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AN EVALUATION OF SUB-SURFACE WATER QUALITY AROUND BHARUCH-SURAT INDUSTRIAL REGION, GUJARAT, INDIA

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ABSTRACT

Water is an important element in everyday life. The basic property of water (H_2O) is static but with the inclusion of different physico-chemical elements, its quality varies from time to time and place to place. The present paper is an attempt to evaluate the property of sub-surface water in Surat-Bharuch Industrial Region of Gujarat, India. 155 sites were selected for the analysis and spatial pattern of physico-chemical parameters like EC, pH, temperature, calcium, sodium, potassium, lithium, iron, fluoride, copper and cadmium were analysed. To understand the distribution pattern of data, measures of central tendency, dispersion and skewness were applied. High concentration of sodium was observed in the northern part of the region while the level of pH was normal in the region. Lithium concentration was high throughout the area except for the south-eastern region. Other physical parameters like EC and temperature and chemical parameters like potassium, fluoride and copper were found to be within the desirable range.

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Multiple correlation among the parameters showed most important and strong relation between EC – Lithium, EC-Calcium and EC-Sodium.

Key Words: *Physico-chemical elements, statistical analysis, IDW, GIS, water quality.*

Introduction

Sub-surface water is a prime natural resource and because of its multiple uses, it is considered to be an important component. The quality of sub-surface water depends upon many natural conditions like amount and intensity of rainfall, slope of the land, grain size of soil etc. (Chang, 2010). At the same time, few anthropogenic factors also affect it and the most important is its injudicious uses (Boyacioglu et al., 2010). The level of water table is directly related with its consumption for different purposes and excessive use can result into its lowering. Heavy leaching from minerals and rocks leads to the disbalance in the quality of sub-surface water. A higher amount of different physical and chemical elements, heavy minerals are at times found more than the desired limit while at times they are either absent or are below detectible limit. All over the world, groundwater is used for different purposes like agricultural, industrial, household, recreational and environmental activities. Hence, it is significant to analyse the physico-chemical properties and assess the quality of groundwater in industrial areas and check the suitability of water for irrigation, domestic and industrial purposes (Shivayogimath et al., 2012). In the last few decades, there has been tremendous increase in the demand of water because of accelerated industrialization, urbanization and rapid population growth (Ravenscroft et al., 2009). Industrialisation is one of the important phenomena which ignites the mechanism of development. Disposal of solid waste in open pits and depression, discharge of untreated liquid waste through open drains and emissions of toxic gases into the atmosphere are a few common features prevalent in the industrial regions and its vicinity. Groundwater is contaminated in various ways such as excessive use of fertilizers in farming, seepage from effluents bearing discharged from industries or human interventions. Once the groundwater gets contaminated, its quality cannot be restored by stopping the pollutants from the source in short span of time (Sadashivaiah, 2008). Garizi et al., (2011), had applied descriptive statistics to evaluate the sub-surface water quality in Chehelchay watershed in northeast of Iran. In this study, it was found that multivariate analysis was really useful in identifying the source of pollution as well as temporal variation in the water quality. The study undertaken by Sargaonkar et al., (2003) mainly focused on the developing mathematical expression to depict actual pollution condition of a region. For the estimation of actual pollution of the region 'Overall Index of Pollution' or OIP' was developed in the study.

Objectives

The objective of the paper is to assess the spatial pattern of some of the physico-chemical parameters of groundwater in Surat-Bharuch industrial region of Gujarat, India.

Study Area

The districts of Surat and Bharuch adjoin the eastern flank of the Gulf of Cambay (Fig. 1). This region covers an area of about 4200 sq. km. and extends between 72°28'E and 73°3'E longitude and 20°59'N and 22°11'N latitude. The Narmada, the Tapi, the Dhadar and the Kaveri are the major rivers which flow downstream towards the Gulf of Cambay. The two districts have many industrial zones like Jambusar, Vagra, Bharuch and Ankleshwar in Bharuch District and Olpad, Surat and Hazira in Surat District. Surat is the major industrial centre of the region. These industries manufacture different types of chemicals, petrochemicals, polymers, polyesters, fibres etc. (**District Census Handbooks Surat and Bharuch, 2011**). This area has a good network by roads and railways. National and state highways and major district roads facilitate the industrial and development of the area. Dahej, Hazira port, which is operated by Gujarat Maritime Board (GMB) is a major port through which commercial transportation is done. The region is associated with hot summer and dryness except in the coastal region. Rivers like the Narmada, the Tapi, the Dhadhar, the Kaveri flows in the westward direction and pour into the Gulf of Cambay (**District Census Handbook Surat and Bharuch, 2011**).

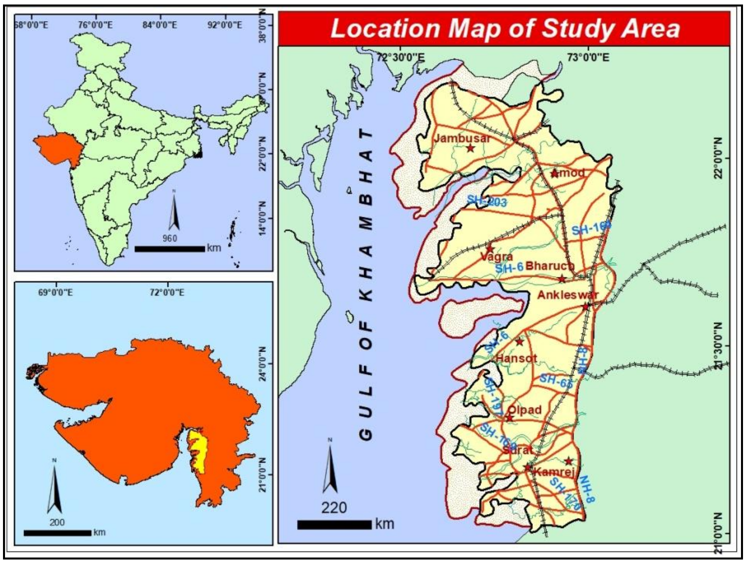


Fig. 1

Methodology

Data Collection and Sample Analysis

155 sub-surface water samples were collected in Premonsoon (May-June) 2016 and standard procedure was followed (APHA, 1998). The entire area of 4200 sq.km. was gridded in 5X5 sq.km. area and from each of the grid at least one sub-surface water sample was collected and analysed (Fig.2). Sampling locations were marked by hand held GPS (Garmin GPSMAP 78S). The sub-surface samples were taken from bore, well and hand pump and physical parameters like pH, EC, temperature etc. were determined on field by portable instrument (**Hanna Make, HI 98129**). For the determination of level/concentration of chemical parameters like calcium, sodium, lithium, and potassium, Esico Flame-Photometer (Model-1385) was used. Hanna made Ion Selective Electrodes were used for the detection of fluoride (HI4110), cadmium (HI 4130) and copper (HI 4108). Elico Double Beam UV-VIS Spectrophotometer (Model S1-210) was used for determination of Iron. All the laboratory work was performed in the laboratory of the Department of Geography, Faculty of Science, The M.S. University of Baroda.

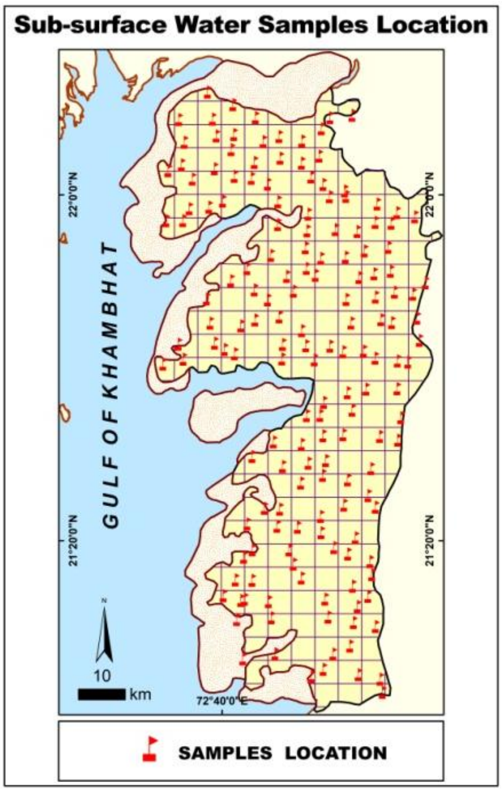


Fig. 2

Spatial Interpolation Method

GIS is a very effective tool for spatial analysis and interpolation. In this paper IDW (Inverse Distance Weighting) method was applied for spatial pattern of the study area. This method gave a better visual illustration to understand the present conditions each of the parameters (Ghosh and Kanchan, 2014). For the graphical representation, ArcGIS 10.2 was used while for the multiple correlation was performed in MS Excel 2013.

Result and Discussion

Temperature

Temperature is one of the factors which affects physical and chemical properties of water (Bhadja et al., 2012). In the present study, the sub-surface water temperature ranged between 26.5°C and 35.70°C. The highest temperature (>31°C) was found in the northern portion as scattered areas in the entire region. 21.29% of the total samples covered (<1.95%) of the total area and had a sub-surface temperature of (>31°C). 30°C to 31°C water temperature was found in 24.52% samples occupying 31.73% of the total area (Fig. 3). This was largely located in the two extremes viz, in the northern and southern parts of the study area. 29°C to 30°C water temperature was noted in 49.29% of the area encompassing 20% of the total samples. It was spread from central to south. 28°C to 29°C of water temperature was observed in 21.94% samples and it covered 15.68% of the total area. This range of sub-

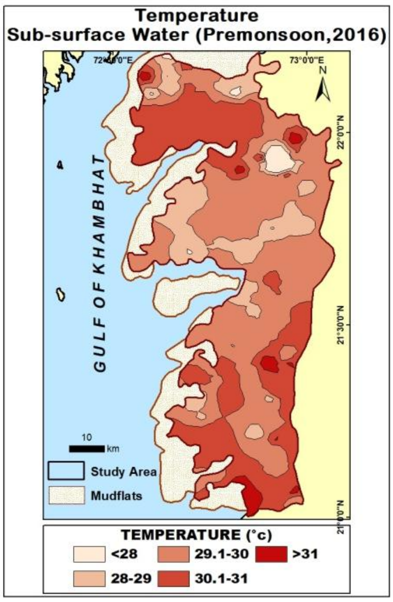


Fig. 3

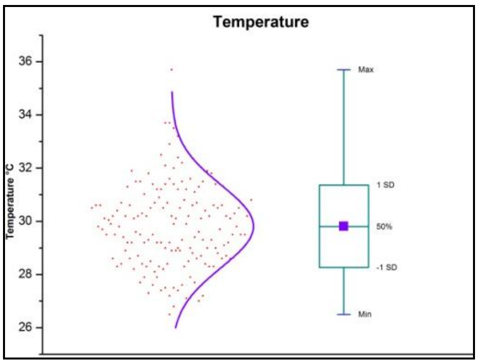


Fig. 4: Box Plot & Distribution Curve

surface water was in patches in central part. The least temperature (<28°C) was found in north-eastern part of the study area which was observed in 12.26% samples covering 1.33% of the total area.

In the distribution of temperature in sub-surface water, the mean was 29.81°C. The diversification of data was low with standard deviation value 1.55. In the distribution curve, skewness value was 0.50 which was near zero (0) so the curve to be near the normal. Kurtosis value of this curve was 0.71 (Fig. 4). It depicted that the distribution curve was more flattened with gentle slope.

pH

pH value in the study area varied between 6.11 and 8.49, but in most of the samples (>80%) this value was between 7.5 and 8. The highest pH value was 8.49 and it was centred in the southern part of the study area. This location was near Surat city. Only 3.87% samples had pH value of <7 and 10.97% had >8. The BIS standard for pH varied from 6.5 to 8.5. Hence, it can be said that in most of the samples the pH values were within the range (Fig. 5).

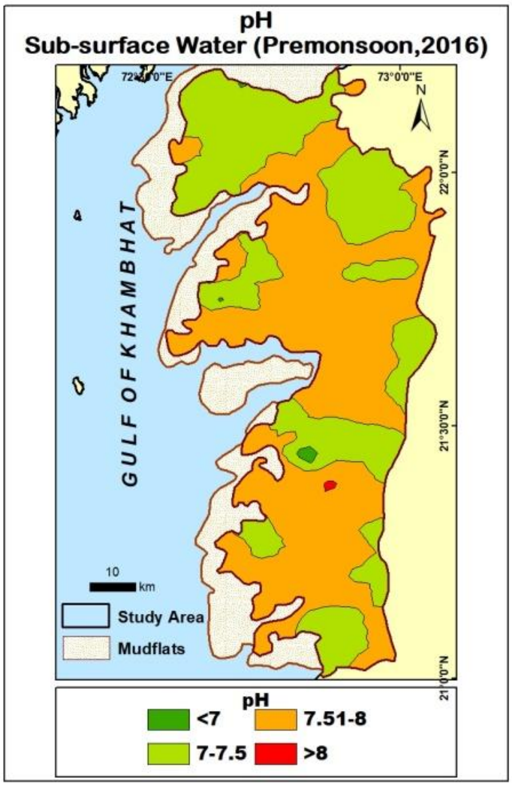


Fig. 5

The spatial distribution of pH depicted that in 0.27% of area the pH was <7 while in 40.63% area it ranged between 7 and 7.5. A continuous patch was noted in the northern segment, while in east of the study area it was in patches. In totality, it covered 5.16% of samples. A large area of study region had pH values varying between 7.5 and 8, which was in 59% of the total area. This pH value was noted in the entire region and only broken by segments with value between 7 and 7.5.

