

**MAJOR ION CHEMISTRY AND QUALITY ASSESSMENT OF
GROUNDWATER IN HARIPUR AREA**

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ABSTRACT

Study was conducted for investigating chemical composition of groundwater, identifying the compositional types of groundwater, delineating the processes controlling the groundwater chemistry and assessing the groundwater quality for drinking / irrigation uses. Groundwater samples collected from shallow (hand pumps, open well, motor pumps) and deep (tube wells) aquifers were analyzed for major cations (Na^+ , K^+ , Ca^{2+} , Mg^{2+}) and anions (HCO_3^- , Cl^- , SO_4^{2-}). The data indicated that Ca^{2+} is the dominant cation in most of the samples followed by Mg^{2+} whereas HCO_3^- is the most abundant anion in all samples. Hydrochemistry provides a clear indication of active recharge of shallow and deep aquifers by modern meteoric water. Carbonate dissolution was found to be the prevailing process controlling the groundwater chemistry. Chemical quality was assessed for drinking purpose by comparing with WHO, Indian and national standards, and for irrigation purpose using empirical indices such as SAR and RSC. The results show that groundwater meets the norms of good quality drinking water and can be safely used for irrigation.

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1. INTRODUCTION

Water sustains life and its importance for the socioeconomic growth can hardly be over-emphasized. Portable and safe drinking water is essential for the health and well being of the community. Groundwater is the most important source of water supply. During recent years much of the emphasis is given at the considerations of its quality. As a result of consumptive way of human life, growing urbanization, industrialization without adequate measures of waste disposal, agricultural activities, etc., the groundwater environment is being polluted with an ever increasing number of pollutants. With the passage of time, the vast subsurface reservoir of fresh water, which a few decades ago was relatively clean, is gradually being degraded.

In Pakistan, groundwater environments are being seriously polluted due to unplanned disposal of untreated industrial effluents as well as domestic sewage, agricultural activities (like use of fertilizers, herbicides, pesticides, fungicides) and changes in groundwater dynamics due to heavy abstraction [1]. In the area selected for the present study, groundwater is the only source of drinking water. Hence its quality is of great importance as it significantly affects the human health. Concentrations of various elements when present in more than certain specified limits have considerable health hazards [1-3]. The recommended limits for concentrations of inorganic constituents in drinking water for human beings have been in use for many years. Acceptable standards vary from country to country. The main standards used are those recommended by the World Health Organization [4].

Present study was undertaken for investigating chemical composition of groundwater, identifying the chemical types of groundwater, delineating the processes controlling the groundwater chemistry and assessing the groundwater quality for drinking / irrigation uses.

2. STUDY AREA

2.1 General Description

Area selected for the present study is a part of Haripur District, Khyber Pakhtoonkha Province (Fig. 1). It is located about 160 km northeast of Peshawar. Haripur Plain is bounded by the river Doar in the north, mountain ranges in the east and west, while the river Haro flows a little away from its southern boundary. The surface is gently undulating except along eastern and western boundaries where badland topography exists. The plain is dissected by numerous gullies. Elevation ranges from 915 meter a.m.s.l. in the north eastern part to 442 meter a.m.s.l. in the southwestern part. Total catchment area of the plain is 622 sq. km. of which 422 sq. km. is alluvial fill. Depth of water table varies widely ranging from 18m in the north, north eastern and western parts to 76m in central and southern parts [5].

2.2 Geology

Haripur Plain is extensively covered with alluvial fill. The western, eastern and southeastern parts of the plain are covered by thick clay deposits which have been eroded and gullied extensively by numerous nalas. Over most of the area, the clay cover varies in thickness from 30 to 60 m. This clay cover is underlain by sand, gravel and boulders of considerable thickness with some layers of clay in between them. The layers of sand, gravel and boulders between Hattar and Dingi in the southern part of the plain, are highly permeable. In the north and northeastern part (between Havalian and Sarai Saleh), the clay cover is comparatively less thick and overlies the boulders and gravels of considerable thickness. These boulders and gravel are highly permeable and form a good aquifer [5].

2.3 Climate

Climate of the area is semiarid with hot summers and mild winters. June and January are the hottest and coldest months respectively. Mean maximum

temperature in the hottest month (June) is 44 °C while the minimum temperature in the coldest month (January) is 3 °C. The mean annual precipitation is about 910 mm while that at the adjoining hills is about 2000 mm [5].

3. FIELD SAMPLING

Groundwater samples were collected from different sampling stations during the two sampling campaigns (April 2006 and October 2006). Location of sampling points is shown in Fig. 1. The sampling points included open wells, hand pumps, motor pumps, tube wells and springs. Open wells, hand pumps and motor pumps represent shallow groundwater while tube wells and springs represent deep groundwater. Two filtered sample aliquots were collected in pre-cleaned polyethylene bottles from each point for analysis of major ions (cations and anions). The samples for cations analysis were acidified with ultra pure nitric acid on site. Physical parameters (pH, electrical conductivity) of all collected samples were measured in the field using portable meters.

4. ANALYSIS

Groundwater samples were analyzed for major cations (Na^+ , K^+ , Ca^{2+} , Mg^{2+}) and anions (Cl^- , CO_3^{2-} , HCO_3^- , SO_4^{2-}). Methods used for sample analyses are given below.

All the plastic and glassware was thoroughly cleaned and subsequently rinsed with distilled and subsequently deionized water. The solutions were prepared with distilled and deionized water. All chemicals were of analytical grade supplied by E. Merck or BDH. The working standards were prepared daily by serial dilution of stock solutions.

Unacidified sample taken from each location was analyzed for anions using standard analytical methods [6]. Carbonate and bicarbonate were analyzed by titration against 0.02 N Sulphuric acid. Chloride concentrations were determined by

ion selective electrode using Orion Research Microprocessor Ionalyzer/901. Turbidimetric method was employed for sulphate analysis and samples were measured on Hitachi Model 220 A Spectrophotometer. Major cations were measured using flame atomic absorption spectrophotometric method. The instrument used was Hitachi Model 180-80 Polarized Zeeman Atomic Absorption Spectrophotometer.

5. RESULTS AND DISCUSSION

Results of chemical analyses of first and second sampling are given in Table 1 and 2. These tables indicate that chemistry of groundwater is almost similar and no temporal variations are observed. Mean data (Table 3) have been used for investigating various aspects of water chemistry and quality.

