



EVALUATION OF CHEMICAL WATER TYPES OF ESTUARINE AQUIFER AND THEIR SUITABILITY FOR DRINKING AS WELL AS AGRICULTURAL USES, WESTERN INDIA, MUMBAI

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ABSTRACT

The hydrochemistry of groundwater of an estuarine aquifer was used to assess the quality of groundwater for determining its suitability for drinking and agricultural uses. The potability of ground water was estimated by considering the individual and/or paired ionic concentration, certain indices like alkali hazards (in terms of Sodium Adsorbed Ratio), % Na, Residual Sodium Carbonate, Permeability Index and hardness etc. Scientific interpretation of analytical data was done using hydrochemical computer program, WATCLAST, to classify ground water into different categories. With the help of Piper diagram hydrochemical facies like, Na-K-SO₄-Cl, Ca-Mg-SO₄-Cl and Ca-Mg-HCO₃ were identified as dominating facies of the site. The factors responsible for their geochemical characterization were also attempted by using standard plot and it was found that the weathering was major factor controlling the groundwater chemistry of the study site although it is under heavy precipitation. After assessment of quality of groundwater, considering all the parameters and indices, the ground water of most of the locations were found to be suitable for irrigation and drinking purposes. However ground water of only a few locations was above standard prescribed levels by BIS (Bureau of Indian Standards) and WHO.

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INTRODUCTION

The term quality, as applied to ground water, embraces the combined physical, chemical characteristics of constituents and their concentration, which are mostly derived from the geological setup of a particular region. The important factors influencing the groundwater quality are, a) Quality of recharged water, b) Atmospheric precipitation, c) Inland surface water and d) Subsurface chemical processes (Twarakavi and Kaluarachchi 2006). Groundwater is the primary source of water for domestic, agricultural and industrial uses in many countries and its contamination has been recognized as one of the most serious problems. In fact, industrial waste and the municipal solid waste have emerged as one of the leading causes of pollution of surface and ground water. In many parts of the country available water is rendered non-potable because of the presence of contaminants in excess. The situation gets worsened during the summer season due to water scarcity. Since estuarine regions have unique importance in hydrogeology as the aquifer is affected by both sea and river water leading to a very complex chemical evolution of ground water. And that is why monitoring the health of estuarine ecosystems has become increasingly important over the past decade. An attempt was made to assess the ground water quality of Ulhas estuarine area, Mumbai, India (Fig. 1) to study its potability

for both drinking as well as for irrigation purposes. In our study, sampling sites were selected near the creek (Vasai), where the Ulhas River meets with Arabian Sea. This region receives the sewerage and effluents discharged from the chemical industries and factories and people use well water for both drinking and irrigation purposes. To assess the quality of the ground water, samples were analyzed for major ions like sodium (Na⁺), potassium (K⁺), magnesium (Mg²⁺), calcium (Ca²⁺), chloride (Cl⁻), sulphate (SO₄²⁻), bicarbonates (HCO₃⁻), fluoride (F⁻) and physical parameters of ground water like pH, EC and TDS, etc. Other parameters like alkalinity hazard in terms of sodium adsorbed ratio (SAR), residual sodium carbonate content (RSC), % of sodium, permeability index (PI), salinity hazard, etc. Data were generated using a hydrochemical computer program, WATCLAST to find ground water potability. Study of geochemical classification in terms of Piper trilinear plot, USSL diagram and also source was carried out to find important ongoing geochemical process.

MATERIALS AND METHOD

Study area

The study area is located in the northern part of Mumbai between latitude 19° 15' 75" N- 19° 16' 14" N and longitude 72° 46' 98" -72° 55' 56" E. The physiographic feature of the study area is broad and flat terrain flanked by north-south trending hill ranges. Climatic condition is fluctuating as it is a coastal

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area and the weather is highly influenced by Arabian Sea. The average temperature remains about 25°C. The average annual rainfall in this region is 2170 mm, the large chunk of which is received during four months of June to September. The study site has a highly humid climate with an annual average relative humidity of more than 60%.

Hydrogeology of study area

The entire area is underlain by basaltic lava flows of upper Cretaceous to lower Eocene age. The shallow alluvium formation of recent age also occurs as a narrow stretch along the river flowing in the area. River alluvium patches can be observed along the course of river and marine alluvium towards coastal area. The alluvial fill of low lying areas underlain by weathered basalt has relatively better ground water potential. The ground water occurs under phreatic conditions and exists in fractures, joints, vesicles and in the weathered zone of basalt. This region receives the sewerage and effluents discharged from the chemical industries and factories (Gupta 2009).