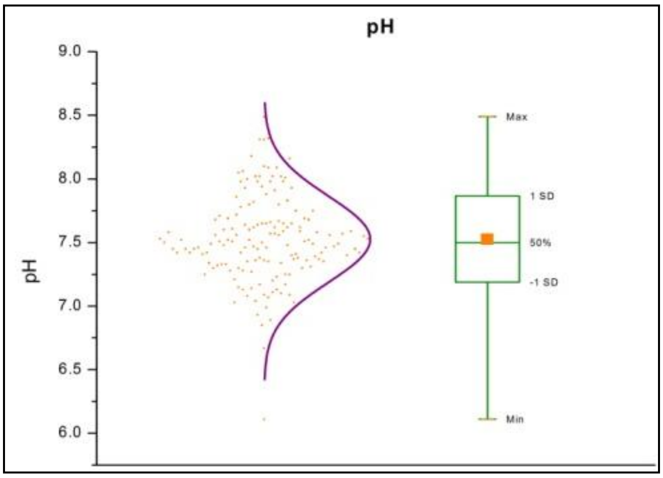


Fig. 6: Box Plot & Distribution Curve

The mean value of the distribution of the data set was 7.53 which was within the BIS standard. The variation of the data set was low while the standard value was 0.34. The skewness was also near the normal value of 0, depicting (-0.10) a neutral case (Fig. 6). The kurtosis curve also depicted a fair distribution on pH over the space.

Electrical Conductivity

Electrical conductivity (EC) is a measure of the concentration of the ionized substance that conveys electric current in water (Kumar et al., 2010). There is a direct positive relationship between EC and TDS. The higher the amount of TDS in water , the greater would be the EC and *vice versa.* In the present study, EC varied from 0.20 mS/cm to 19.11 mS/cm. Maximum (55.48%) samples had (<2 mS/cm) which covered 29.60% of the total area and were near to the Tapi river and Surat City. 62.90% area had 2 mS/cm to 4 mS/cm EC values this range was noted in 28.39% samples. The entire northern part and region were near the Narmada river had EC between 2 mS/cm and 4 mS/cm. Higher concentration (>8 mS/cm) was seen in bits and pieces in the north of the study area. It covered just 1.9% of the area (Fig. 7).

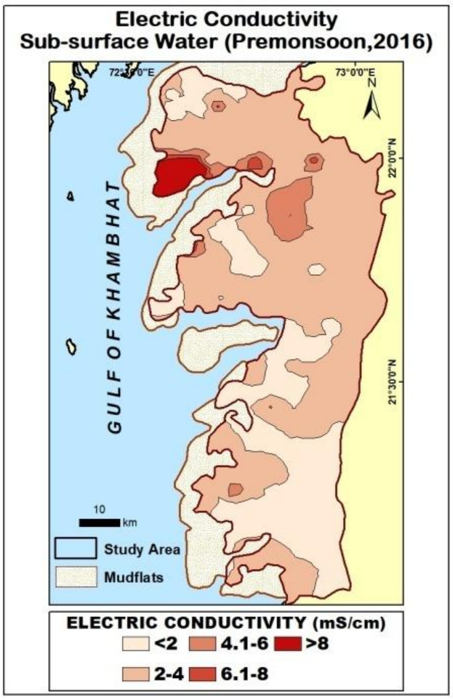


Fig. 7

In this distribution, the mean value of the data was 2.69 with a standard deviation value of 2.90. This depicted a medium range of the data set. The skewness and kurtosis value of the curves were 3.23 and 14.01 respectively and showed that the curve had a positive skewness with steep slope (Fig. 8).

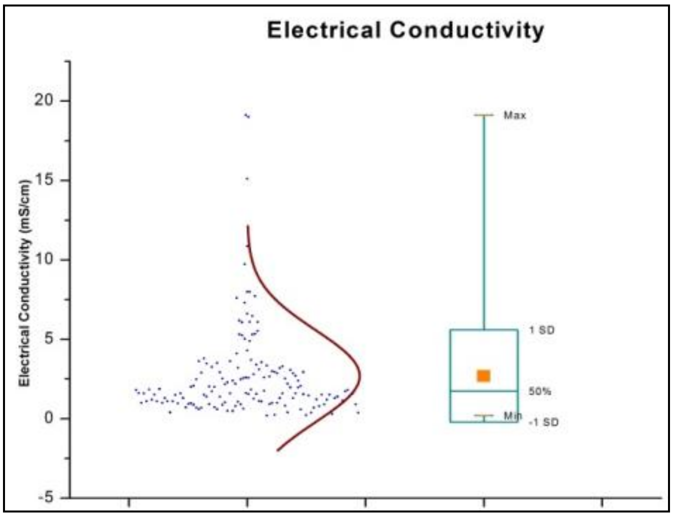


Fig. 8: Box Plot & Distribution Curve

Iron

Iron is a common element in water but its presence in water differs. The concentration of iron varied between 0.01 mg/l and 3 mg/l in the study area. The BIS standard for iron in drinking water was 0.3 mg/l. 83.23% of samples were under the BIS range while only 16.77% samples were above this standard. In 12.26% samples iron concentration was relatively higher (>1.2 mg/l). 58.97% of area had <0.3 mg/l of iron concentration. This spread over the entire mainland and it was broken as patches of >0.3 mg/l. 23.3% of area had iron concentration between 0.3 mg/l and 0.4 mg/l which was slightly higher than the BIS standard and 8.55% of area had between 0.62 mg/l and 0.9 mg/l. A higher concentration between 0.9 mg/l and 1.2 mg/l and above 1.2 mg/l covered 4.16% and 5.03% of total area. The higher concentration was found mostly along the sea coast (Fig. 9).

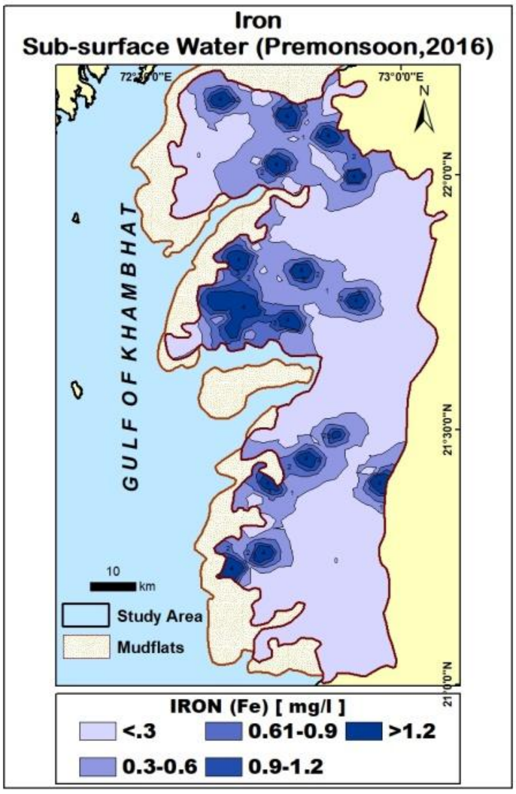


Fig. 9

The mean value of the iron distribution was 0.40. It was a little higher than the BIS standard. Skewness value was 2.39 so the distribution was positive while the Kurtosis value of the distribution was 3.65 depicting normal slope (Fig. 10).

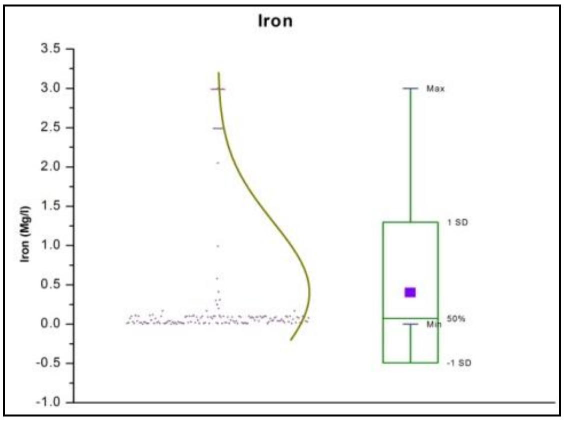


Fig. 10: Box Plot & Distribution Curve

Calcium

Calcium is an important required element which is commonly present in water. According to BIS standard, the permissible value of calcium in water is 75 mg/l and acceptable range is 200 mg/l. In the study region, the calcium concentration varied from 19.1 mg/l to 250 mg/l. A small number (1.29%) samples had calcium concentration above the BIS standard. <50 mg/l of calcium concentration was found in 35.48% samples and it covered 15.09% of the area. It was mostly localized in the south eastern part of the region. 50 mg/l to 75 mg/l of calcium concentration was noted in 30.97% samples which covered 61.23% of the total area. This concentration was noted in the entire region. 75 mg/l to 100 mg/l calcium concentration was observed in 19.34% area and 18.06% samples. This range of calcium was more pronounced in the northern region. Calcium concentration from 100 mg/l to 125 mg/l was found in 10.32% samples and 2.35% of area respectively. Some small patches of higher concentration >125 mg/l were found in just 1.97% of the total area and 5.16% of total samples of Bara tract (Fig. 11).

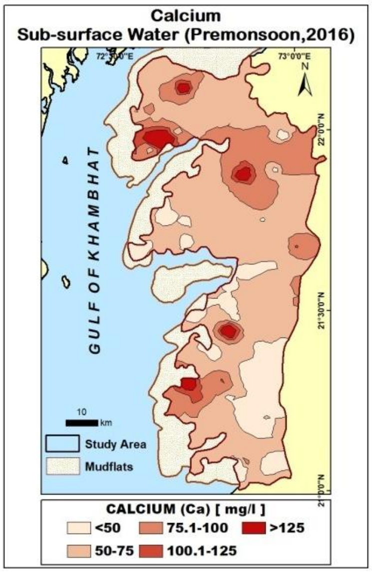


Fig. 11

In the study area, the mean of calcium in sub-surface water was 68.45. The variation of the data was high with standard deviation value of 44.37. This distribution had a positive skewness value of 2.41. The kurtosis value of this distribution was 7.38 (Fig. 12).

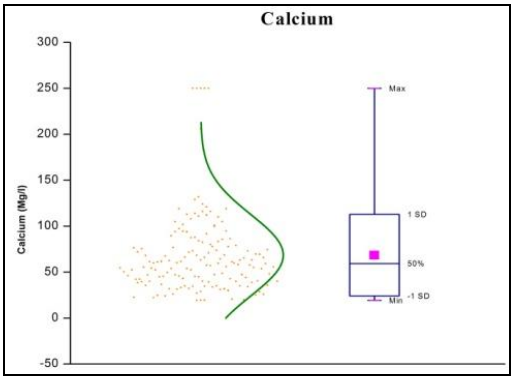


Fig. 12. Box Plot & Distribution Curve

Sodium

The presence of sodium in water is because of the higher solubility of sodium in water. The concentration of sodium in this region was high. It ranged from 55 mg/l to 400 mg/l whereas the WHO standard value for sodium is 200 mg/l. 37.3% sub-surface water samples were below this standard. Concentration of <100 mg/l was noted in 22.58% samples but it covered only 1.67% of the total area. It was distributed as small patches throughout the region. 12.25% samples had sodium from 100 mg/l and 150 mg/l. It covered 9.48% of total area and was also found in patches in the entire region except for the north-eastern part. 16.12% samples of sodium concentration were between 150 mg/l and 200 mg/l. It covered 26.3% area, mostly as patches. Slightly high sodium concentration from 200 mg/l to 250 mg/l was noticed in 4.51% of samples and was spread over 22.6% of the area. A very high sodium concentration which was >250 mg/l was observed in 44.51% samples which stretched over 39.87% of the total area. It was mainly concentrated in the northern part the Bara tract (Fig. 13).

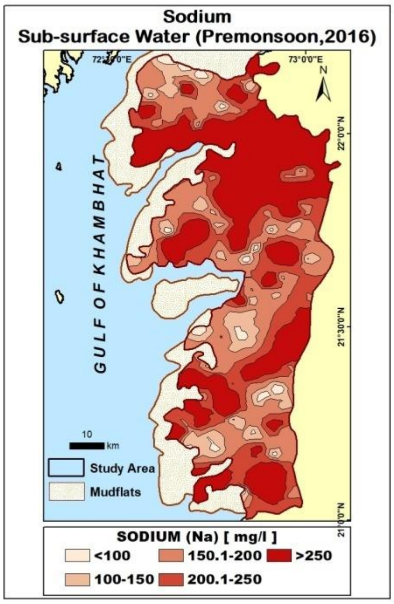


Fig. 13

The mean value of sodium in sub-surface water was 229.31 mg/l. It was slightly higher than WHO standard (200 mg/l). A very high standard deviation value (148.38) showed that the variation in the data was very high. The skewness of the distribution was normal with value of 0.02. Kurtosis value of the distribution was less than 3 (-1.62) so that the peak of the curve was flat (Fig. 14).