5.1 Physico-chemical Parameters

Groundwater in Haripur Plain has low salt contents and fairly good quality. In case of first sampling, EC values of shallow and deep groundwater lie in the range of 318 to 781 $\mu\text{S/cm}$ and 386 to 728 $\mu\text{S/cm}$ respectively. EC values of shallow and deep groundwater in 2nd sampling vary from 297 to 854 $\mu\text{S/cm}$ and 321 to 659 $\mu\text{S/cm}$ respectively. This means that there is no considerable difference in the salt contents of shallow and deep groundwater. Similarly pH values of shallow and deep groundwater are also similar in the two seasons. These values at most of the locations are 7 to slightly more than 7 indicating neutral to slightly alkaline character. As the pH is always less than 8, alkalinity is mainly due to HCO_3^- content.

5.2 Major Ion Chemistry

In shallow groundwater, concentrations (mg/L) of Na^+ , K^+ , Ca^{2+} , Mg^{2+} range from 3.7 to 68.2, 0.9 to 3, 34.4 to 76.2 and 10.9 to 31.4 respectively. Average concentrations (mg/L) of these major cations are 21.8, 1.9, 53.7 and 25.6 respectively. In case of major anions, HCO_3^- is dominant in all shallow groundwater

samples. Its values range from 158 to 419 mg/L with an average of 298 mg/L. As regards the concentrations of Cl^- and SO_4^{2-} , their values vary from 12.1 to 35.5 mg/L (average = 19.3 mg/L) and 8.6 to 26.2 mg/L (average = 12.7 mg/L) respectively.

In deep groundwater, Na^+ , K^+ , Ca^{2+} and Mg^{2+} concentrations (mg/L) vary from 6.9 to 38.6 (average = 17.3), 0.9 to 3.8 (average = 1.9), 35.9 to 75.9 (average = 52.3) and 13.5 to 42 (average = 22.2) respectively. HCO_3^- values varying between 194 mg/L and 379 mg/L (average = 262 mg/L) are much higher than the other major anions (Cl^- , SO_4^{2-}). Concentrations of Cl^- and SO_4^{2-} lie in the range of 12.5 to 25 mg/L and 8.8 to 15.4 mg/L respectively. Average values of these anions are 18.7 mg/L and 12.3 mg/L respectively.

Summary of water chemistry analysis data (Table 4) reveals that the shallow and deep groundwater have similar composition with no clear difference. Average values of all parameters are close in both cases. These indicate that Ca^{2+} is the dominant cation followed by Mg^{2+} and Na^+ . Meanwhile, K^+ constitutes the least concentrations in all samples. In case of anions, HCO_3^{2-} (predominant in all samples) is followed by Cl^- and SO_4^{2-} .

5.3 Groundwater Types

Identification of areas with a particular type of groundwater helps for the sustainable management of the water resources. For determination of geochemical facies of groundwater, percentage of equivalent concentration of each cation and anion (milli equivalent/liter, meq/L) as a function of total cation and anion concentration respectively was calculated. Data plotted in Fig. 2 indicates that Ca is the dominant cation in most of the groundwater samples followed by Mg. Bicarbonate appears to be the dominant anion invariably (Fig. 3). Compositional types of water were identified on the basis of % equivalent concentrations of different ions. Groundwater is attributed to a particular type when the concentration of individual cation and anion is at least 50% of the total cation and anion concentration respectively. If no individual cation and anion has concentration more than 50%,

groundwater belongs to mixed type [7,8]. Based on these criteria, the groundwater samples are classified into three main groups, namely Group-1: Ca-HCO₃, Group-2: Ca-Mg-HCO₃ and Group-3: Mg-Ca-HCO₃.

Shallow groundwater at 60% surveyed locations belongs to a distinct type while remaining samples (40%) belong to mixed (transitional) types. Out of the 15 samples of first category, 14 samples belong to Ca-HCO₃ type while one belongs to Mg-HCO₃ type. In case of second category, groundwater samples showing mixed character in terms of cations i.e. Ca-Mg-HCO₃ and Mg-Ca-HCO₃ type samples are equally abundant (4 samples fall in each type). Deep groundwater shows similar trend. In this case also, sixty percent (60%) samples are of Ca-HCO₃ type. Four samples show Ca-Mg-HCO₃ character while 3 samples show Mg-Ca-HCO₃ character.

The data illustrate that the shallow as well as deep groundwater is dominantly of Ca-HCO₃ type low mineralized water and such type of waters are distributed in most sites of the study area. It is a clear indication of active recharge of shallow and deep aquifers by modern meteoric water (rain). It further indicates that shallow and deep aquifers are well connected.

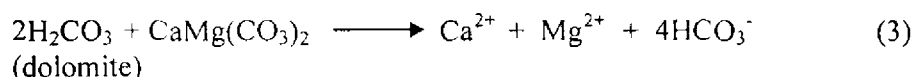
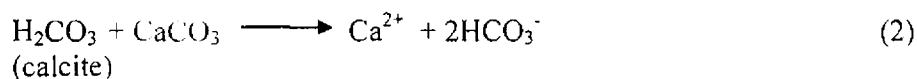
5.4 Geochemical evolution of groundwater

The chemistry of groundwater evolves according to the available minerals and equilibrium conditions. During the movement of groundwater, chemistry does not change abruptly until and unless it meets rocks with entirely different character. Total chemistry of groundwater at a particular space and time is the result of continued action of dissolution, ion exchange and precipitation processes. During the movement of groundwater, total salinity increases with time but one or more ions may be disappearing from the solution by ion exchange or by precipitation where saturation conditions are reached for that particular ion [9-11].

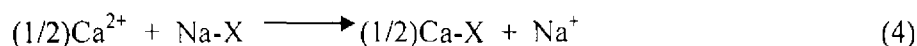
In order to ascertain the geochemical evolution of groundwater, concentrations of various ions as a function of total dissolved ions concentration

(TDIC) were studied and the data has been plotted in Figs. 4 - 10. The bi-variant plot of Na^+ shows positive correlation but it is not so strong. Ca^{2+} increases with the increase in TDIC up to TDIC value of 12 meq/l. This represents a dissolution process. Beyond this TDIC value, groundwater samples show depressed Ca^{2+} concentrations. In case of magnesium, a significant positive correlation between the two parameters can be clearly seen over the entire TDIC range which points to a strong lithological source of groundwater magnesium concentrations. Potassium concentrations are very low which is usual in natural groundwater systems. Fig. 8 reveals that bicarbonate and total dissolved ion concentrations increase linearly indicating carbonate dissolution. Chloride also shows some linear relationship with TDIC. However, sulphate has a poor correlation with TDIC.

The above mentioned facts suggest that chemistry of groundwater is mainly controlled by dissolution of Mg^{2+} and Ca^{2+} containing minerals (carbonate dissolution) as shown in equations 1-3.



Data showed that relative concentration of Na^+ increases with the increase in groundwater mineralization. Cation exchange process is responsible for Na^+ enrichment [12]:



where X denotes cation exchange sites.