Sampling and Pre-analysis treatment

A grid sampling scheme was prepared with the help of topocopy for a total area of about 200 km² on both sides of the creek (Fig. 1) with sub grid dimension of 4 km × 2 km. The study site was classified into 25 sub locations. Two aliquots of ground water samples from each hand dug wells were collected and filtered through 0.45 micron cellulose acetate membrane (Millipore Corporation) and stored in, acid washed, 200 ml capacity polypropylene bottles. One of the aliquot was acidified with 0.01M of nitric acid (AR Grade, Merck, Mumbai, India) and samples were kept in refrigerator at temperature 4°C till analysis.

Analysis Techniques

Field Measurements

Field measurements consisted of evaluating unstable parameters which included electrical conductivity (EC), pH and temperature. EC was measured using an Orion model 122 conductivity meter with a conductivity cell (model: 012210). The conductivity readings were checked in the field against freshly prepared KCl standards ranging from 0.0005 to 0.05 M. An Orion model: 290A portable pH meter was used for pH measurements. A glass electrode with a silver/silver chloride reference was used for the pH measurements, calibrated against the standard buffer solution of pH 4, pH 7 and pH 9.2 buffers.

Major cations and anions

Major ions like Na⁺, K⁺, Mg²⁺, Ca²⁺, F⁻, Cl⁻ and SO₄²⁻ in ground water samples were estimated by conductivity suppressed Ion Chromatography System (DIONEX600, USA). The Cation analysis was carried out using Ion Pac CS17 (cation-exchange column) as a stationary phase and 6 mM of methane sulphonic acid (MSA) as mobile phase. Similarly for anion analysis Ion Pac AS17 (anion-exchange column) was used as stationary phase with 12 mM of NaOH as mobile phase. The instrument was calibrated and

standardized with the stock solution of ultra pure standards (Fluka, Switzerland) for the above cations and anions. The eluent flow rate was confined to 0.25 mL/min under isocratic flow. The unknown samples were analyzed by measuring the peak area of the ions (identified by retention time), and comparing it with the standard curve. HCO₃⁻ was estimated titrimetrically using autotitrator (Metrohm-798 MPT Titrimetric, Switzerland). Silica (Si) in ground water was determined by Atomic Absorption Spectrophotometer (GBC Avanta, Australia). The quality assurance was made by spike recovery, replicate analysis and cross method checking. The relative standard deviation was calculated to be 3 to 8%.

RESULTS AND DISCUSSION

The basic statistical analysis (minimum, maximum, mean, inter quartile range, standard deviations and % coefficient of variance) of different physicochemical parameters of groundwater samples is presented in the Table 1. Standard deviation (SD), inter quartile range (IQR) and % coefficient of variance (%CV) represents the dispersion of the data. The %CV for all parameters except pH showed very wide variation (42.5 to 230.3%) indicating that there was non-homogeneity in the distribution of ionic contents throughout the study area. The weathering processes, the differential rate of mineralisation of ground water and anthropogenic input etc. might have caused the wide dispersion in the data. Correlation coefficient (*r*) represents the relationship between two variables. It explains how one variable influences the other and their interdependency. The results of the correlation analysis are considered in the subsequent interpretation. A high degree of correlation (near 1) means a good relationship between two variables, and a correlation coefficient around zero means no relationship (Independent). Positive values of '*r*' indicate a positive relationship while negative values indicate an inverse relationship. The correlation coefficients of the studied parameters are presented in Table 2.

Physico-chemical parameters

pH

The pH of all groundwater samples ranged from 6.25 to 8.1 with an average of 7.37 (alkaline). The measured pH was found to be within the permissible range (6.5 to 8.5) recommended by the Bureau of Indian Standard (BIS) guidelines for drinking water (BIS 1999). Some well water having higher value of pH may be due to weathering of plagioclase feldspar by dissolving atmospheric carbon dioxide that will release Na⁺ and Ca²⁺ which progressively increase the pH of water (Eby 2004).