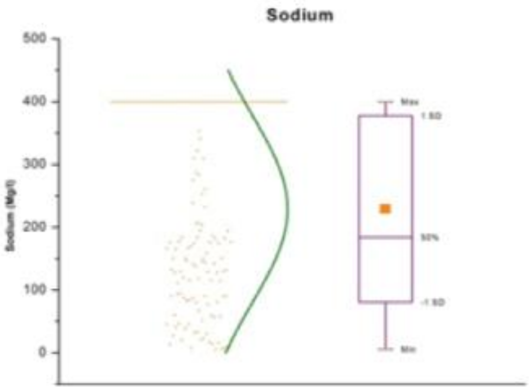


Fig. 14: Box Plot & Distribution

Potassium

Potassium is an essential element of soil. The sub-surface water gets this element from leaching of the soil. In this region the concentration of potassium varied between 0.20 mg/l and 50 mg/l. High concentration of potassium was in the northern and western parts of the region (740 mg/l). It covered 5.90% of the total area and included 24.52% of the samples. 30 mg/l to 40 mg/l of potassium concentration was found in 1.29% samples spread over 9.57% area. This range was mainly found in the northern part of the study area. 20 mg/l to 30 mg/l potassium was found in 5.81% samples and covered 17% of the total study area. 10 mg/l to 20 mg/l of potassium in water was noted in 17.42% samples and covered 39.11% of the total area. This range of concentration was observed in the northern and parts of south-western segment. The southern part of the study area had <10 mg/l of concentration. It covered 28.42% of the total area and 50.97% total samples (Fig. 15).

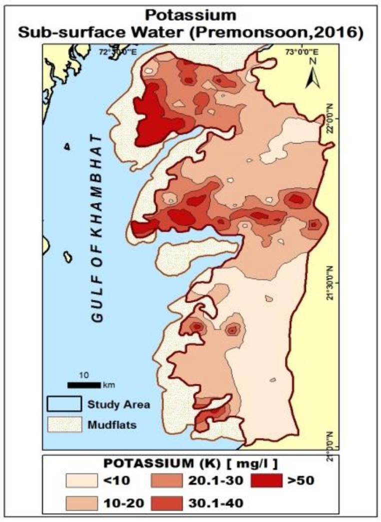


Fig. 15

From the **Table 1**, it is observed that the mean value of potassium was 68.45 mg/l and standard deviation value 44.37. It depicted a scattered distribution of the data set. Skewness value of the distribution was 0.87, so the curve was said to be normally skewed. Kurtosis value was (-0.99) : so the shape of the curve was gentle (Fig. 16).

Table 1: Physico-chemical Characteristics of Sub-surface Water in The Study Area

Parameters	Minimum	Maximum	Mean	Standard deviation	Skew-ness	Kurtosis
pH	6.11	8.49	7.53	0.34	-0.10	1.67
EC	0.20	19.11	2.69	2.90	3.29	14.01
Temperature	26.50	35.70	29.81	1.55	0.50	0.71
Calcium (Ca)	19.10	250.00	68.45	44.37	2.41	7.38
Potassium (K)	0.20	50.00	18.46	19.26	0.87	-0.99
Sodium (Na)	5.50	400.00	229.31	148.38	0.02	-1.62
Lithium (Li)	0.06	3.50	0.60	0.47	3.08	13.34
Fluoride (F)	0.02	1.51	0.18	0.16	4.14	28.10
Iron (Fe)	0.00	3.00	0.40	0.89	2.33	3.65
Cadmium (Cd)	0.00	0.20	0.03	0.05	1.63	1.84
Copper (Cu)	0.00	0.20	0.03	0.02	2.61	14.62

Source: Computed

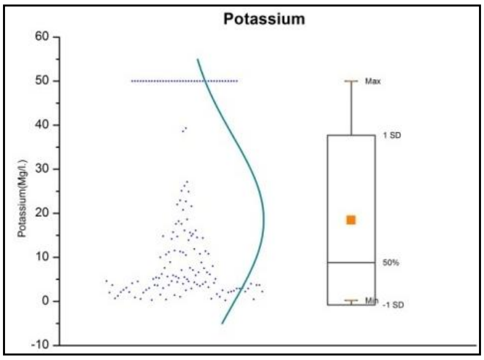
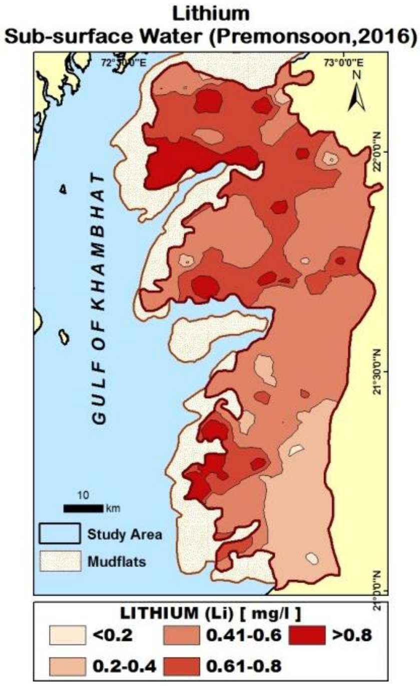


Fig. 16: Box Plot & Distribution Curve

Lithium

In this area Lithium concentration in sub-surface water was low. It varied between 0.06 mg/l and 3.5 mg/l. 19.47% samples had values of >0.8 mg/l and covered 8.9% of the total area. 0.61 mg/l to 0.80 mg/l lithium concentration was in 17.4% samples which covered 27.2% of total area. This range of lithium concentration was largely confined to the north of the study area. 0.41 mg/l to 0.60 mg/l lithium was found in 27.1% water samples and it covered 48.1% of the total area. It was noted in the entire region excepting in the south-eastern parts of the study the area. In the south eastern part of the study area, lithium concentration was between 0.2 mg/l and 0.4 mg/l. It covered 15.5% of total area and 25.2% total samples. Very low lithium was found in 11% of the total samples and 0.3% of the total area (Fig. 17).



In the distribution of lithium, the mean value was 0.60 mg/l. The standard deviation value of the distribution was 0.47; so the variation in the data was less. According to the skewness value (3.08), it was positively skewed. Kurtosis value of the distribution was very high (13.34), showing the peaks of the data curve (Fig. 18).

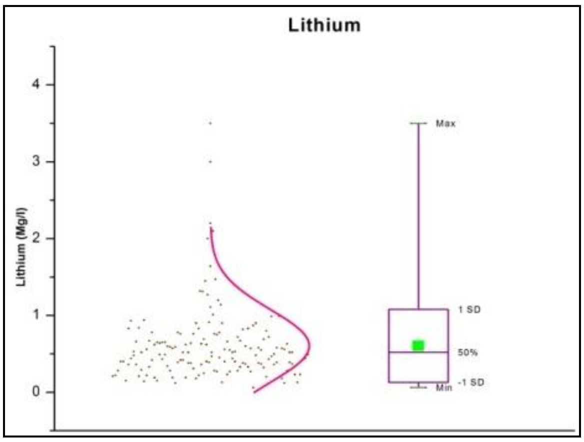


Fig. 18: Box Plot & Distribution

Copper

Copper is an important trace element which provides for nutrition to the human beings. Daily requirement of copper for and adult person has been estimated to be 2.0 mg/l (APHA, 2004). As per the BIS recommendations, 0.05 mg/l is the desirable limit and 1.5 mg/l is the permissible limit. In this study, copper concentration varied between 0.05 mg/l and 0.10 mg/l. Higher concentration (0.1 mg/l) copper was noticed in the northern part of the study area which covered 2.58% samples and 0.58% of area in a small patch. 0.05 mg/l to 0.1 mg/l copper concentration was noticed in 10.17% area and 15.48% samples. This too, like the former noted in many small segments spread over the entire area. <0.05 mg/l copper concentration of this element was observed in 89.24% of the study area and 81.94% of samples (Fig. 19).

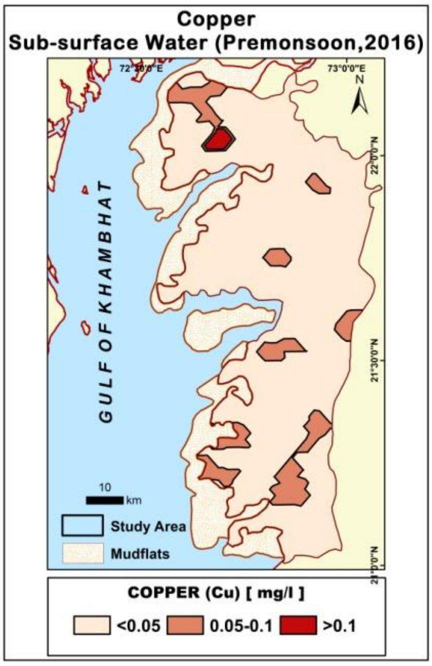


Fig. 19

Mean value of copper distribution was 0.03 mg/l which was lower than BIS limit (0.05 mg/l -1.5 mg/l). The variation of the data was very low with standard deviation value 0.02. The data had positive skewness (2.61) with high kurtosis value (14.62). The slope of the distribution curve was steep (Fig. 20).

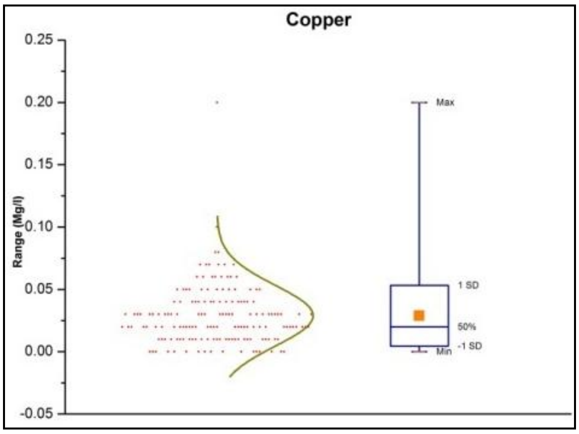


Fig. 20: Box Plot & Distribution Curve

Cadmium

The amount of cadmium in groundwater varied from 0.01 mg/l to 0.04 mg/l. According to BIS standard, the desirable limit is 0.01 mg/l. 60.65% samples had the concentration level below the BIS desirable (<0.01 mg/l) limit. It was spread over 49.89% of the total area and was found in the entire region, particularly nearer the Narmada River. The remaining 7.10% samples had 0.01 mg/l to 0.02 mg/l cadmium and were located in the north-eastern parts near the Palej industrial region. It covered 10.50% area. 4.97% area with 1.94% samples had 0.021 mg/l to 0.03 mg/l cadmium. This range was found in small patches scattered in the north–western parts of the study area. There are many salt industries in this part. Another patch was observed nearer the Tapi River. 0.31 mg/l to 0.04 mg/l range was in 4.48% area with 3.23% samples. This patch was found near the Dahej industrial region which is located near the sea. 27.10% samples covering 30.16% area had >0.04 mg/l cadmium concentration and were noted in north, central and southern parts of the study area. The central part encompassed Bharuch and Ankelswar industrial regions (Fig. 21).

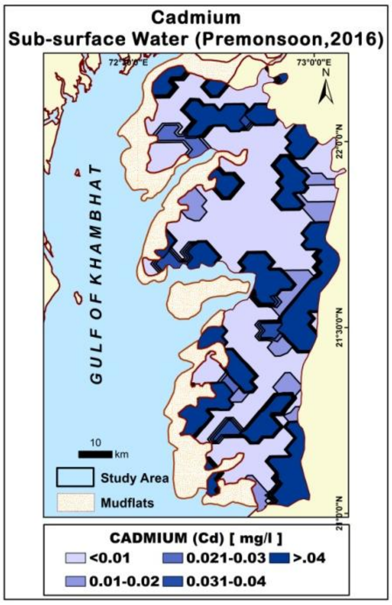


Fig. 21

In the cadmium distribution, mean value was 0.03 mg/l and standard deviation value was 0.05. Low standard deviation value refereed that the range of the distribution was low. In this distribution curve a positive skewness (1.63) was observed and kurtosis value was of 1.84. In case of cadmium distribution the slope of the curve was gentle (Fig. 22).