This reaction (eq. 4) explains the increase in Na^+ concentrations. The recharging waters exchanging calcium with sodium when interacting with clay lenses [13] which are common in the study area.

5.5 Groundwater Quality

Chemical quality of groundwater was evaluated for drinking and irrigation purposes.

5.5.1 Drinking use

In the present study, groundwater quality for drinking purpose was evaluated by comparing with WHO, Indian and national standards [14, 15]. Evaluated water quality parameters were: sodium, potassium, calcium, magnesium, sulphate, chloride and bicarbonate (Table 5).

(a) Sodium

Elevated drinking water levels of Na may cause hypertension. Similarly high Na (NaCl) may cause vomiting, muscular twisting, rigidity, etc. Chemical data of groundwater obtained in this study reveals that all the samples meet the WHO criteria for good quality drinking water (HDL). No limits have been defined for this parameter in the remaining criteria (Indian as well as national).

(b) Potassium

Some studies have documented the effect of K on the blood pressure. The available chemical data shows that groundwater at all the locations is of good quality with respect to this parameter according to all criteria.

(c) Calcium

Calcium in drinking water has been associated with cardiovascular diseases, certain nervous system defects, prenatal mortality and various types of cancer. High Ca concentrations (hardness) in water may lead to formation of solid scales in pipes, encrustation of kitchen utensils and increased soap consumption. Table 3 shows that all the samples from the study area except only 2 have Ca concentrations below the

highest desirable level (HDL) specified by all three criteria (WHO, Indian and National).

(d) Magnesium

Ca and Mg may be considered as having similar effects as in their contribution towards water hardness. The hazards of hardness can be seen under Ca. It is also associated with stomach disturbances. Data shows that concentration of Mg in all shallow as well as deep groundwater samples are below the HDL given by WHO and PSI criteria. When compared to Indian and PCRWR criteria, norm of good quality water (30 mg/l) is exceeded at 13 locations.

(e) Sulphate

High levels of sulphate in drinking water cause gastrointestinal disorders in human beings and corrosion in pipes. Evaluation of groundwater quality with respect to WHO, Indian and the national criteria indicates that all the samples fulfill the criteria of good quality water.

(f) Chloride

Elevated Cl concentrations in drinking water have significant health hazards. The health hazards of Cl when present in the form of NaCl can be seen under Na. Chloride has also been reported to be associated with colorectal and bladder cancer in several epidemiological studies. It also causes corrosion in pipes. None of the samples was found to have concentrations more than HDL specified in various criteria. Hence, it fully meets the norm of good quality water.

5.5.2 Irrigation Use

Chemical quality of groundwater for irrigation use is quite important as poor quality irrigation water has significant hazards. A number of empirical indices have

been established to determine these hazards [15]. Two very important indices used in this study are discussed hereafter.

(a) Sodium adsorption ratio (SAR)

The ratio between univalent and bivalent cations in irrigation water is indicated by SAR which is defined by:

$$\text{SAR} = [\text{Na}^+ / \{(\text{Ca}^{+2} + \text{Mg}^{+2}) / 2\}^{1/2}] \quad (5)$$

where all concentrations are in meq/L.

The degree of suitability of water is inversely proportional to its SAR. With a higher value of SAR, sodium replaces calcium and magnesium in the soil colloids which destroys the soil structure as it becomes compact and impervious. Acceptable value of SAR in irrigation water is up to 10. The groundwater in the study area has SAR values ranging from 0.2 to 2.3. This implies that groundwater has very good quality and has no sodium hazard at all. It can be used for irrigating for all types of soils.

(b) Residual sodium carbonate (RSC)

To quantify the complications caused by carbonate precipitation or dissolution, an empirical parameter called RSC is used. This parameter is given by:

$$\text{RSC} = \{(\text{CO}_3 + \text{HCO}_3) - (\text{Ca} + \text{Mg})\} \quad (6)$$

where all concentrations are in meq/L.

Water having RSC less than 1.25 is safe for irrigation use, those having RSC from 1.25 to 2.5 are marginal and the waters having RSC more than 2.5 are not suited for this use. RSC values of groundwater encountered in the present study at different locations was always found to be less than 1.25. Hence, groundwater at all the surveyed locations is quite safe for irrigation use.

6. CONCLUSIONS

By converging all evidences based on hydrochemistry, following conclusions were drawn.

- Shallow as well as deep groundwater is dominantly of Ca-HCO₃ type low mineralized water and such type of waters are distributed at most of the sites in the study area.
- Hydrochemistry provides a clear indication of active recharge of shallow and deep aquifers by modern meteoric water.
- Carbonate dissolution is the prevailing process controlling the groundwater chemistry.
- Groundwater in the study area is relatively fresh and has not been subjected to strong water-rock interaction or gone through significant geochemical evolution.
- At most of the surveyed locations, groundwater has low dissolved chemical load and meets the norms of good quality drinking water.
- Groundwater is quite safe for irrigation use.

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Table 1. Chemical composition (mg/L) of groundwater in Haripur Area (1st sampling)

Sample No.	Type	EC ($\mu\text{S/cm}$)	pH	Na	K	Ca	Mg	Cl	HCO ₃	SO ₄
HR-1	Shallow	366	7.2	5.2	0.6	48.3	11.6	19	194	8.6
HR-2	Deep	386	7.1	6.9	0.9	50.3	18.6	21	212	9.8
HR-3	Shallow	351	7.3	6.1	1.4	53.2	12.2	15	217	12.6
HR-4	Shallow	496	7.2	9.6	1.1	74.7	13.3	18	251	11.5
HR-5	Shallow	438	7.2	10.1	2.4	58.7	12.1	17	217	16.2
HR-6	Shallow	781	7.3	13.1	0.8	88.5	23.2	28	345	24.3
HR-7	Shallow	363	7.5	12.4	1.3	49.8	10.4	16	192	10.8
HR-9	Shallow	318	7.7	3.7	3	46.6	11.9	13	163	10.6
HR-10	Deep	460	7.4	7.7	1.2	62.4	16.6	17	234	10.1
HR-11	Shallow	525	7.5	10.1	1	65.6	18.9	16	265	18.2
HR-12	Deep	457	7.6	9.1	1.4	57.3	16.4	22	211	12.6
HR-13	Deep	504	7.4	11.9	1.9	68.9	19.5	27	244	12.0
HR-14	Deep	512	7.3	12.6	1.3	58.8	18.1	19	272	10.7
HR-15	Shallow	569	7.3	18.9	3.7	64	20.1	28	268	13.5
HR-16	Shallow	547	7.5	21.5	2.3	58.9	23.6	25	276	15.8
HR-17	Deep	493	7.2	12.1	1.8	72.2	20.4	27	269	12.3
HR-18	Deep		7.4	14.2	1.5	75.9	21.12	25	212	11.4
HR-19	Shallow		7.6	8.9	0.9	61.6	16.28	16	204	12.0
HR-20	Deep		7.3	11.5	1.2	71.5	23.1	22	290	14.3
HR-21	Deep		7.3	14.6	1.7	69.3	21.56	22	264	12.9
HR-22	Shallow		7.4	8.7	1.4	68.2	17.82	16	277	13.8
HR-23	Deep	728	7.3	52.2	1.1	29.5	45.5	14	397	7.6
HR-24	Deep	562	7.4	46.7	2.3	20.8	18.5	16	316	10.2