Electrical conductivity (EC)

EC is a useful tool to evaluate the purity of water. EC of ground water sample of all the locations recorded in the range of 181 to 5890 µmhos/cm with a mean value of 1170.9 µmhos/cm. The result indicated that the majority of the water samples were within the permissible limits of 2250 µmhos/cm except at two locations. The higher EC value may be attributed to the mixing of ground water with sea water, or higher rate of mineralization of ground water due to

Table1 Statistical summary of hydrochemical parameters of groundwater

Parameters	Mean. Conc. (mg.l ⁻¹)	Standard Deviation	%CV	Minimum	Maximum	IQR	Range
Cl	260.85	486.78	186	12.36	1960.88	161.81	1948.52
NO3	45.42	62.12	136	0.1	208.3	75.37	208.2
SO4	64.57	117.02	181	2.52	543.59	27.668	541.07
Na	136.29	299.76	219	9.07	1493.84	96.79	1484.77
K	6.44	6.48	100	0.59	21.27	7.74	20.68
Mg	16.25	17.98	110	3.98	76.01	11.14	72.03
Ca	59.51	32.42	54	13.78	138.47	44.48	124.685
pH	7.36	0.46	6.3	6.25	8.1	0.535	1.85
HCO3	142.89	61.97	43	40.23	323.4	73.23	283.17
SI	4.11	2.13	51	1.169	10.17	1.69	9.001
F	0.75	0.98	130	0.087	3.27	0.51374	3.27
TDS	745.3	841.53	113	116.12	3767.9	466.195	3651.78
EC	1170.9	1307.32	112	181	5890	694	5709

Table 2 Correlation matrix for all data (N=25)

Parameter	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	pH	HCO ₃ ⁻	TDS	EC	F ⁻
Cl ⁻	1.00											
NO ₃ ⁻	0.58	1.00										
SO ₄ ²⁻	0.18	0.13	1.00									
Na ⁺	0.69	0.32	0.22	1.00								
K ⁺	0.56	0.79	0.35	0.46	1.00							
Mg ²⁺	0.50	0.47	0.21	0.80	0.51	1.00						
Ca ²⁺	0.62	0.64	0.15	0.65	0.72	0.60	1.00					
pH	-0.05	0.07	0.26	-0.09	0.31	-0.01	0.27	1.00				
HCO ₃ ⁻	0.33	0.30	0.58	0.42	0.55	0.37	0.55	0.30	1.00			
TDS	0.90	0.55	0.20	0.85	0.58	0.65	0.66	-0.05	0.34	1.00		
EC	0.42	0.33	0.51	0.21	0.06	0.16	0.26	-0.09	0.22	0.30	1.00	
F ⁻	-0.08	0.24	0.15	-0.17	-0.09	0.00	0.00	-0.02	-0.10	0.15	0.43	1.00

Table 3: Result of computer program WATCLAST

Geochemical Classifications					
Category	Grade	N=25	Category	Grade	N=25
Na% - (Wilcox, 1955)			Na% - (Eaton, 1950)		
Excellent	0 - 20	1	Safe	< 60	21
Good	20 - 40	15	Unsafe	> 60	4
Permissible	40 - 60	5			
Doubtful	60 - 80	3	Sawyer and McCarty Hardness		
Unsuitable	> 80	1		< 75	4
			Soft	75-150	3
			Slightly Hard	150-300	11
			Moderately Hard	>300	7
			Very Hard		
S.A.R. - (Richards, 1954)			Schoeller Classification (1965)		
	0 - 10	23	Type-I	r(CO3) > r(SO4)	22
Excellent	10 - 18	1	Type-II	r(SO4) > r(Cl)	1
Good	18 - 26	1	Type-III	r(Cl) > r(SO4) > r(CO3)	2
Fair	> 26	0	Type-IV	r(Cl) > r(SO4) > r(CO3)r(Na) > r(Mg) > r(Ca)r = Concentration in epm	0
Poor					
R.S.C. - (Richards, 1954)			TDS Classification (USSL, 1954)		
	< 1.25	25		< 200	2
Good	1.25-2.5	0		200-500	11
Medium	> 2.5	0		500-1500	10
Bad				1500-3000	1
ION FACIES			Chloride Classification (Stuyfzand, 1989c)		
Calcium-Magnesium Facies		3		< 0.141	0
Calcium-Sodium Facies		22	Extremely Fresh	0.141-0.846	6
Sodium-Calcium Facies		0	Very Fresh	0.846-4.231	9
Sodium Facies		0	Fresh	4.231-8.462	6
Bicarbonate Facies		0	Fresh Brackish	8.462-28.206	2
Bicarbonate-Chloride-Sulfate Facies		1	Brackish	28.206-282.064	2
Chloride-Sulfate-Bicarbonate Facies		18	Brackish-Salt	282.064-	0
Chloride Facies		6	Salt	564.127	0
			Hyperhaline	>564.127	