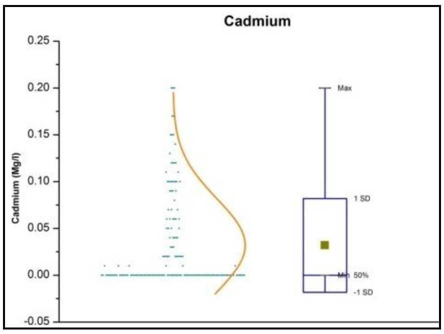


Fig. 22: Box Plot & Distribution Curve

Fluoride

Fluoride concentration in the study area ranged from 0.2 mg/l to 1.51 mg/l. The BIS standard for fluoride was 1 mg/l to 1.5 mg/l. The fluoride concentration in all the sample sites was within the BIS standards. 63.23% samples had fluoride concentration <0.20 mg/l. It was spread over 73.46% of the total area, both in the northern and southern parts of the study area. 0.20 mg/l to 0.40 mg/l fluoride concentration was found in 30.23% samples which covered 25.70% of the total area. It was mainly localised in the central parts of the study area and in some segments in south of the study area. 0.41 mg/l to 0.60 mg/l fluoride concentration covered 0.46% of the total area and 3.87% of the total samples. 1.29% of samples had fluoride concentration between 0.61 mg/l and 0.80 mg/l with 0.21% area. 0.15 % of total area and 1.29% samples had > 0.80 mg/l concentration (Fig. 23).

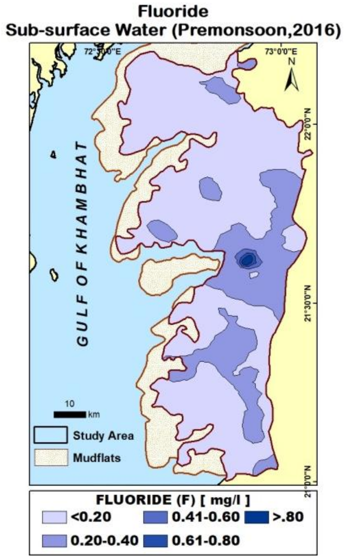


Fig. 23

The mean of the fluoride distribution was 0.18 mg/l. It was lower than the BIS range (1-1.5). Standard deviation value of the distribution was 0.16 showing that the range of the data was low. Skewness value (4.14) depicted positive skewness. Kurtosis value (28.10) indicated the peakedness of the curve (Fig. 24).

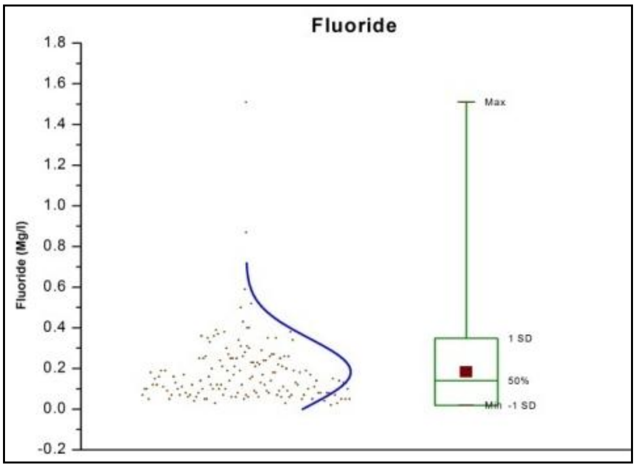


Fig. 24

Table 2: Standards for Drinking Water

Parameters	BIS/WHO Guideline value
pH	6.5 to 8.5 (BIS)
EC	—
Temperature	—
Calcium (Ca)	75 to 200 (BIS)
Potassium (K)	—
Sodium (Na)	200 (WHO)
Lithium (Li)	—
Fluoride (F)	1-1.5 (BIS)
Iron (Fe)	0.3 (BIS)
Cadmium (Cd)	0.01 No relaxation (BIS)
Copper (Cu)	0.05-1.5 (BIS)

Source: BIS (2012), WHO (2004)

Correlation

For depicting the relationship among the parameters, multiple correlation was performed on the data set. Strong positive correlation was found between EC with sodium (0.51), lithium (0.81), calcium (0.63) and lithium with calcium (0.68). Moderately high correlation was found between sodium and lithium (0.41) and calcium (0.39), while no correlation was found between temperature with other parameters. Negative correlation was noted between pH with EC (-0.19), potassium (-0.04), lithium (-0.13), calcium (-0.304), iron (-0.07). Negative correlation was also mark between cadmium and other parameters except pH and fluoride. Correlation between sodium with other parameters was mostly positive but only negative with cadmium (-0.22) and temperature (-0.05).

Conclusion

The present study is focused on the spatial pattern of physico-chemical parameters in sub-surface water. The study showed that cadmium concentration was more than the BIS standard which was very high near the industrial regions like Bharuch, Ankleshwar, Surat, Jambusar and near the Tapi and the Narmada Rivers. the Iron concentration was high in the western part of the study area. These segments adjoin the Arabian Sea and the slope of the land is from east to west. High sodium concentration was observed in the northern part and as patches near the Tapi River. pH values were near the normal range in the entire region. Only high pH value was noted in Surat city. Lithium concentration was high throughout the area except for the south eastern segments. Other physical parameters like EC and temperature and chemical parameters like potassium, fluoride and copper were more or less within the desirable range.

Table 3: Correlation Matrix of Sub-surface Water Parameters

	pH	EC	Temp	Sodium	Potassium	Lithium	Calcium	Fluoride	Iron	Cadmium	Copper
pH	1										
EC	-0.192	1									
Temp	0.097	0.055	1								
Sodium	0.128	0.511	-0.054	1							
Potassium	-0.043	0.284	0.017	0.175	1						
Lithium	-0.133	0.819	0.022	0.414	0.559	1					
Calcium	-0.304	0.631	-0.048	0.394	0.25	0.682	1				
Fluoride	0.245	-0.073	-0.028	0.146	-0.125	-0.101	-0.135	1			
Iron	-0.078	0.012	-0.086	0.078	0.083	0.035	0.001	0.107	1		
Cadmium	0.088	-0.231	-0.045	-0.221	-0.123	-0.143	-0.188	0.134	-0.083	1	
Copper	-0.015	-0.113	-0.109	-0.095	-0.112	-0.086	-0.053	-0.072	0.011	0.218	1

Source: Computed

Acknowledgements

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Assessment of Sub-surface Water Quality using Multivariate Statistical Analysis along the Gulf of Khambat, Western Gujarat, India

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Abstract: *The study is based on 152 sub-surface water samples collected from different sources during monsoon of 2016 (September–October). The correlation matrix was built for 10 physico-chemical parameters such as Electrical Conductivity (EC), salinity, temperature, pH, sodium, calcium, potassium, lithium, fluoride and iron. Correlation matrix was analysed by Principal Component Factor Analysis (PCFA). The exploration of correlation matrix permitted to uncover strong associations between some variables (EC, salinity, lithium, calcium and sodium) as well as poor associations between the others (pH, temperature, potassium, fluoride and iron).*
PCFA showed the existence up to three significant factors which accounted for 67.43% of the total variance and it also explained the characterisation of sub-surface water quality and identified the probable source of ions. Factor 1 represented high positive loading on EC, salinity, calcium, lithium and sodium and Factor 2 included concentration of temperature, iron and potassium, while Factor 3 represented higher positive loadings on pH and fluoride. The physico-chemical relationships suggested that the sub-surface water quality is mainly controlled by hydrogeological factors and seawater intrusion.

Key words: Multivariate statistical analysis; sub-surface water quality, seawater intrusion, geological formation, Geographic Information System (GIS)

Introduction

Sub-surface water is one of the most precious resources on the earth and our health totally depends on it. Hence, we need to protect the sub-surface water quality. All around the world, it is utilised in agriculture, industries, irrigation and drinking, particularly in the arid and semi-arid regions (Prajapati *et al.*, 2017). The quality of sub-surface water varies over space and time. It is determined by many natural and anthropogenic factors (Shishaye and Asfaw, 2020). Natural factors like geologic formations, seawater intrusion, lithology, tidal embayment and estuaries, sediment transportation, sub-surface aquifer systems, hydraulic gradient, rate of groundwater withdrawal and recharge govern the physico-chemical quality of sub-surface water in the coastal region (Rina *et al.*, 2014; Saha *et al.*, 2018). Khatri and Tyagi (2015) studied the influences of natural factors on sub-surface water quality in rural and urban areas and reported that natural processes cause changes in the pH and alkalinity of the water, increase in fluoride content due to heavy metal pollution. According to the study by Guo *et al.* (2018), geologic setting, water-rock interaction, bedrock weathering and seasonal variation impact the sub-surface water quality.

Subsequently, direct inputs of different contaminants including toxic elements from the industries, agricultural, municipal waste disposal are also responsible for water quality deterioration (Upadhyaya *et al.*, 2014). Güler *et al.* (2012) studied the anthropogenic activities on the groundwater hydrology and chemistry in Tarsus coastal plain of south-eastern Turkey. These factors are responsible for the sub-surface water quality. This signifies the importance of analysing and evaluating the spatial variability of water quality.

The vital physico-chemicals parameters of the sub-surface water are interdependent. Hence, applying appropriate statistical technique is one of the ways of reaching probable generalisation. Factor analysis is one of the most widely used statistical techniques in hydro-chemistry and very useful for the sub-surface water quality data interpretation in terms of hydro-geochemical processes (Ghosh and Kanchan, 2014).

According to the study of Singh *et al.* (2011), factor analysis helps in interpreting the underlying variable structure and suggests possible sources responsible for the occurrence of ions and metals in the study

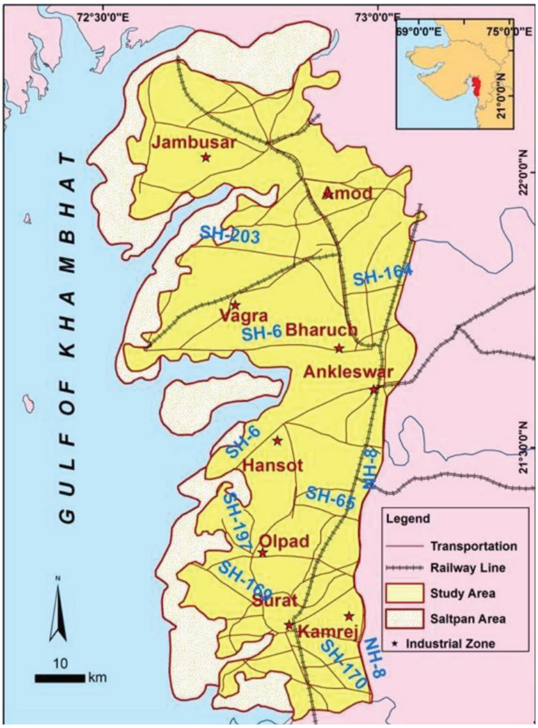


Figure 1. Location map of the study area

Table 1. Physico-chemical Characteristics of Sub-surface Water in the Study Area

Parameters in mg l^{-1}	Min	Max	Mean	Standard Deviation	Skewness	Kurtosis	BIS/WHO Guideline value (1998)
pH*	6.89	8.47	7.52	0.31	0.43	0.08	6.5–8.5 (BIS)
EC**	0.20	17.00	2.24	2.51	3.44	14.91	-
Temp. ***	25.60	33.30	28.85	1.17	0.46	0.84	-
Salinity#	0.09	8.83	1.08	1.31	3.67	16.70	-
Calcium (Ca)	37.00	250.00	124.51	58.04	1.09	0.38	75–200 (BIS)
Sodium (Na)	9.80	400.00	211.95	104.45	-0.44	–1.12	200 (WHO)
Potassium (K)	0.67	50.00	18.18	18.45	0.88	–0.83	-
Lithium (Li)	0.16	5.50	0.85	0.70	3.30	15.24	-
Fluoride (F)	BDL	1.50	0.36	0.25	0.96	1.65	1–1.5 (BIS)
Iron (Fe)	0.11	6.20	0.65	0.82	3.73	17.30	1.3 (BIS)

*pH No Unit, ** EC is in mS cm^{-1} *** Temp. in °C and # Salinity in psu

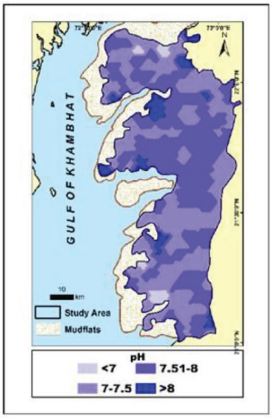


Figure 2. pH distribution of sub-surface water (Monsoon, 2016)

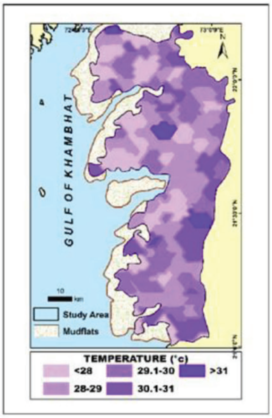


Figure 3. Temperature distribution of sub-surface water (Monsoon, 2016)

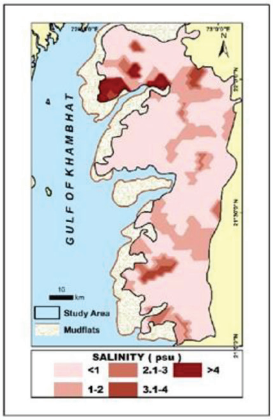
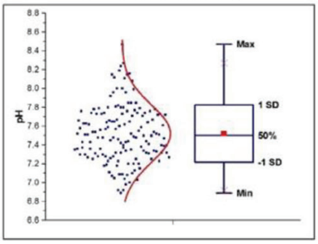


Figure 4. Salinity distribution of sub-surface water (Monsoon, 2016)



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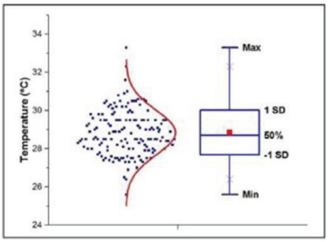

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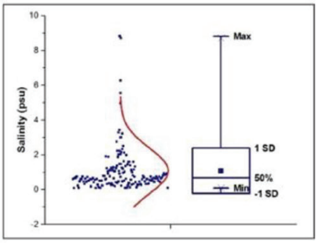


Figure 4.1

area. Yammani *et al.* (2008) performed a study on seasonal variability in different parameters and identification of influencing factors related to groundwater quality in Andhra Pradesh using factor analysis. Liu *et al.* (2003) discussed about the groundwater quality in a blackfoot disease area and applied factor analysis techniques in Taiwan.