Table 2. Chemical composition (mg/L) of groundwater in Haripur Area (2nd sampling)

Sample No.	Type	EC ($\mu\text{S/cm}$)	Na	K	Ca	Mg	Cl	HCO ₃	SO ₄
HR-1	Shallow	344							
HR-2	Deep	321	5.8	1.3	36.7	12.4	11	164	10.3
HR-3	Shallow	367	12.4	1.3	46.8	10.2	16	192	10.6
HR-4	Shallow	539	18.2	2.3	56.9	20.6	25	256	12.8
HR-5	Shallow	479	7.7	1.2	59.3	16.7	17	239	10.1
HR-6	Shallow	854	64.2	2.1	32.5	49.5	32	427	27.9
HR-7	Shallow	324	4.2	1.4	44.6	11.4	12	170	9.9
HR-9	Shallow	297	3.7	3	40.6	10.9	11	153	9.5
HR-10	Deep	429	8.1	6.3	12.2	35.3	12	228	11.8
HR-11	Shallow	464	10.6	3	48.7	20.9	13	243	12.2
HR-12	Deep	523	10.1	1	62.6	18.9	16	265	18.2
HR-13	Deep	587	20.4	2.1	36.8	40.2	14	328	14.4
HR-14	Deep	446	10.1	2.4	58.7	12.1	17	217	16.5
HR-15	Shallow	523	10.1	1	62.6	18.9	16	265	18.2
HR-16	Shallow	568	49.9	2.3	27.8	22.5	16	306	10.7
HR-17	Deep	432	10.1	2.4	58.7	12.1	17	217	16.3
HR-23	Deep	648	24.9	2.1	42.4	38.5	22	351	10.0
HR-24	Deep	518	12.6	1.3	58.8	18.1	19	272	10.7
HR-25	Shallow	659	24.9	2.1	44.5	39.4	19	351	10.0
HR-26	Shallow	597	18.4	1.2	64.5	17.7	19	287	11.9
HR-27	Deep	632	24.9	2.1	44.5	39.4	22	341	10.0

Sample No.	Type	EC ($\mu\text{S/cm}$)	Na	K	Ca	Mg	Cl	HCO ₃	SO ₄
HR-28	Deep	516	12.6	1.3	58.8	18.1	19	272	10.5
HR-29	Deep	469	7.7	1.2	62.4	16.6	17	234	10.1
HR-30	Shallow	586	19.4	2.1	33.8	37.8	14	318	10.8
HR-31	Shallow	708	40.7	3.7	27.5	42.9	19	384	14.7
HR-32	Deep	437	9.6	2.4	59.7	12.1	17	227	17.2
HR-33	Spring	355	6.1	1.4	43.2	12.2	13	187	11.6
HR-34	Deep	398	12.5	1.7	40.7	16.6	14	214	12.4
HR-35	Shallow	365	12.4	1.3	44.8	10.4	12	192	10.8
HR-36	Shallow	499	9.6	1.1	64.7	13.3	18	251	11.5
HR-37	Deep	368	12.4	1.3	42.8	10.4	11	182	9.8
HR-38	Shallow	589	28.4	1.2	64.5	21.7	19	297	14.9
HR-39	Deep	503	11.9	1.9	58.9	19.5	27	244	12.0
HR-40	Shallow	649	24.9	2.1	44.5	39.4	22	341	16.7
HR-41	Deep	627	18.5	1.8	68	26.4	33	316	17.8
HR-42	Shallow	644	24.9	2.1	40.3	39.4	22	351	12.2
HR-43	Shallow	598	18.4	1.2	64.5	23.7	19	307	14.9
HR-44	Shallow		27.8	1.2	57.2	33.99	22	371	11.4
HR-45	Shallow	730	52.2	1.1	29.5	45.5	14	397	7.6
HR-46	Shallow	613	27.6	1.3	52.3	33.4	14	346	10.2
HR-47	Shallow	766	68.2	2.1	41.7	30	24	405	9.5

Table 3. Mean chemical composition (mg/L) of groundwater

Sample No.	Type	EC ($\mu\text{S}/\text{cm}$)	Na	K	Ca	Mg	Cl	HCO ₃	SO ₄
HR-1	Shallow	355							
HR-2	Deep	386	6.9	0.9	50.3	18.6	21	212	9.8
HR-3	Shallow	359	9.3	1.35	49.8	11.2	15.5	204.5	11.7
HR-4	Shallow	518	13.9	1.7	65.8	16.9	21.5	254	12.2
HR-5	Shallow	459	8.9	1.8	59.0	14.4	17	228	13.2
HR-6	Shallow	818	38.7	1.45	60.5	36.4	30	386	26.1
HR-7	Shallow	344	8.3	1.35	47.2	10.9	14	181	10.4
HR-9	Shallow	307	3.7	3	43.6	11.4	12	158	10.2
HR-10	Deep	445	7.9	3.75	37.3	25.9	14.5	231	10.9
HR-11	Shallow	495	10.5	2	57.2	19.9	14.5	254	15.2
HR-12	Deep	490	9.6	1.2	59.9	17.7	19	238	15.4
HR-13	Deep	545	16.2	2	52.8	29.9	20.5	286	13.1
HR-14	Deep	479	11.4	1.8	58.8	15.1	18	245	13.5
HR-15	Shallow	546	14.5	2.5	63.3	19.5	22	267	15.9
HR-16	Shallow	558	35.7	2.3	43.4	23.1	20.5	291	13.0
HR-17	Deep	463	11.1	2.1	65.5	16.3	22	243	14.3
HR-18	Deep		14.2	1.5	75.9	21.1	25	212	11.4
HR-19	Shallow		8.9	0.9	61.6	16.3	16	204	12.0
HR-20	Deep		11.5	1.2	71.5	23.1	22	290	14.3
HR-21	Deep		14.6	1.7	69.3	21.6	22	264	12.9
HR-22	Shallow		8.7	1.4	68.2	17.8	16	277	13.8
HR-23	Deep	688	38.5	1.6	35.9	42.0	18	374	8.8

