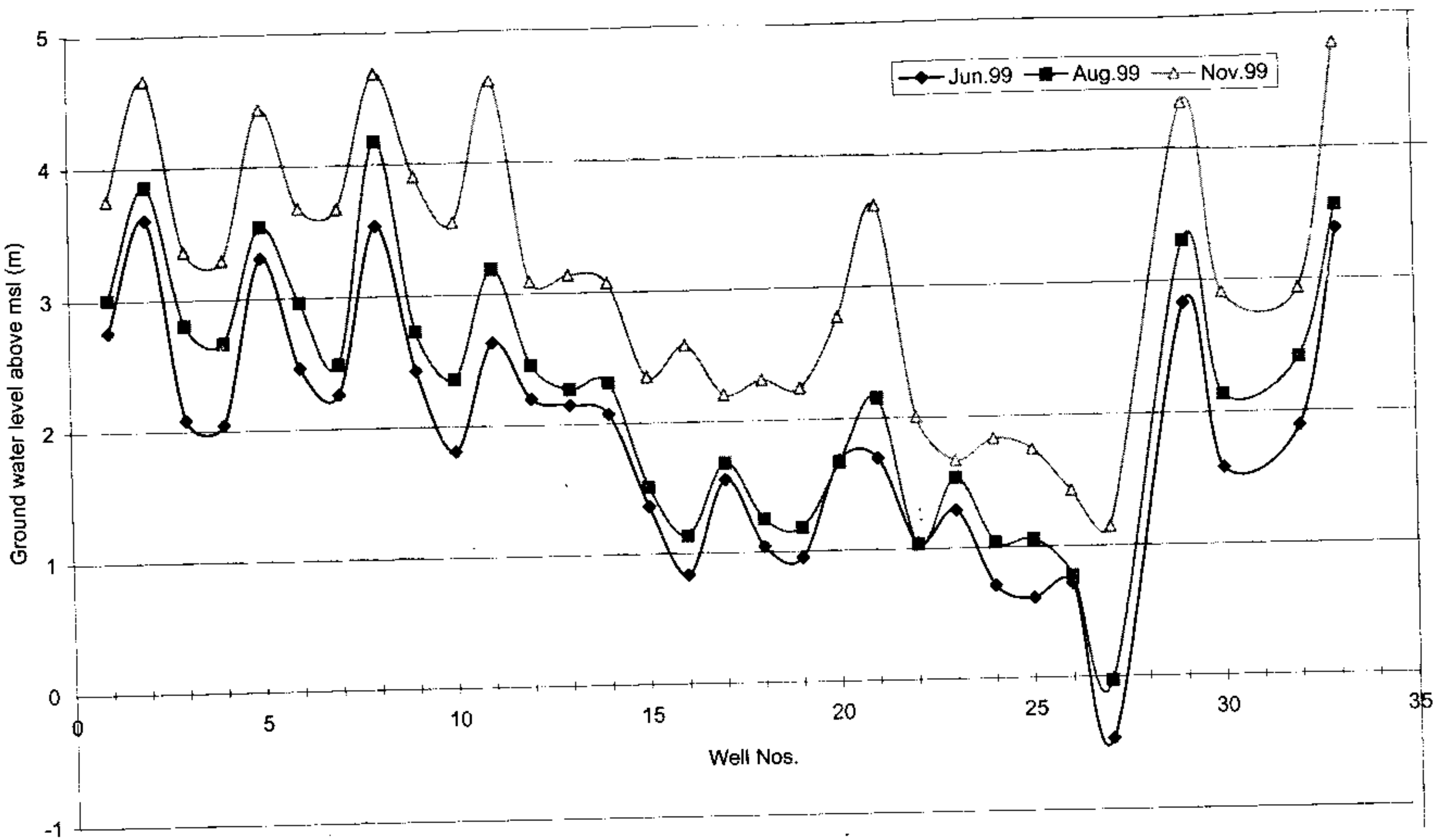

Fig.24. Seasonal water level fluctuations in few observation wells.

5.0 CONCLUSIONS

Total 186 groundwater samples have been collected in the study area and analysed for physical and chemical parameters. For each sample the Ion Balance Error (IBE) has been calculated and found that error is within ± 10%. The range of temperature, pH, and EC during the study period is 28^0C to 32^0C, 6.6 to 7.9 and 390 to 8,222 μmho/cm respectively. The range of major anions of Cl, HCO_3, SO_4 and NO_3 is 32 to 1800 ppm, 112 to 1128 ppm, 28 to 1168 ppm and 0 to 345 ppm respectively. Similarly the range of cations of Ca, Mg, Na and K is observed as 34 to 390 ppm, 4 to 200 ppm, 45 to 1200 ppm and 6 to 500 ppm respectively.

The major cation and anion in the study area are Sodium and Chloride respectively. The samples collected in the month of Nov. 99 are classified according to Chadha (1999) diagram. Among 77 dug wells samples collected in the month of November-99, 49% of samples is NaCl type, 23% is $CaCl_2$ type, 21% is $CaHCO_3$ and 7% is $NaHCO_3$ type in the study area. The comparison between Chadha's classification and Piper's classification indicated that the Chadha's diagram could be used as alternative for Piper's trilinear classification.

High correlation coefficient of EC with Cl, Na, HCO_3 and Total Hardness with Ca, Mg, SO_4, Cl are observed in the study area. A good relation of TH with Ca, Mg, SO_4 and Cl indicates that the hardness in groundwater is mainly due to dissolved Sulphates of calcium, Magnesium and Chloride.The general groundwater quality in the study area is hard to very hard (150 to 300 ppm or more).

The spatial distribution maps of water quality parameters of Cl, HCO_3, Na, SO_4, TDS and NO_3 are prepared. The high values of these parameters are observed at well No. 59 (Navara) & nearby area and also near Bikkavolu drain. The high Nitrate concentrations are observed not only from these places but also some places in the town.

The deviation of SO_4/Cl ratio from 0.25 indicates high Nitrate concentrations in the study area. The average ground water table in the study area is above MSL during the study period. The present network of observation wells within the hydrologic boundaries is not uniformly distributed. Few more wells are to be identified at the upstream of the study area. The combined study of water levels with quality leads to better understanding of flow process and pollution sources in the study area.

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