The concerned study area is Surat-Bharuch industrial region in Gulf of Khambat, Gujarat, India. It is one of the few areas which lies near the coast that contains a large number of chemical and petrochemical industries. Therefore, a detailed study was necessary to distinguish the zones of differential sub-surface water quality as per the level of contamination and identify the interrelated factors. The understanding of physico-chemical characteristics, hydrological set-up and statistical techniques (factor analysis) provided better opportunity to understand the sub-surface water quality in the concerned region.

Study area

The study area extends between 20°59′N to 22°11′N and 72°28′E to 73°3′E and covers ~4,200 km^2 in the Baroda and Bharuch plains, Gujarat. Narmada and Tapi rivers intersperse this region as they join the Gulf of Khambat by developing estuaries.

The slope is 23.5° in the north-eastern part, which gets reduced to 5° in the south and south-west. The Aliabet Island is found at the mouth of the Narmada estuary. The region is endowed with numerous mudflats and marshy vegetation along the coast. The study area falls in the subtropical climatic region and receives a substantial amount of annual rainfall from the south-west monsoon. The average annual rainfall ranges between 60–85 cm (District Census Hand Book, 2011). Geomorphologically, the terrain is a flat level plain with an altitude varying between 5–100 m above AMSL.

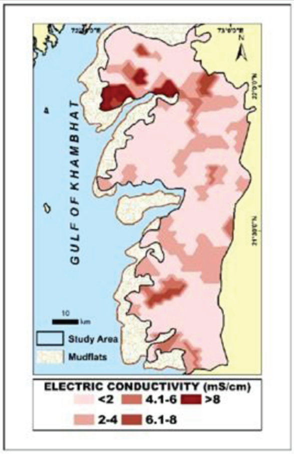


Figure 5. EC distribution of sub-surface water (Monsoon, 2016)

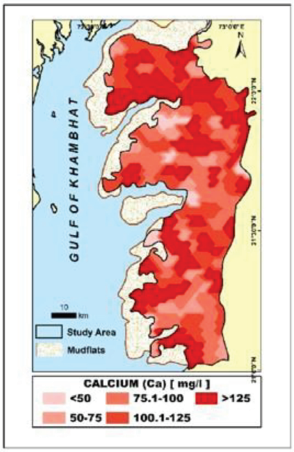


Figure 6. Calcium distribution of sub-surface water (Monsoon, 2016)

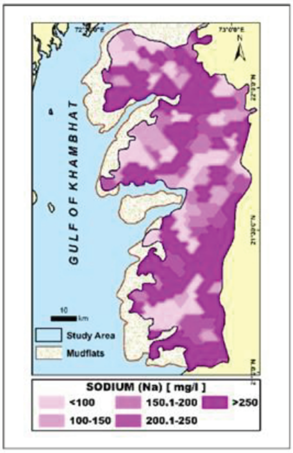
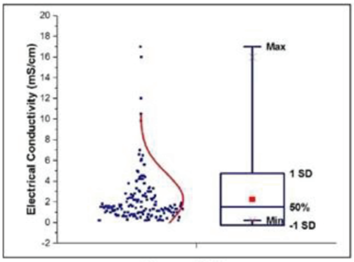


Figure 7. Sodium distribution of sub-surface water (Monsoon, 2016)



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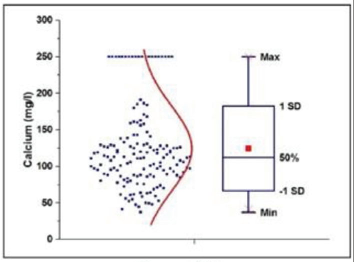

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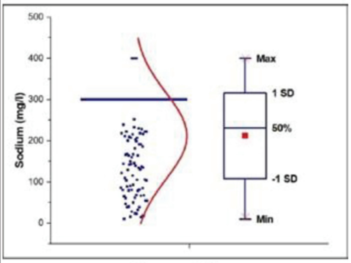


Figure 7.1

Hydrogeological set-up

Hydrogeologically, this area, spanning within Bharuch and Surat districts, is largely affected by coastal salinity. Bharuch district is occupied by the semi-consolidated Cretaceous and Tertiary formations, unconsolidated alluvial deposits and hard rocks consisting of multi–aquifer systems, therefore exhibiting unconfined as well as confined sub-surface water conditions. In the Tertiary formations, sub-surface water quality is poor due to inherent salinity. The movement of sub-surface water is confined mainly to the fractures and joints in the limestones and sandstones. The discharge in dug wells ranges between 30–50 m^3/day^{-1}.

The western part of the Surat district, comprising of Choryasi, Olpad and Kamrej talukas, is covered by alluvium. This aquifer zone can be divided into two parts, namely—newer alluvium and older alluvium. The newer alluvium is present along the Tapi river course and comprises of fine to coarse grained sand trap wash with clay intercalations. The sand is unconsolidated but shows some degree of cohesion at places. Older alluvium is present in inter river plains and comprises of sand, clay, kankar, grave and silt. The sub-surface water in this part is mostly present under unconfined conditions. Besides, semi-confined conditions are also observed at some places due to the presence of clay lenses. The sub-surface water level in the wells ranges between 0.5–15 m b.g.l., with almost 90% wells having water level less than 10 m b.g.l.

Materials and Methodology

Data preparation: Instruments and Analytical procedures

152 sub-surface water samples were collected during the monsoon season and standard procedure for the collection of water

samples was followed (APHA, 1998). The entire area of 4,200 km^2 was gridded in 5x5 km^2 segments and from each grid, at least one sub-surface water sample was collected and analysed. Sampling locations were marked by a handheld GPS (Garmin GPSMAP 78S). Water samples were collected from various sources *viz.* bore, hand-pump and dug-well, between 5 to 10 m depth. 300 ml capacity bottles were used for collecting samples and each sample was stored in clean and colorless standardised (polytheneteraphalate) bottle. Before the collection of sample, the bottles were washed with HCL and rinsed with distilled water. All bottles were sealed properly with clearly marked sample ID. Various physico-chemical parameters such as electrical conductivity, pH, temperature etc. were determined on field by a portable instrument (Hanna-make, HI 98129). Within two days after sample collection, chemical parameters were analysed. For the determination of chemical parameters like calcium, sodium, lithium, and potassium, Esico Flame-Photometer (Model-1385) was used. Hanna-made Ion Selective Electrodes were used for the detection of fluoride (HI4110), Elico Double Beam UV/VIS Spectrophotometer (Model S1-210) was used for the determination of iron. All the laboratory work was performed at the Department of Geography, The Maharaja Sayajirao University of Baroda.

Data analysis

Descriptive statistical analysis was performed for all the variables of sub-surface water data. Kaiser–Meyer–Olkin (KMO) and Bartlett's test were performed in SPSS version-19 (IBM). KMO is a measure of the adequacy of a sample to indicate if the variables can be grouped into a small number of underlying factors. Similarly, Kolmogorov–Smirnov statistics was used to test the goodness of fit of the dataset to normal distribution. Statistical significance was accounted when the p-value was between <0.05 and <0.01. Descriptive statistical analysis was used to find out the interrelationship between the variables. For this study, Radial Basis Function method was used in ArcGIS platform to visualise the data, which identifies the physico-chemical function in the study area. For spatial representation of the results, ArcGIS 10.2 software was used.

Result and Discussion

Physico-chemical characterisation of Sub-surface water

Table 1 represents the results of physico-chemical parameters which were statistically analysed. These results were compared with the reported values by the Bureau of Indian Standards [Bureau of Indian Standards (BIS), 2012].

In the studied monsoon season, the pH of sub-surface water varied from 6.89 to 8.47 with an average value of 7.52 and a low standard deviation of 0.31, indicating that the water is mildly alkaline. Skewness and kurtosis exhibited low positive values of 0.43 and 0.08, respectively. The pH value of the sub-surface water in the central region was found between 7.5 and 8. pH >8 was observed in small patches at Mangrol and Roza Tankaria villages in Bharuch district (Fig. 2).

During the study period, the maximum temperature was 33.3°C and minimum temperature was 25.6°C. The mean and standard deviation values were 28.85°C and 1.17°C, respectively. Skewness and kurtosis indicated low and positive values of 0.46 and 0.84, respectively. The higher temperatures were observed at Vagra tehsil and near Kosamba village, while the lower temperatures were found at the western part of the study area (Fig. 3).

The average salinity distribution was 1.08

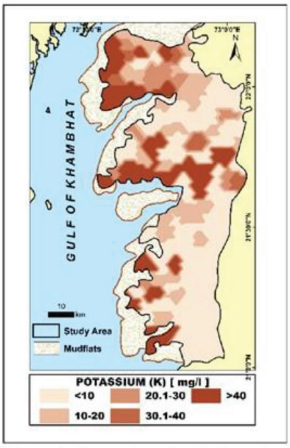


Figure 8. Potassium distribution of sub-surface water (Monsoon, 2016)

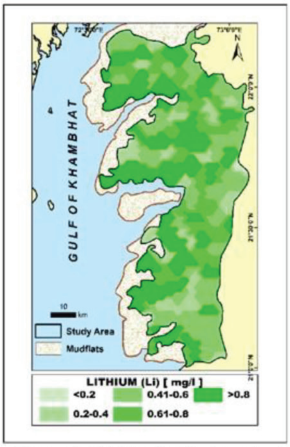


Figure 9. Lithium distribution of sub-surface water (Monsoon, 2016)

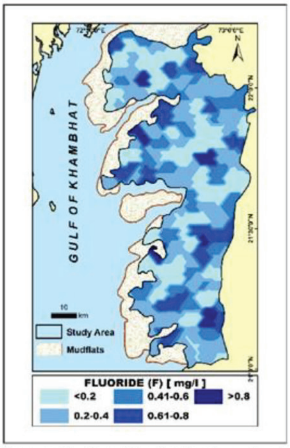
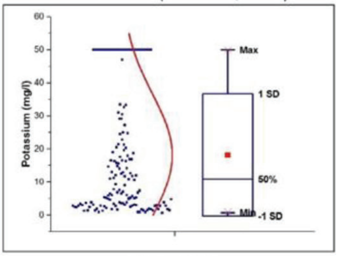


Figure 10. Fluoride distribution of sub-surface water (Monsoon, 2016)



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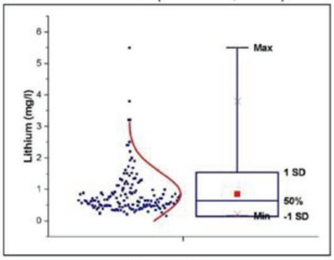

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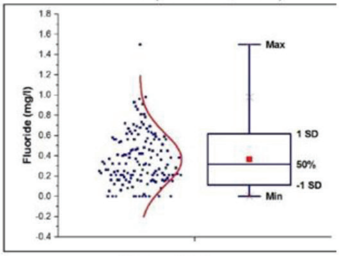

Figure 10.1

during the study period. The salinity varied between 0.09 to 8.83 psu with a standard deviation of 1.31. The concentration of salinity was low in range throughout the space. Skewness value (3.67) depicted positive skewness. Kurtosis value (16.70) denoted the peakedness of the curve. The higher salinity concentration was observed in the north-western part and a few patches in southern segment of the study area (Fig. 4).

The electric conductivity ranged between 0.2 mS cm^{-1} and 17.0 mS cm^{-1}, having a mean value of 2.24 and standard deviation of 2.51. Skewness and kurtosis showed very high and positive values of 3.44 and 14.91, respectively. The value of kurtosis depicted high peakedness, explaining the higher standard deviation and positive skewness (Fig. 5).

In the study area, the mean calcium concentration in sub-surface water was 124.51 mg l^{-1}. The standard deviation was 58.04, indicating a wide range of concentration throughout the area. The concentration of calcium varied from 37 to 250 mg l^{-1}. This distribution had a positive skewness value of 1.09 and presented an asymmetric tail to the right of the median. Kurtosis showed a low value of distribution (0.38). The higher concentration of calcium was observed in a continuous patch in the northern and south-western parts of the study area (Fig. 6).