Sample No.	Type	EC ($\mu\text{S/cm}$)	Na	K	Ca	Mg	Cl	HCO ₃	SO ₄
HR-24	Deep	540	29.6	1.8	39.8	18.3	17.5	294	10.4
HR-25	Shallow	685	32.8	2.9	36.0	41.2	19	368	12.3
HR-26	Shallow	622	21.7	1.6	54.5	28.6	20.5	324	10.9294
HR-27	Deep	677	33.1	2.1	47.2	38.5	23.5	379	14.3294
HR-28	Deep	546	18.0	1.7	48.8	30.7	16.5	310	10.7254
HR-29	Deep	448	12.3	1.5	54.1	17.7	18	236	10.7
HR-30	Shallow	557	24.9	2.3	41.1	30.2	16.5	312	10.5
HR-31	Shallow	683	22.8	3	45.4	40.6	17.5	384	11.9
HR-32	Deep	431	12.0	3	52.2	15.2	15.5	230	14.7
HR-33	Spring	369	11.8	2.6	41.2	13.5	13	195	13.7
HR-34	Deep	422	15.2	1.8	44.3	16.9	14.5	219	12.2
HR-35	Shallow	376	13.9	1.5	45.8	13.5	15	208	11.6
HR-36	Shallow	517	15.7	1.9	54.7	22.1	21	278	9.8
HR-37	Deep	398	15.6	1.5	47.5	13.5	12.5	210	11.2
HR-38	Shallow	582	25.5	1.5	57.6	19.8	17.5	285	12.8
HR-39	Deep	525	20.4	1.9	50.6	25.1	20.5	284	10.9
HR-40	Shallow	628	26.3	1.7	48.4	36.4	18	344	13.4
HR-41	Shallow	663	18.5	1.8	58.2	41.4	35.5	341	15.3
HR-42	Shallow	615	21.6	1.7	52.4	28.6	20.5	319	12.1
HR-43	Shallow	624	16.5	2.2	76.2	19.2	21	319	16.6
HR-44	Shallow		27.8	1.2	57.2	33.9	22	371	11.9
HR-45	Shallow	714	50.8	1.3	34.4	38.1	19.5	388	9.8
HR-46	Shallow	635	31.9	1.2	56.6	35.4	17	377	8.8
HR-47	Shallow	731	68.2	2.1	46.7	37.0	23	420	8.6

Table 4. The summary statistics of chemical composition (mg/L) of groundwater

Parameter	Shallow Groundwater			Deep Groundwater		
	Minimum	Maximum	Average	Minimum	Maximum	Average
EC ($\mu\text{S}/\text{cm}$)	307	818	567	369	688	495
pH	7.18	7.89	7.42	7.12	7.97	7.46
Na^+	3.7	68.2	21.8	6.9	38.6	17.3
K^+	0.9	3.1	1.8	0.9	3.8	1.9
Ca^{2+}	34.4	76.2	53.7	35.6	75.9	52.3
Mg^{2+}	10.9	41.4	25.6	13.5	42.1	22.2
Cl^-	12	35.5	19.3	12.5	25	18.7
HCO_3^{2-}	158	420	298	195	379	262
SO_4^{2-}	8.6	26.1	12.7	8.8	15.4	12.3

Table 5. Evaluation of groundwater quality for drinking use

Parameter	Concentration in groundwater		WHO Criteria		Indian Criteria		National Criteria					
			HDL	MPL	HDL	MPL	PCRWR		PSI		Pak EPA	
	Minimum	Maximum					HDL	MPL	HDL	MPL	HDL	MPL
Ca (mg/L)	34.4	76.2	75	200	75	200			75	200		
Mg (mg/L)	10.9	41.4	50	150	30	150	30	150	50	150		
Na (mg/L)	3.7	68.2		200								
K (mg/L)	0.9	3.1		12								
Cl (mg/L)	12	35.5	200	600	200	1000	200	600	200	600	250	
SO ₄ (mg/L)	8.6	26.1	200	400	200	400	200	400	200	400		