Table 4 Origin of Major aqueous species in ground water

Aqueous species	Origin
Na ⁺	NaCl dissolution (some pollution), Plagioclase weathering, Rainwater addition.
K ⁺	Biotite weathering-feldspar weathering
Mg ²⁺	Amphibole and pyroxene weathering, Biotite (and chlorite) weathering, Dolomite weathering, Olivine weathering, Rain water addition.
Ca ²⁺	Calcite weathering, Plagioclase weathering, Dolomite weathering
HCO ₃ ⁻	Calcite and Dolomite weathering, silicate weathering.
SO ₄ ²⁻	Pyrite weathering (some pollution), Gypsum OR Anhydrite dissolution.
Cl ⁻	NaCl dissolution (some pollution),rainwater addition
HSiO ₄ (aq.)	Silicate weathering.

dissolution of soil minerals contact with ground water at the site. From correlation matrix (Table 2), it can be predicted that second factor was predominant, as all the ions exhibited poor to moderate degree of correlation with EC. On the basis of electrical conductivity (Wilcox 1955), 3 locations were found to be under excellent type, 8 locations under good type, 11 locations under permissible, 2 locations under doubtful type and 1 location under poor categories (Table 3).

TDS

The TDS of the water samples ranged from 116.1 mg/L to 3767.9 mg/L with a mean value of 745.3 mg/L. As per BIS and WHO, the desirable limit for TDS is 500 mg/L and the maximum permissible is 2000 mg/L (WHO 1994). Few locations showed a very high value of TDS greater than desirable limits making it unsuitable for drinking purposes.

Chloride

It was observed that mean value for chloride concentration is 260.85 mg/L which is greater than the desirable limit (250 mg/L) prescribed by BIS. Two locations showed higher concentration of chloride which is beyond extended limit (>1000 mg/L). Good correlation of Cl⁻ with Na⁺, NO₃⁻, Ca²⁺ and Mg²⁺ (see Table 2) revealed that, they have a common source of origin.

Fluoride

Small concentrations of fluoride in drinking water can be considered to have a beneficial effect on the human body. The low concentration of fluoride (< 0.5 mg/L), however, causes dental caries and higher concentration beyond 1.5 mg/L can lead to dental and skeletal fluorosis. The fluoride content of groundwater samples of the study area ranged from 0.087 to 3.27 mg/L with a mean value of 0.75 mg/L which is below the maximum allowable limit of 1.5 mg/L (WHO 1984; BIS 1999). Two locations showed higher concentrations of fluoride exceeding permissible limits.

Nitrate

Nitrate content in ground water ranged from 0.1 to 208.3 mg/L with a mean value of 45.42 mg/L which is just above the desirable limit of 45 mg/L prescribed by BIS and WHO. Significant correlation between potassium and nitrate (Table 2) showed that, higher concentration may be due to leaching of fertilizers (NPK) from the soil matrix to ground water. Locations showing elevated concentration of nitrate were found nearby agricultural fields.

Sulphate

The mean sulphate content of the study area was 64.57 mg/L and varied between minimum and maximum value of 2.52

mg/L and 543.6 mg/L respectively. Only two locations exceeded the BIS desirable limit of 200 mg/L. Possible sources of sulfate may be pyrite weathering, gypsum or anhydrite dissolution. The presence of high concentration of sulphate at a few locations of the study area may be due to discharge of domestic sewage and littering of organic wastes in the region (Table 4).

Bicarbonate

The values of HCO₃⁻ in the water samples varied from 40.23 to 323.4 mg/L with a mean value of 142.89 mg/L. The bicarbonate level of ground water was within the desirable limit. Good correlation between Mg²⁺, Ca²⁺ and HCO₃⁻ revealed that the possible sources of bicarbonate in ground water may be calcite and dolomites weathering i.e. carbonate weathering (Table 4).

Sodium

Sodium content of study site ranged from 9.07-1493.84 mg/L with mean value of 136.3 mg/L which is almost three times of the permissible limit of 50 mg/L. About seven locations showed higher concentration of sodium in ground water. Possible sources of Na in ground water are halite (NaCl) dissolution or rainwater addition (Table 4). Some ground water showed high ratio (>1) of Na/Cl in ground water indicating that, Na was released as incongruent dissolution of sodium bearing silicate minerals like Plagioclase weathering (Eby 2004).