The range of sodium concentration was between 9.8 mg l^{-1} and 400 mg l^{-1}, which was slightly higher than WHO standard (200 mg l^{-1}). The mean concentration was 211.95 mg l^{-1}, with a very high deviation from the mean (104.45 mg l^{-1}). Skewness and kurtosis showed negative and low values (–0.44 and –1.12, respectively). Kurtosis indicated that the distribution had lighter tails and a flatter peak than normal distribution, while skewness denoted tail extending towards the left. Sodium concentration was largely found

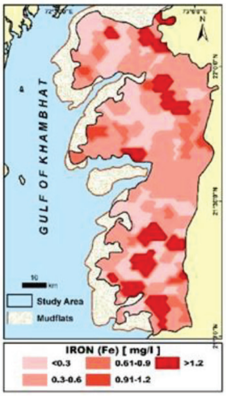

Figure 11. Iron distribution of sub-surface water (Monsoon, 2016)

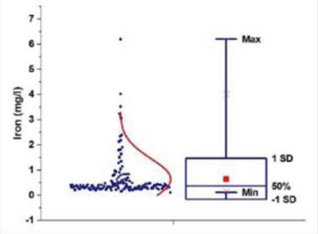

Figure 11.1

in the northern part and from central portion to the southern region of the area (Fig. 7).

The concentration of potassium varied between 0.67 to 50.0 mg l^{-1}. The mean concentration was 18.18 mg l^{-1} and the deviation from mean was 18.45 mg l^{-1}, indicating clustering of data set around the mean value. Skewness was positive (0.88), indicating a moderately skewed distribution. Kurtosis had a negative value of –0.83. Potassium was widely spread in the north-western part of the region with considerably higher value, while the rest of the area showed low concentration of potassium (Fig. 8).

The lithium concentration during monsoon season varied between 0.16 and 5.50 mg l^{-1}. The standard deviation was 0.70 mg l^{-1}, indicating a very small variation in the concentration. Highly skewed and positive values of skewness (3.30) and kurtosis (15.24) depicted a heavy tail. Higher concentration of lithium were found in the western part of the study area, which has gradually decreased in the eastern segment (Fig. 9).

The mean value of fluoride concentration was 0.36, with the range from BDL to 1.50 mg l^{-1}. The standard deviation was 0.25, showing low concentration range throughout the space. The Skewness value (0.96) depicted positive skewness, while Kurtosis (1.65) denoted the peakedness of the curve.

Table 2. Rotated Component Matrix

Variables	Component		
	1	2	3
EC	**.943**	.112	.008
Salinity	**.937**	.089	.001
Lithium (Li)	**.906**	–.085	–.121
Calcium (Ca)	**.834**	–.001	–.164
Sodium (Na)	**.558**	.385	.352
Temperature	.110	**.764**	.173
Iron (Fe)	.062	**.629**	–.348
Potassium (K)	.528	**–.537**	–.041
pH	–.066	.024	**.789**
Fluoride (F)	–.047	–.025	**.680**

Extraction method: Principal Component Analysis.
Rotation method: Varimax with Kaiser normalisation. Rotation converged in six iterations.
Significant loadings are in boldface

Table 3. Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.915	39.149	39.149	3.915	39.149	39.149	3.896	38.956	38.956
2	1.51	15.104	54.252	1.51	15.104	54.252	1.445	14.451	53.407
3	1.318	13.178	67.43	1.318	13.178	67.43	1.402	14.023	67.43
4	0.839	8.39	75.82						
5	0.79	7.905	83.725						
6	0.662	6.625	90.349						
7	0.531	5.308	95.657						
8	0.28	2.797	98.454						
9	0.154	1.54	99.994						
10	0.001	0.006	100						

The concentration of fluoride was observed in small isolated pockets of the entire study region. In the central part of the region, the concentration of fluoride was relatively less (Fig. 10).

Factor Analysis

Factor Analysis is a multivariate statistical analysis tool which determines the interdependence amongst the data sets and reduces the data dimension without losing any original information (Liu *et al.*, 2003). In this method, the original variables are rearranged with the help of a correlation mattrix. Further, a group of similar variables was constructed and a new set of related factors was produced. The PCA method was used for the extraction of factors from the covariance matrix. The number of factors were retained on the basis of 'Kaiser Criterion', where only more than 1 component of eigen values were taken for further interpretation (Davis, 1986; Reyment and Joreskog, 1993). The varimax rotation method maximises the variance in each factor and gives better explanation of variables. In addition, communalities of each single parameter was calculated and the percentage of variance was estimated (Kaiser, 1960; Vega *et al.*, 1998). Higher percentage of variance indicates high communality of the data, whereas, low communality reveals less importance of variable in the dataset. Lastly, factor scores were computed for each variable (Liu *et al.*, 2003) and they were plotted on the map to understand the geographical distribution. The entire factor analysis technique explains the grouping of larger number of variables into smaller ones (Ghosh and Kanchan, 2014).

Factor Loading Interpretation

In the present study, the factor analysis was performed on 10 variables and factor scores were analysed from normalised datasets. Thereafter, significant factors were identified. The factor extraction was done by minimum acceptable eigen values that exceed 1.0 (Kaiser, 1958; Kim and Mueller, 1987).

Three significant factors were extracted using varimax rotation with eigen values more than 1, explaining 67.43% of the total variability of the data (Table 3). High factor loading in Factor 1 was noted in electrical conductivity (0.943), salinity (0.937), lithium (0.906), calcium (0.834) and sodium (0.558). It accounted for 38.96% of the total variation amongst the samples. Factor 2 had 14.45% of variance with higher positive loadings on temperature (0.764), iron (0.629) and potassium (-0.537). Third factor had 14.02% variability within the dataset. It depicted positive loadings on pH (0.789) and fluoride (0.680). Factor loadings of the three factors of the data set are listed in Table 2.

Inter-factorial Relationship

A group of interrelated variables (factors) extracted from the factor analysis is widely used for understanding the importance of each of the factors, and also their interdependence between them through scatter plot. Factor 1 retains electrical conductivity, salinity, lithium, calcium, sodium, and all the parameters showed high positive loadings. Similarly, factor 2 having temperature, iron and potassium (as shown in Fig. 12.1) also reflect high positive loadings. Positive loadings of (factor 1) electrical conductivity,

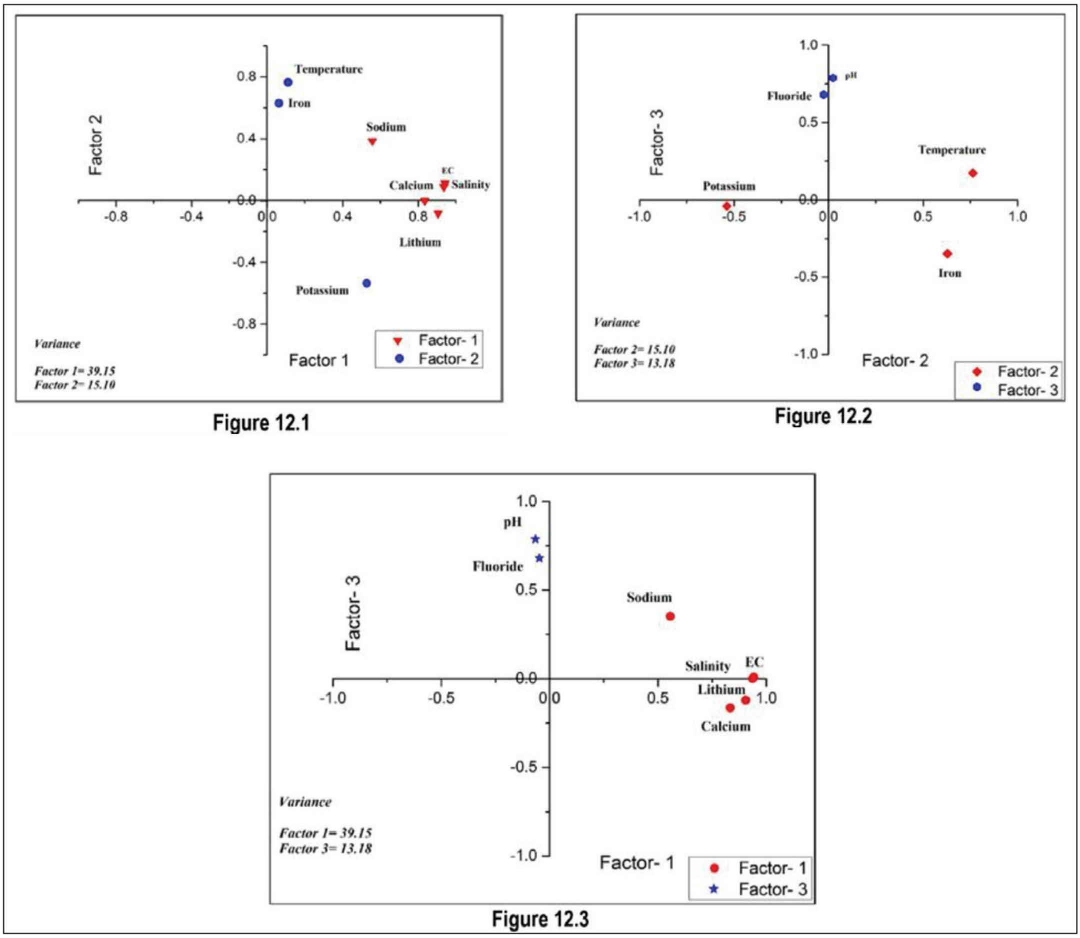

Figure 12. Interfactoral relationship. 12.1: factor 1 and factor 2; 12.2: factor 2 and factor 3, 12.3: factor 1 and factor 3.

salinity, calcium and sodium indicate a relationship with temperature and iron (factor 2). The negative loading on potassium and lithium indicated inverse relationship between the two factors (factors 1 and 2).

Positive loadings on both factor 1 (Electrical Conductivity, salinity, sodium) and factor 3 (pH and fluoride) showed strong control on both the factors (Fig. 12.3). Between factor 2 and factor 3, their was a positive loading between fluoride and pH on temperature and inverse relationship was noted between Iron and potassium (factor 2) with pH and fluoride (factor 3) (Fig. 12.2).

Factor Categorisation

In factor 1 scores distribution (Fig. 13), high positive loadings were found on electrical conductivity, salinity, lithium, calcium and sodium, which were noticed in the northern part of the study area and in small pockets of south. Therefore, factor 1 can be controlled by the seawater intrusion. It is due to overexploitation-induced lowering of sub-surface water table and mixing of seawater and freshwater, hydrochemistry of the region was stimulated (Gastmans *et al*,. 2010; Rina *et al.*, 2013; Upadhyaya *et al.*, 2014). High factor 1 score was more pronounced on the eastern banks of Dhadhar and Tapi rivers. The higher concentration was observed at the confluence of sea and river.

Influence of seawater intrusion on sub-surface water increases the elictrical conductivity and salinity concentration in the coastal region, which is confirmed in Fig. 13. The lower factor scores are more pronounced towards the south-western part.

Fig. 14 represents factor 2, which is mainly related with three elements *viz.* temperature, iron and potassium. The high positive scores of the three elements were observed in the north-western part and in small pockets of south, while low scores were observed along the Gulf of Khambat. The association of iron and potassium reflects the influence of geological formations (Saha *et al.*, 2018) whereas the temperature is mainly controlled by the local atmospheric conditions (Saito *et al.*, 2016).

Central part of the region is mainly dominated by factor 3. Higher positive

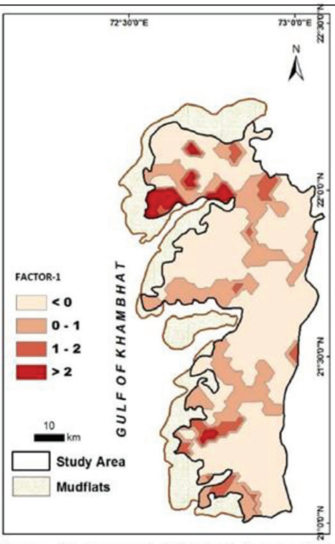

Figure 13. Factor 1 (Elictrical Conductivity, Salinity, Lithium, Calcium & Sodium) score distribution of sub-surface water (Monsoon, 2016)

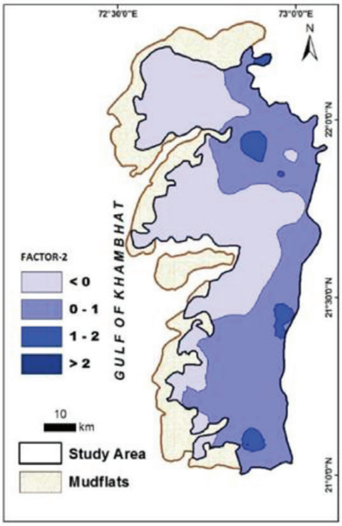

Figure 14. Factor 2 (Temperature, Potassium & Iron) score distribution of sub-surface water (Monsoon, 2016)

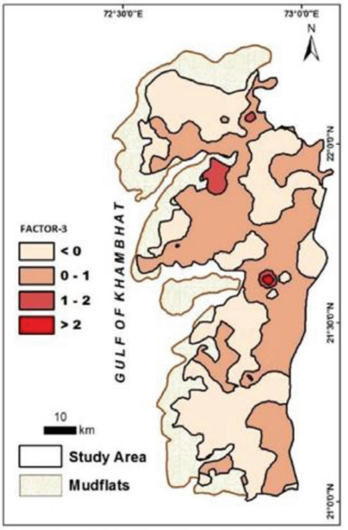

Figure 15. Factor 3 (pH & Fluoride) score distribution of sub-surface water (Monsoon, 2016)

loading of pH and fluoride were found in the north-central part of the study area (Fig. 15). The pH of water influences chemical reactions and biological processes in the groundwater (Ghosh and Kanchan, 2014). The increase in the fluoride of sub-surface water samples might be due to the high amount of soluble and insoluble fluoride in source rocks. The other causes may be the contact duration of water with rocks, soil temperature, rainfall, and oxidation-reduction process (Paya *et al.*, 2010).