HDL: Highest Desirable Level

MPL: Maximum Permissible Level

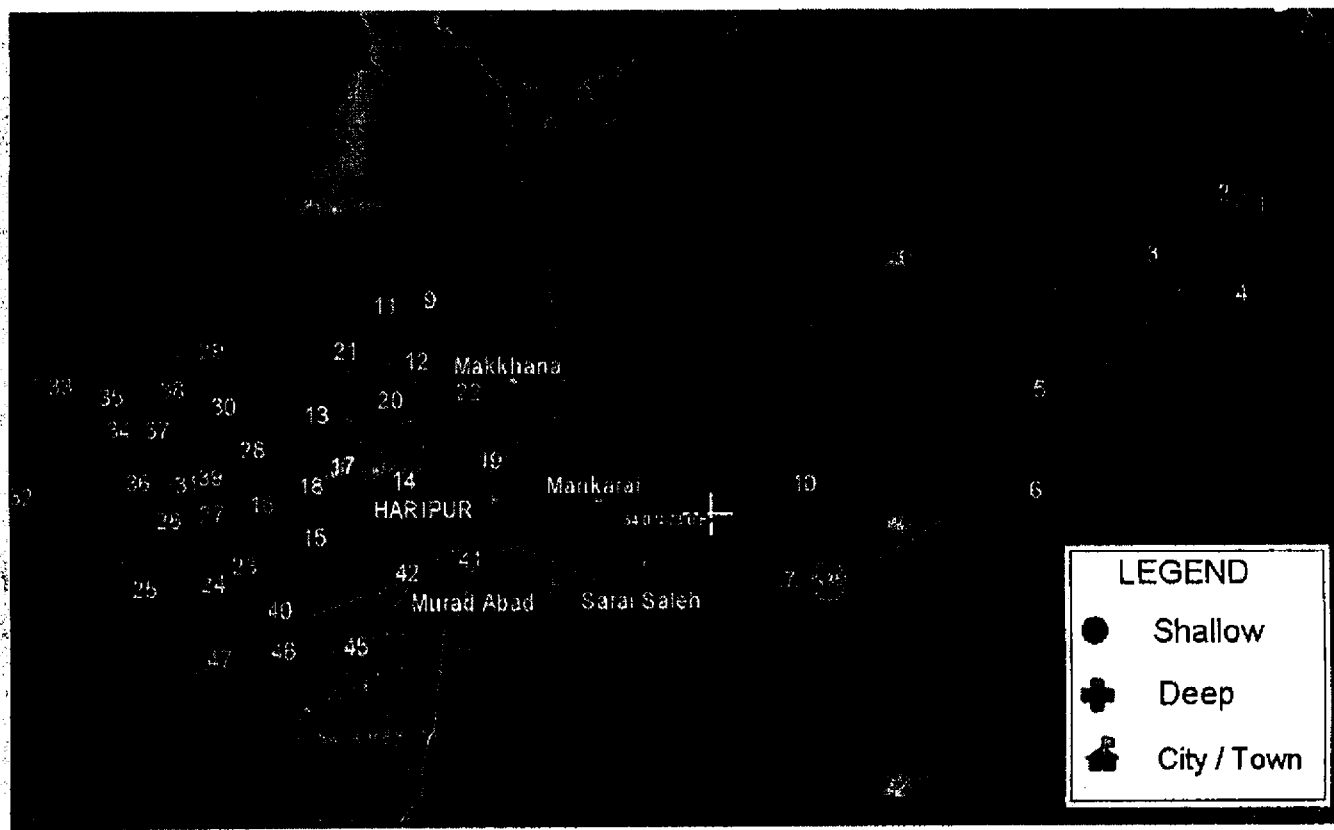
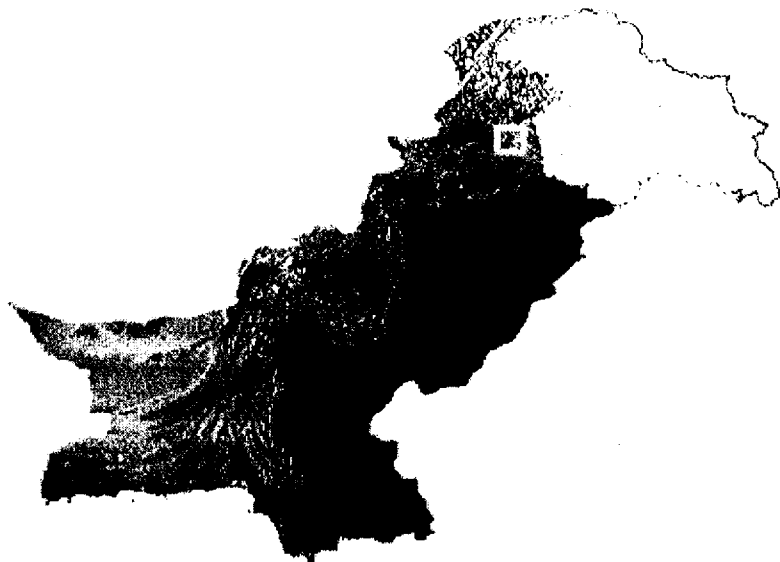


Fig. 1. Location of study area and sampling points

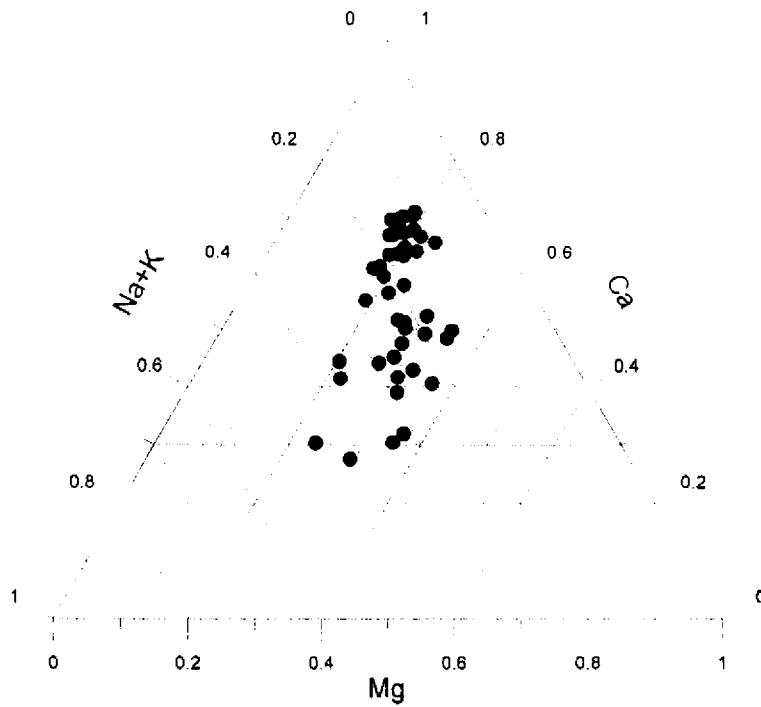


Fig. 2. Triangular plot of major cations (mean data)

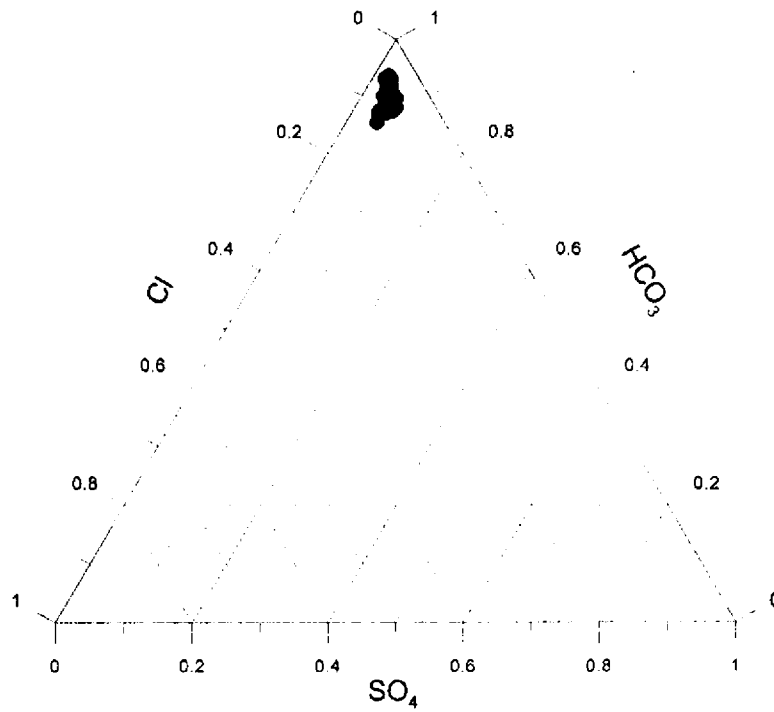


Fig. 3. Triangular plot of major anions (mean data)