Potassium

In the present study of almost all of the water samples were found to have potassium content lower than the permissible limit of 0.5 meq/L (20 mg/L) as prescribed by BIS. The values ranged from 0.59 to 21.3 mg/L. The possible sources of potassium in water are dissolution of potassium bearing silicate minerals like biotite weathering and/or feldspar weathering (Table 4) or NPK fertilizer.

Calcium and Magnesium

Ca²⁺ and Mg²⁺ are mainly responsible for the hardness of water. The mean concentration value for Ca²⁺ and Mg²⁺ were within the permissible limits prescribed by BIS (i.e. 75 mg/L and mg/L respectively). In our study it was found that, 5 locations showed higher concentrations of Ca and 3 locations for high Mg content in ground water. The possible sources may be weathering of amphibole, pyroxene, biotite (and chlorite), dolomite, olivine, and rain water addition, etc.

Other sources may be calcite, plagioclase, and dolomite weathering (Table 4).

Irrigation water quality

The suitability of groundwater for irrigation purpose is mainly based upon SAR, Na% and RSC. Total 'Na' concentration and EC are important in classifying the irrigation water (Wilcox 1955). Salinity of groundwater and SAR determines its utility for agricultural purposes. Salinity originates in groundwater due to the weathering of rocks, leaching from topsoil, and from anthropogenic sources. The level of Na^+ and HCO_3^- in irrigation groundwater affects the permeability of soil and drainage of the area (Kelly 1976; Tijani 1994). Na^+ is an important cation, which if in excess, deteriorates the soil structure and reduces crop yield. Different parameters which determine the suitability of irrigation water are discussed in the following sections:

Alkalinity hazard or SAR

The sodium/alkali hazard is typically expressed as SAR which is an estimate of the extent to which sodium ion present in the water would be absorbed by the soil and is expressed as,

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

Where, concentration is expressed in equivalent per million (epm). As per classification (Richard 1954), 23 locations of the site fell under excellent category, 1 location under good and remaining 1 under the fair category (See Table 3). The analytical data plot on the United State Salinity Laboratory diagram (Wilcox 1948) is presented in Fig. 2., the plot elucidates that, ground water of 11 locations fell in the field of C3S1 followed by 8 locations in C2S1, 3 in C1S1 and 1 in C4S3 respectively. The result revealed that, ground water of most of the locations possesses high salinity and low sodium content, which can be used for irrigation on almost all types of soil with little danger of exchangeable sodium.

Sodium percentage

The ratio of sodium and potassium in the sum of cation is the important factor in considering water for agriculture uses (Wilcox 1948) which is expressed as Na% and calculated using following equation,

$$Na \% = \frac{(Na + K)}{(Ca + Mg + Na + K)} \times 100$$

The sodium concentration of irrigation water is of prime importance and plays a significant part in determining the permeability of soil. 'Na' absorbed on clay surface, as a substitute for Ca and Mg may damage the soil structure making it compact and impervious. Na combining with CO_3 can add to the formation of alkaline soils and Na combining with Cl form saline soils. Both these soils affect the growth of plants. A maximum of 60% of Na in groundwater is allowed for agriculture purpose (Ramakrishna 1998). Based

upon the Na% in ground, Wilcox, classified ground water into excellent, good, permissible, doubtful, and unsuitable categories (Wilcox 1948). And in our case it was found that, 1 location in excellent category, 15 locations were under good, 5 locations under permissible, 3 locations under doubtful and 1 location under unstable category. However based upon Eaton classifications (Eaton 1950) ground water of 21 locations was found to be safe for irrigation and remaining 4 were unsafe for use. (See Table 3).

Residual sodium carbonate (RSC)

The water having an excess of carbonate and bicarbonate can cover the alkaline earth metals mainly Ca and Mg, if present in excess of allowable limits, affects agriculture unfavourably (Richards 1954).

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

The concentration of alkaline earth metals influences the suitability of water for irrigation purpose. The water gets more precipitated with Ca and Mg and as a result Na in water gets increased in the form of sodium carbonate. Based upon the RSC of groundwater it is classified into three categories as good, medium and bad (Table 3). Looking at RSC values of water of study site, groundwater of all the locations categorised under the good category.