Conclusion

In the study area, the sub-surface water quality is controlled by salinity, calcium, sodium and iron ions. The pH values reveal alkaline to slightly acidic soil character. The concentrations of iron and sodium were little higher than the standards. Based on the factor analysis and spatial distribution, seawater intrusion and hydro-geological factors are two main responsible processes for changing the chemical composition of sub-surface water along the Gulf of Khambat, Western Gujarat.

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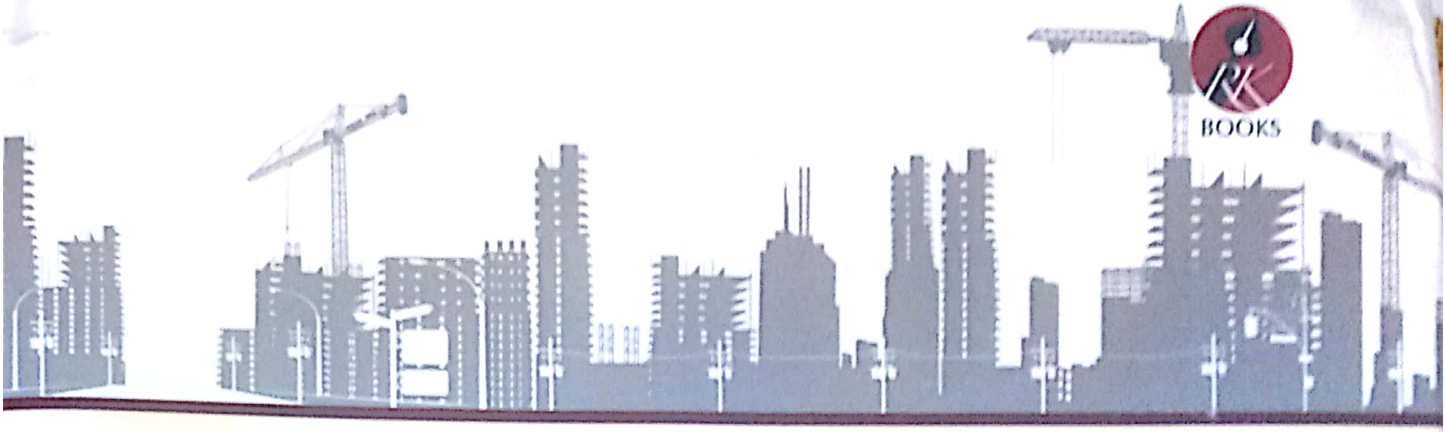

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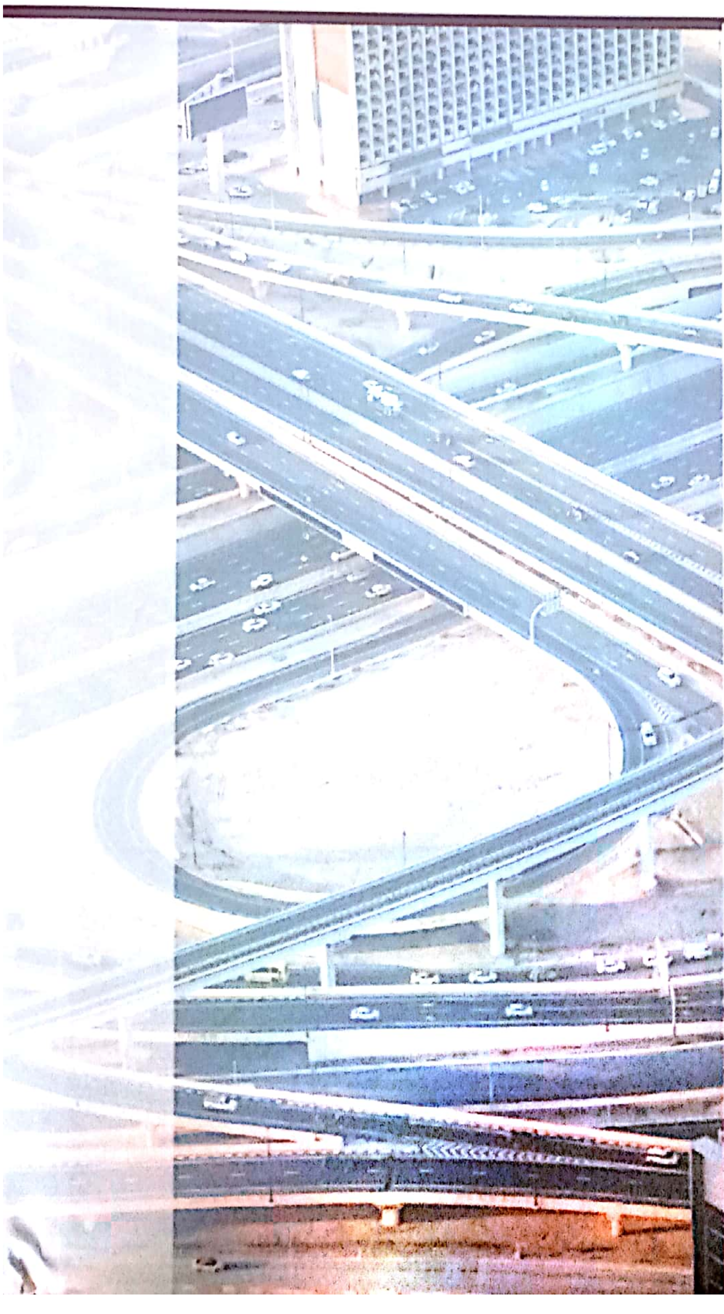

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Physico-chemical Appraisal of Sub-surface Water Characteristics in the Coastal Urban Industrial Belt of Mainland Gujarat, India

Rolee Kanchan, Tathagata Ghosh,
Sukanta Kumar Saha and Somnath Saha

Introduction

Among all the available resources on this earth, fresh water has immense significance from the very beginning of human civilization. Dependency on the fresh water has increased for different purposes like agriculture and drinking etc. throughout the time period. It has been observed that water is always associated with the different natural and anthropogenic effects (Shrestha and Kazama, 2007). In several instances it was observed that anthropogenic (urban, industrial and agricultural activities) as well as natural processes (weathering and erosion of the rocks) degrade the quality of it and restrict its uses (Simeonov et al. 2003). As far as its very limited availability is concerned, scientists from different field of sciences tried to address the issue and also focused on probable remedy of it both in terms of quality and quantity. Mair et al. (2013) worked on the groundwater recharge characteristics on Jeju island of Korea in terms of spatial and aspects. In the study the ten years drought condition was depicted from the historical precipitation trend and the other parameters like climate-landused change scenario was selected on the basis of 21st century climate projections. The result showed the fact that the as fraction of mean annual rainfall, recharge was only 42%. On the other hand researchers like Ghosh and Kanchan (2014) focused on the different physico-chemical parameters of groundwater to evaluate the groundwater characteristics in the Bengal alluvial tract by using geo-statistical techniques. In the study it was found that, eastern portion of the study area showed higher level of contamination than the western portion. Simeonov et al. (2003) discussed about the impact of excessive withdrawal of groundwater and also depicted its consequences in terms of groundwater level. Ghosh and Kanchan (2011, 2012) also worked on the similar line of thinking in the thick unconfined aquifer of alluvial tract of Bengal, India.

Kazakis and Voudouris (2015), Ghosh and Kanchan (2016), Napolitano and Fabbri (1996) were mainly concerned with the preparation and application of the groundwater vulnerability models to depict the groundwater contamination zones as well as the safe zones using number of hydro-geological parameters. Hosono et al. (2009) discussed about the impact of anthropogenic activates on the groundwater flow in the South Korea by using number of isotopes. Groundwater composition in an alluvial aquifer by using principal component analysis was performed by Helena et al. (2000). On the basis of the results, the groundwater was characterized as natural and saline. In the study it was concluded that, where groundwater characterized as natural was attributed to the natural mineralization during recharge while saline water attributed to contamination due to leakages from sanitary system. Geochemical characteristics were analyzed by Stuben et al. (2003) in the Murshidabad district of West Bengal. In the study the authors included the statistical analysis like principal component analysis. Scholars like Giridharan et al. (2008) and Yammani et al. (2008) put emphasis on the seasonal variability of groundwater quality in part of Chennai and Andhra padesh respectively. Oinam et al. 2011 depicted spatial and temporal pattern of groundwater quality in the Manipur state using cluster analysis. Different physico-chemical parameters were incorporated in the study. Kannel, Lee and Lee (2008) evaluated spatio-temporal pattern of both surface and subsurface quality in Nepal by using number of physico-chemical parameters. In the study it was found that in several places groundwater levels are lower than the consequent surface water levels and these regions were considered to be vulnerable in terms of contamination. Upadhyaya et al. (2014) worked on the number of heavy metals and boron contamination in the groundwater of Gulf of Khambhat region of Gujarat. As the study was associated with the temporal aspect, it was observed that, majority of the metals enters in to the region during monsoon season. It was concluded that, Co, Cu, Cd and Zn were interrelated to each other and anthropogenic influence was there while Pb and Cr are those heavy metals that enters through the atmospheric deposition in the study area. Das, 2003 worked in the Cuttack City of India. In this study also several geochemical parameters were taken in to considerations and spatio-temporal variations were analysed.

The present is study focused in the southern part of mainland Gujarat near the gulf of Khambhat covering major portion of district of Bharuch and Surat which are considered to be fast growing industrial hub. In the last few decades the entire region has experienced a rapid rate of industrial development. Thus it is necessary to evaluate the quality of sub-surface water and find out if any significant relation could be established. In this study major focus was on the characteristics of physico-chemical parameters of sub-surface water.

Study Area

The present study area is located in the mainland of Gujarat adjoing Gulf of Cambay, Gujarat, India. It covers the districts of Bharuch and Surat. The entire area covers almost 5000 km^2 area. Narmada and Tapi are two major rivers that flow from east to west and drains into the gulf (Fig. 1). The coastal area of the region is associated with mudflats and salt pans and dotted with mangroves. The average temperature ranges between 20.7°c to 33.9°c (CGWB, 2013). Physiographically entire region is divided into division like the high relief, piedmont zone, alluvial plain and coastal area. Groundwater potential is relatively higher in the western portion of the study area. In the northern portion the soil type is mainly associated with sandy, saline and alkaline soil whiles in the southern segment the dominance of saline light coloured soil and black cotton soil are found. In the recent decades, the entire region is experienced and enhanced rate of industrialization. The number of industrial