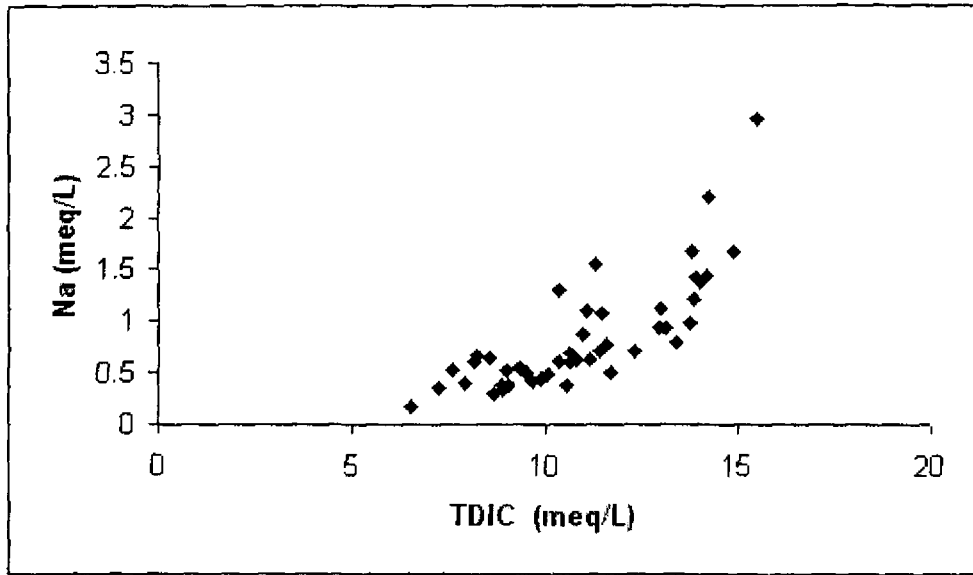


Fig. 4 Bi-variant plot of Na⁺ versus TDIC

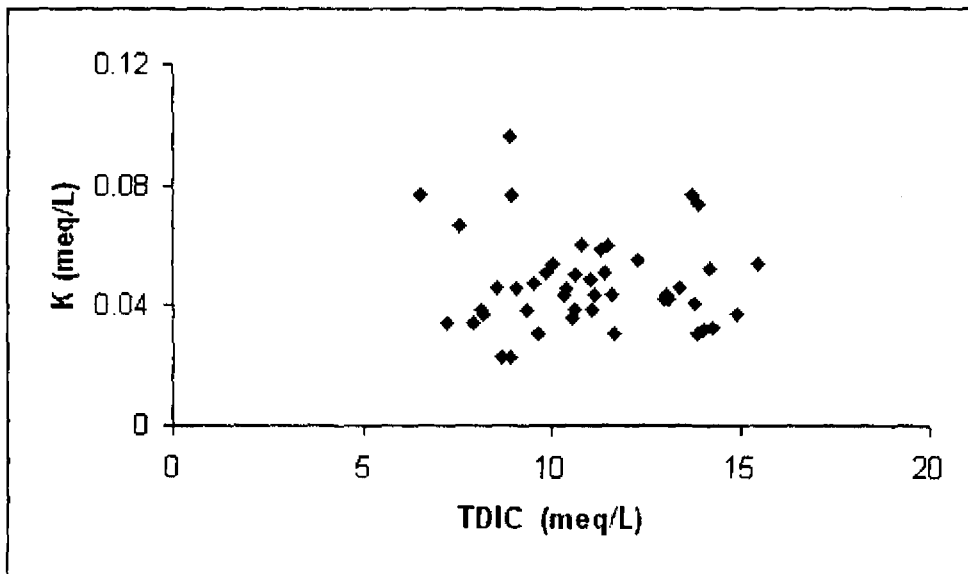


Fig. 5 Bi-variant plot of K⁺ versus TDIC

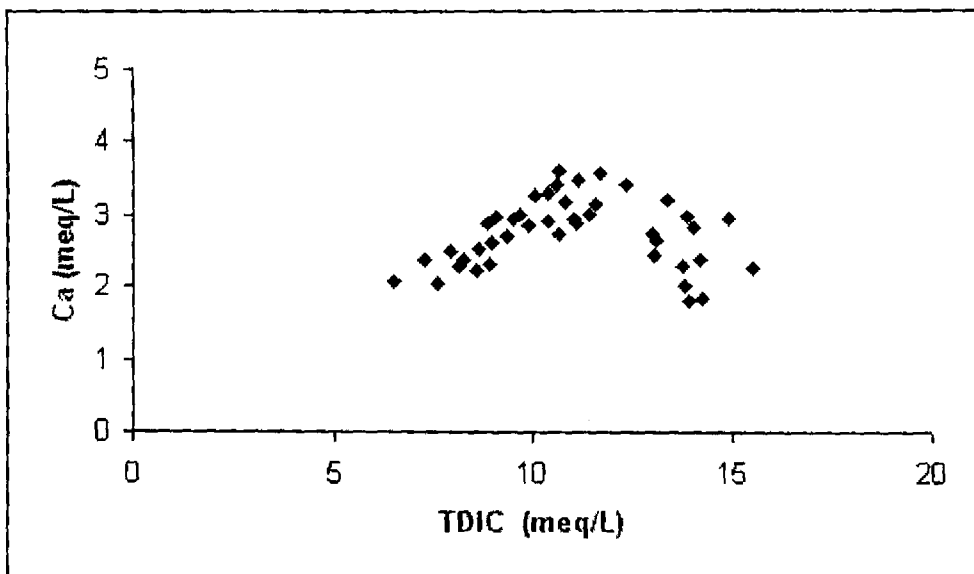


Fig. 6 Bi-variant plot of Ca^{+2} versus TDIC

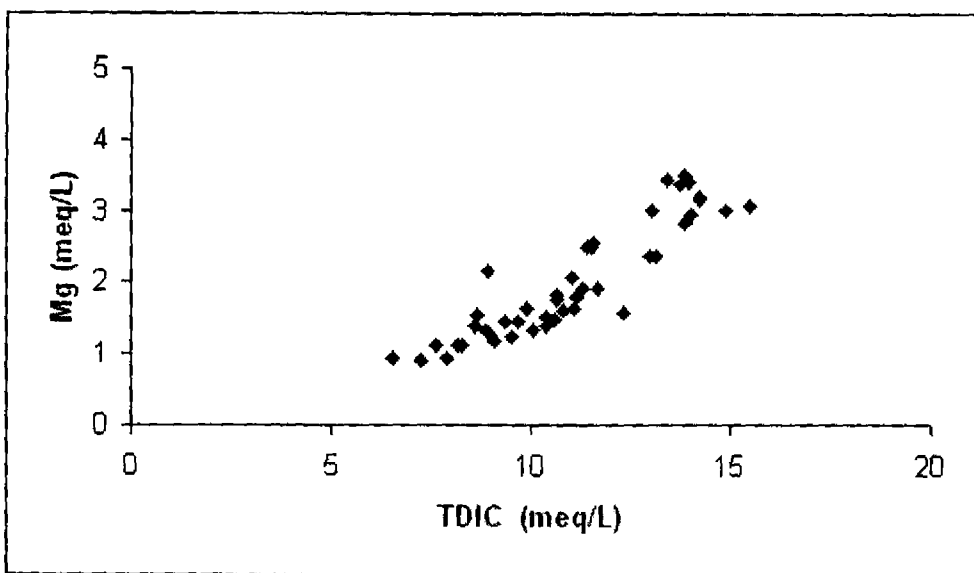