Permeability index

Based upon permeability index (Doneen 1948) irrigation quality of water are classified into three classes. The formula used to calculate the permeability index (PI) is as follows. Where, concentrations of ionic species are in epm. Permeability indices of ground water of the study site (Fig. 3) showed that locations fall under class-I, in class-II and in class-III. This indicated that groundwater of (Type I and II) of locations were suitable for irrigation purposes except at 5 locations.

$$PI = \frac{100(Na + \sqrt{HCO_3})}{(Ca + Mg + Na)}$$

Hydro-geochemical classification

Piper Classification

The geochemical evolution of groundwater can be understood by plotting the concentrations of major cations and anions in the Piper trilinear diagram (Fig. 4). The main function of the Piper diagram is to identify the facies of groundwater, nevertheless, it also help us to understand the several geochemical process along the flow path of the ground water. This diagram can also be used to classify the water types (Wen et al. 2005). The plot shows that, groundwater of 7 locations were strongly alkaline ($\text{Na}^+ + \text{K}^+ > 50 \text{ mg/L} \%$), 10 locations were of Ca^{2+} type ($\text{Ca}^{2+} > 50 \text{ mg/L} \%$) and the remaining 8 locations were without a dominant cation type (Na^+ , K^+ , Mg^{2+} and Ca^{2+} , $< 50 \text{ mg/L} \%$). Similarly for anions, groundwater of 9 locations were of bicarbonate type ($\text{HCO}_3^- > 50 \text{ mg/L} \%$), 9 were chloride type and remaining 7 were without any dominant anion type (Cl^- ,

HCO₃⁻ and SO₄²⁻ < 50 mg/L %). On this basis, groundwater was also classified into three dominant chemical facies of (Na+K)-(SO₄+Cl) type (8 locations), (Ca + Mg)-(SO₄+Cl) type (10 locations), (Ca+Mg)-(HCO₃) type (7 locations).

Metasomatism of Ground water (Scholler Classification)

Quality of ground water change from the point of their entry to the point of exit. Scholler proposed a measure called "Index of Base Exchange" (IBE) to describe metamorphic reactions taking place in. There are substances, which absorb and exchange their cations with cations present in groundwater. Those substances are called Permutolites e.g. clay minerals like Kaolinite, Illite, Chlorite, Halloysite, Glauconite, Zeolites and organic substances. these are the clay minerals in which ions are held at edges and their ionic exchange capacity is low. The case is reverse in Montmorillonite and Vermiculite, where the exchange capacity is higher when the number of ions held on the surface (is mainly based upon estimation of parameters like SAR) are more. Chloro-alkaline indices, CAI1 and CAI2 are used to measure extent of Base Exchange during rock water interaction. Where,

$$CAI\ 1 = \frac{Cl - (Na + K)}{Cl}$$

And

$$CAI2 = \frac{Cl - (Na + K)}{(SO4 + HCO3 + CO3 + NO3)}$$

In the above equation all ionic concentration are expressed in epm. When there is an exchange of Na⁺ and K⁺ in groundwater with Mg²⁺ or Ca²⁺, in rock/alluvium, both the indices. The indices of Base Exchange indicated that, at 12 locations, there was an exchange of Na+K in rock to the Ca+Mg in groundwater. Rest of locations, however, showed an inverse reaction i.e. removal of Ca and Mg ion from rocks to ground water system. Scholler (Scholler 1965), further, has categorized ground water in to different types based upon their residence time (See Table 3.) from the classifications it was found that, ground water of 22 locations fell in Type I, 1 in type-II and rest 2 in type-III. From this classification it may be concluded that, ground water of most of the locations were juvenile.

Hardness

Hardness of water is related to its reaction with soap and to the scale of incrustation accumulating in containers (or) conductors where water is heated or transported, since soap is precipitated by Ca and Mg ion. Hardness is defined as the sum of concentration of their ion expressed as mg/L % of CaCO₃. Hardness increases with increase in metallic ion dissolved in water. Hardness is used as an indicator of the rate of scale formation in hot water heater in the low-pressure boiler. Scaling and deposition problems in air conditioning plants are associated with total hardness of the water. Total hardness of more than 180 mg CaCO₃ per litter can treated as very hard water and it can lead to scaling problems in air

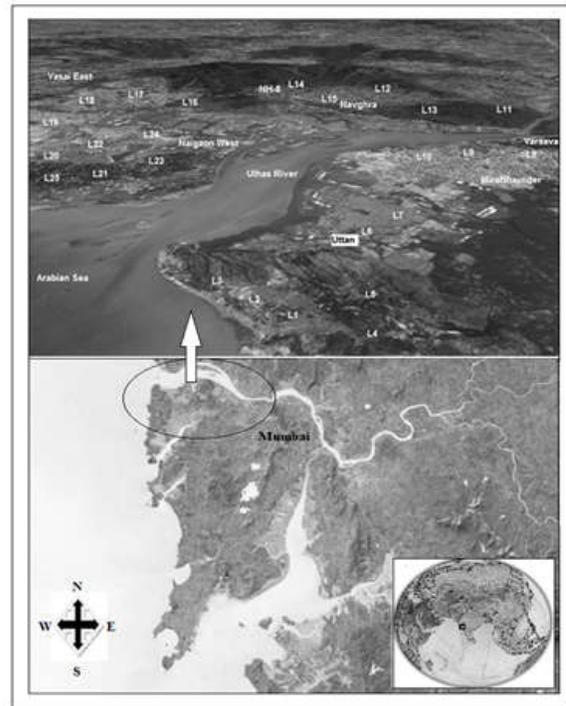


Fig.1 map of study site, a) Hydrogeology map of greater Mumbai, b) sampling locations

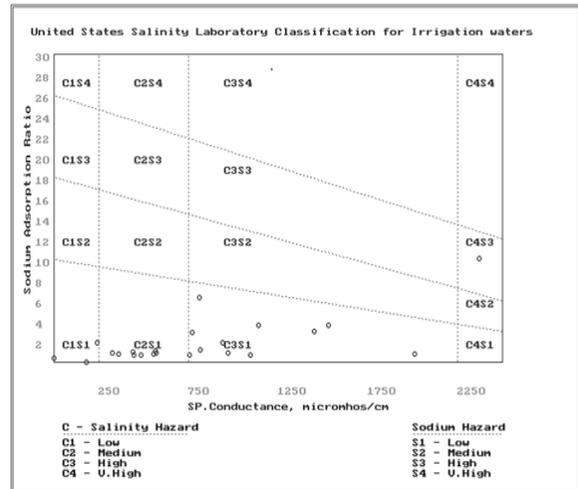


Fig. 1 USSL Diagram for ground water of study site

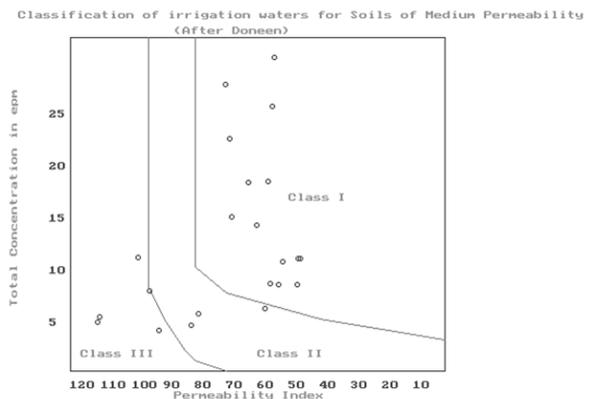


Fig. 2 Doneen Permeability classification diagram

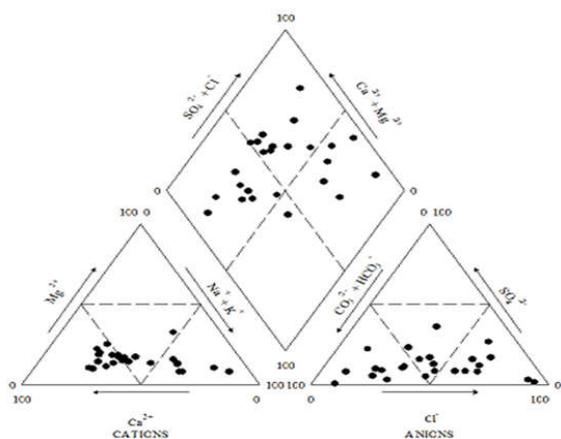


Fig. 3 A Trilinear Piper's plot for ground water

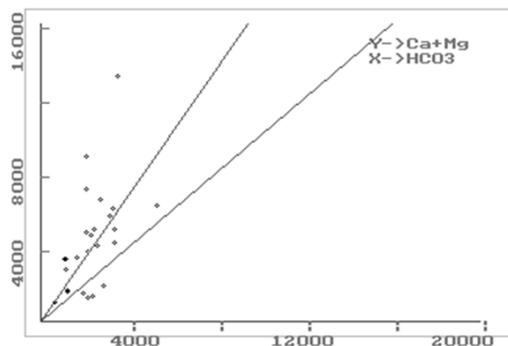


Fig. 5 Ionic relation plot of (Ca +Mg) Vs (HCO₃+SO₄)