Fig. 7 Bi-variant plot of Mg^{+2} versus TDIC

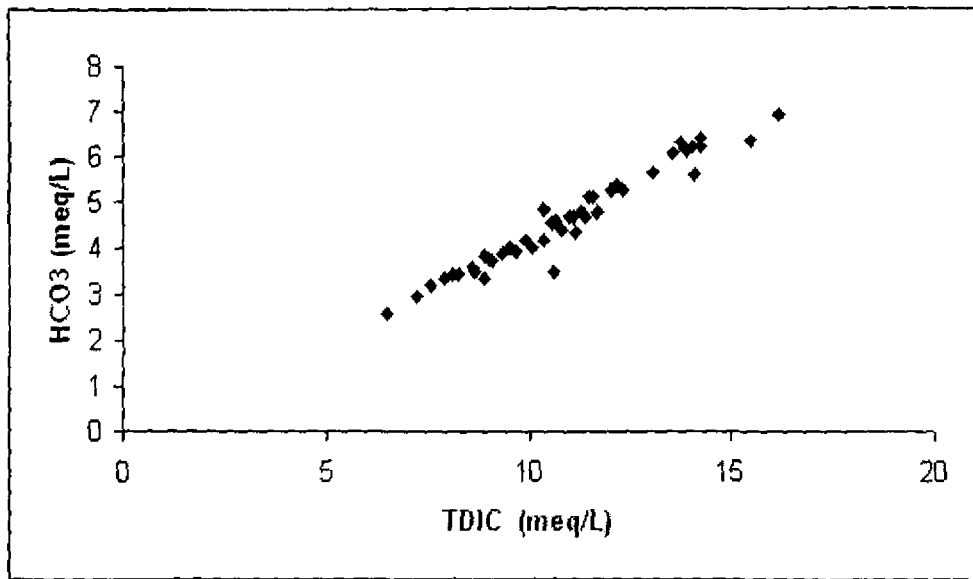


Fig. 8 Bi-variant plot of HCO_3Na^- versus TDIC

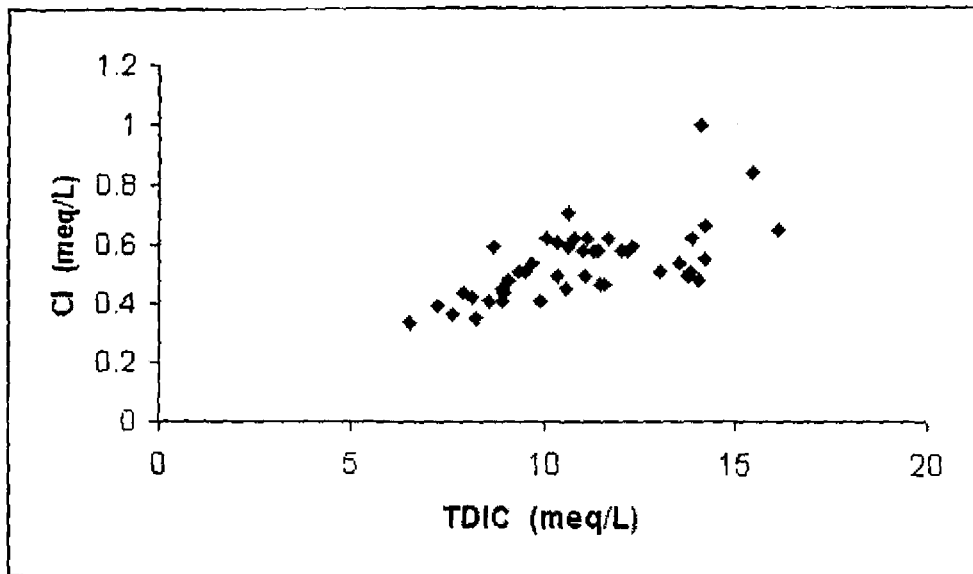


Fig. 9 Bi-variant plot of Cl^- versus TDIC

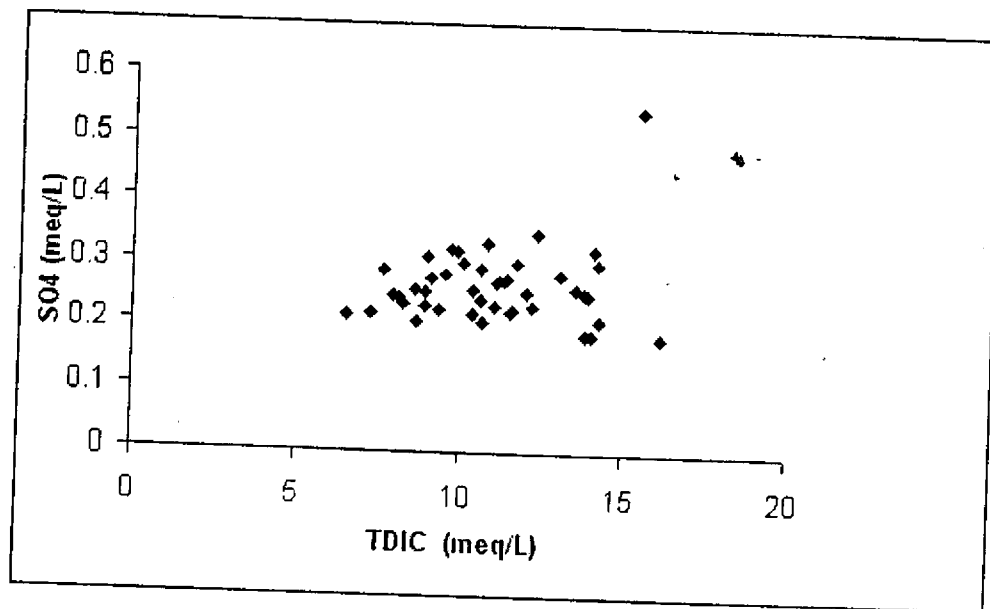


Fig. 10 Bi-variant plot of SO_4^{2-} versus TDIC