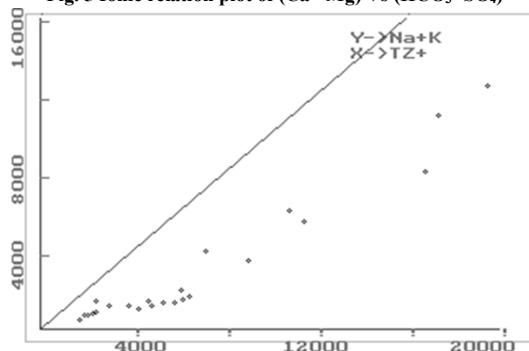


Fig. 6 Ionic relation plot of (Na + K) Vs TZ+

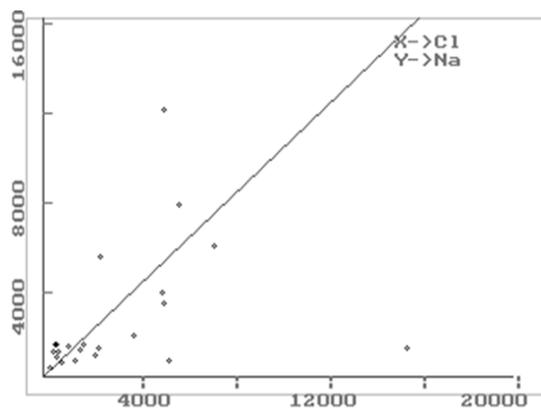


Fig. 7 Ionic relation plot of Na Vs Cl

conditioning plants (Hem 1970). Based upon hardness of ground water it can be classified in to four categories i.e. soft, slightly hard, moderately hard and very hard. In the present study it was found that, 4 locations were of soft water type, 3 were slightly hard type, 11 moderately hard type and 7 locations of very hard type (Table 3).

Source

The results from the water analysis were used as inputs to identify the sources and mechanisms affecting the groundwater composition in the area. The source of origin of ions can be predicted by different ionic relations. The Ionic relation plot of (Ca+Mg) versus (HCO₃+ SO₄) presented in Fig. 5, showed that 21 locations lie above equiline, indicating bicarbonates may not be the dominant factor. This may be due to reaction of feldspar minerals with carbonic acid in the presence of water. Which releases HCO₃⁻ rather than dissolution of minerals like calcite, gypsum and dolomite and this is the important factor in determining the ion chemistry of ground water. The plot for (Na+K) versus TZ+ (Fig. 6) revealed that all the samples lie below the equiline, which indicates that Ca+Mg was the dominant factor, responsible for hardness in water. The ionic relation plot for Na Versus Cl (Fig. 7) elucidated that majority of sampling locations lies closer to equiline. This suggested that dissolution of halite was an important factor controlling concentration of Na and Cl in ground water. Few samples lie far from equiline indicating dissolution of sodium bearing silicate mineral (those are in Na-zone) and leaching of Cl (those are in Cl-zone) from fertilizer, human and animal waste.

Conclusions

On the basis physicochemical parameters, the ground water of most of the locations was found suitable for drinking purposes as they are within the extended limits of BIS and WHO. The groundwater of a few locations which exceed the extended limits should be avoided for drinking. The irrigational quality of groundwater were assessed using different parameters like SAR, RSC, Na%, PI and salinity hazard and groundwater of almost all the locations were found to be suitable for irrigation, except a few locations, which were unsafe even for the irrigation purpose due to its high Na%, high salinity and less permeability. The piper trilinear diagram, a well known graphical presentation for hydrochemical facies determination, was used for hydrogeochemical classification of groundwater of the area. It identified three predominating hydrochemical facies i.e. (Na+K)-SO₄+Cl, (Ca+Mg)-(SO₄+Cl) and (Ca+Mg)-HCO₃ type. The Scholler Classification, which primarily determines the age of the groundwater, identified 22 locations to have young groundwater while rest of the locations have relatively mature type of groundwater. Study of source approximation indicates that, weathering is an important geochemical process controlling the chemistry of the ground water of the study site.

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