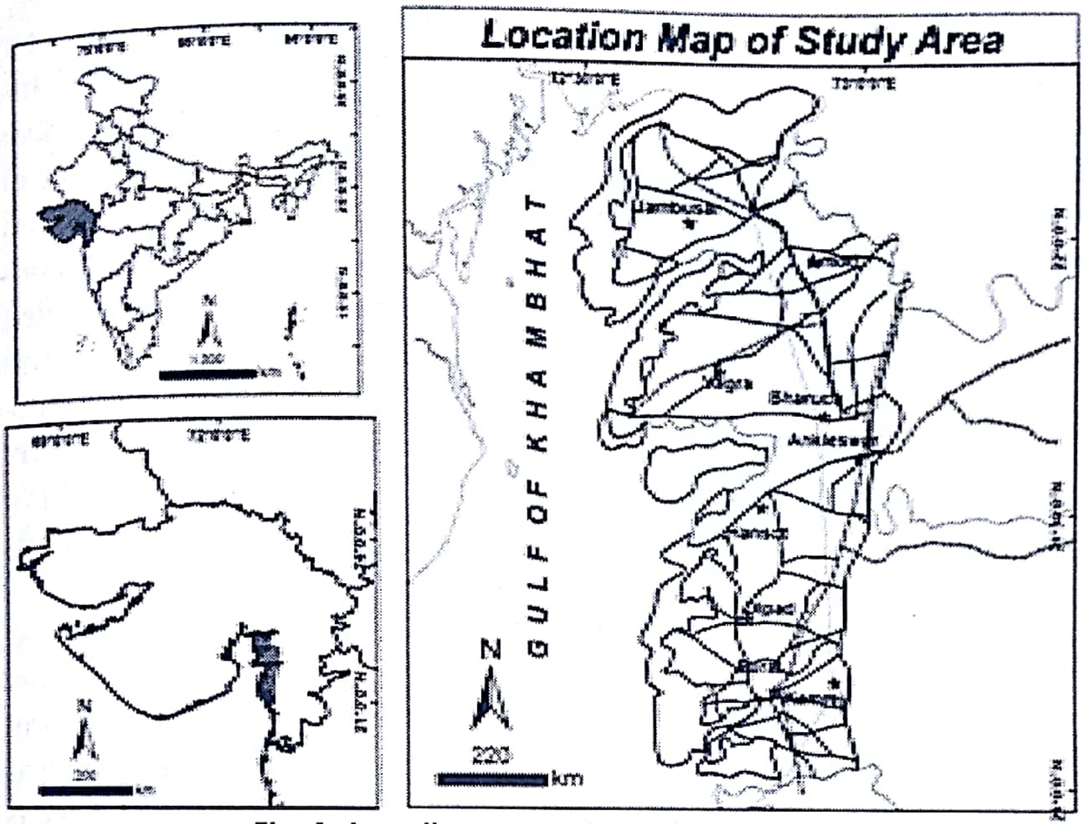

Fig. 1: Location map of the study area

zones engaged are Vagra, Jambusar, Bharuch, Ankleswar; Olpad And Hazira in Surat amount are some of them. Companies like Gujarat state petroleum corporation limited, National thermal power corporation, Ankelswar; Gujarat Industrial Development Corporation (GIDC), Jambuswar staling economic zone are some of the important companies which are associated with chemicals, petrochemicals, polymers, polyester, fiber etc. The entire study area is well connected with the NH-8 and number of district highways as well as railway lines (District Census Handbook, Bharuch, 2001; District Census Handbook, Surat, 2001).

Methodology

Initially the entire study area was digitized in the GIS environment and divided into 5 km^2 area grids. From each of the grid, one sub-surface water sample was collected where most of them were related to hand pump bore wells and dug wells. This made a total 163 sampling sites during post monsoon season of 2015. All of the samples were collected in PET (polyethylene terephthalate) bottles. Before collecting samples from hand pumps, they were rigorously pumped for 1 min to then clean the internal portion pipe.

After collection of the samples they were acidified with HCl and retained under cold condition pH, electrical conductivity and Temperature parameters were determined on the field through the digital pH meter (Hanna make, Model No. HI-9827), electrical conductivity meter (Hanna make, Dist 4, Model No. HI 98303) and digital temperature meter (Eurolab make, pen type). The samples were analysis for major ions like calcium, sodium, potassium and Lithium by using flame photometer (ESICO Mod.1385) by using standard methods prescribed by APHA 2005. All of the obtained results were incorporated into the GIS environment for preparation spatial distribution maps using Arc GIS 10. Further, statistical analysis like descriptive statistics, correlation analyses factor analysis was performed in statistical package like SPSS 19.

Factor analysis is an important statistical tool whose main objective is to reduce the dimension of the entire dataset without compromising any data. Principle component analysis method was adopted in the factor analysis. Eigen values were extracted using Kaiser critarion and all the values >1 was retained whereas < 1 were ignored. During the operation, varimax rotation was applied on the data set to maximize the variation.

Results and Discussion

Descriptive Statistics: The present study was associated with 163 subsurface water samples. Temperature (°c) was as high as 33.3 °c with the mean of 29.4 °c where the SD shown a lower value of 2.61 which indicated the fact that the entire region was associated with the temperature with less variability. The level of Na ranged between BDL (1 mg/l)- 300 mg/l with mean of 139.35 mg/l and relatively higher SD (94.67). The next parameter was potassium, where the concentration widely varied from BDL (1 mg/l) to 909 mg/l with relatively lesser mean (23.3 mg/l) and higher SD 95.86. The level of calcium ranged between BDL (20 mg/l) to 155 mg/l with a lower mean of 45.46 mg/l and 26.21 as SD. The level of lithium was varied between a small range of 45.46 mg/l and 26.21 as SD. The level of lithium was varied between a small range of BDL (.5 mg/l) -1.46 with low mean and low SD. (0.11 mg/l and 0.18 respectively) (Table 1). The level of pH ranged from BDL (2) to 8.5 which are alkaline in nature. The mean value was 7.03 with a low SD of 0.75. The level of EC ranged between BDL to 16.98 mS/cm and SD of 2.4. The salinity of entire of 9.12 psu with mean of 1.2 psu and SD of 1.25. In terms of skewness and kurtosis, extreme values are reflected in the results in all the parameters which gave a clear indication that there were significant variations in the entire region.

Table 1: Descriptive statistics of different parameters

	Na (mg/l)	*K (mg/l)*	*Ca (mg/l)*	*Li (mg/l)*	*pH*	*EC (mS/cm)*	*Temp (° C)*	*Salinity (psu)*
MEAN	139.36	23.04	45.47	0.11	7.03	2.71	29.40	1.29
Min	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Max	300	909	155	1.46	8.5	16.98	33.3	9.12
Standard Deviation	94.68	95.87	26.21	0.18	0.73	2.45	2.62	1.25
Skewness	0.51	8.29	1.38	4.59	-5.49	2.54	-8.78	2.77
Kurtosis	-1.00	71.46	2.66	27.78	52.23	9.42	99.38	11.37

BDL=Below detection limit, psu= practical salinity unit

Spatial Distribution of Different Parameters

The concentration of potassium showed a decreasing trend from west towards east. The concentration in the western most segments was higher. Similar kind of higher concentration was also observed in southern portion of the study area. Some smaller patches of higher concentration can also be observed in the central western portion (Fig.2). The concentration of calcium showed different pattern than the potassium. In the northwestern segment of the study area, >75 mg/l of calcium concentration was observed. Some smaller patches of higher concentration were found in the region. In the central southern portion of the study area also higher concentration was observed (Fig.3). The level of lithium showed relatively higher concentration throughout the space. Northwestern and southern portion of the study area showed higher concentration. The entire southern portion had 0.13mg/l to 0.18 mg/l concentration (Fig.4) of lithium. The level of Sodium showed higher concentration throughout the region. The level varied between < 80 mg/l to >200 mg/l. Number of patches of sodium with higher concentration (>200 mg/l) were found throughout the region. The north central region of the study area depicted higher level of sodium while in the northwestern and southeastern portion of the study area showed

Fig. 2

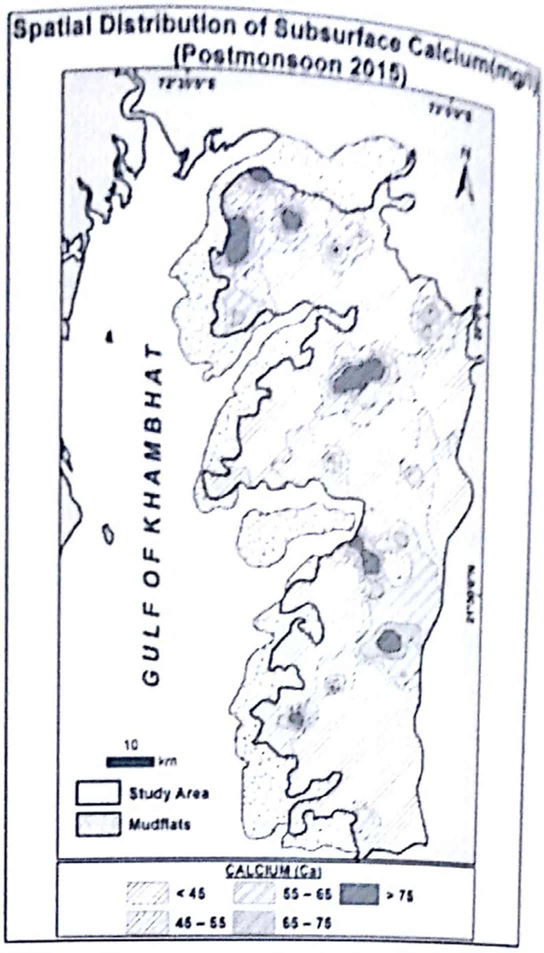

Fig. 3

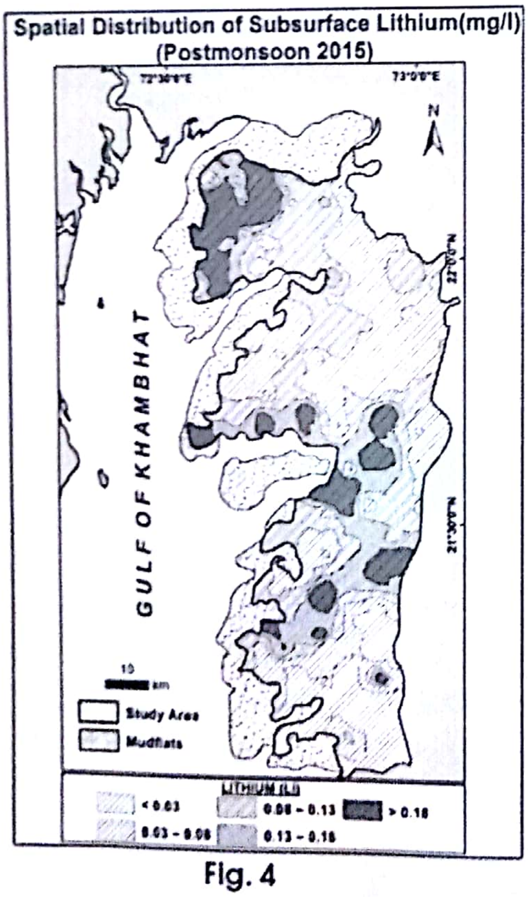

Fig. 4

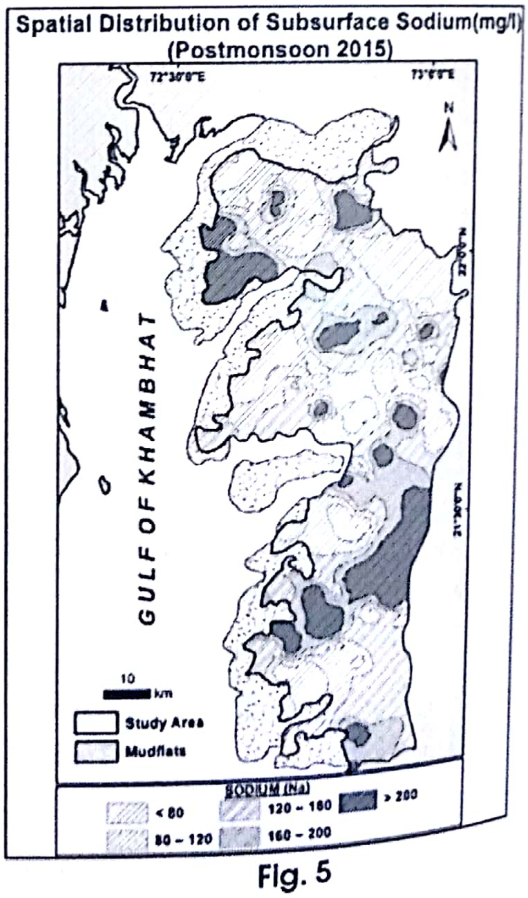

Fig. 5

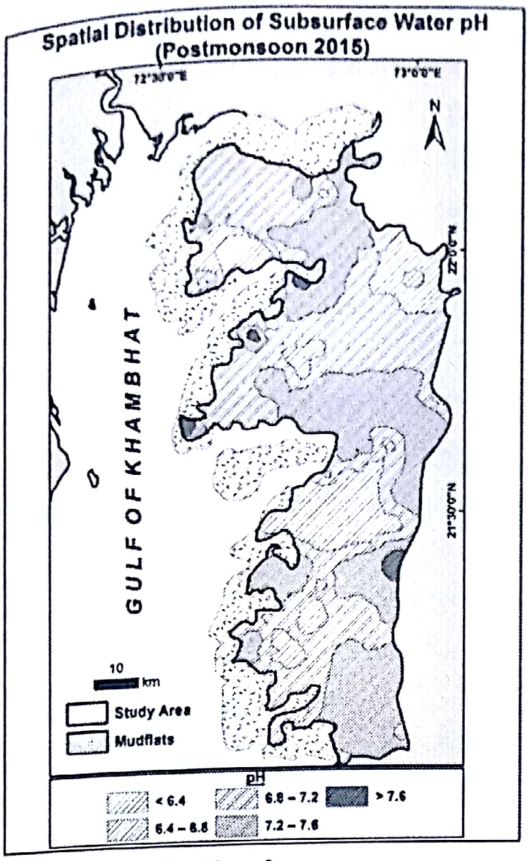

Fig. 6

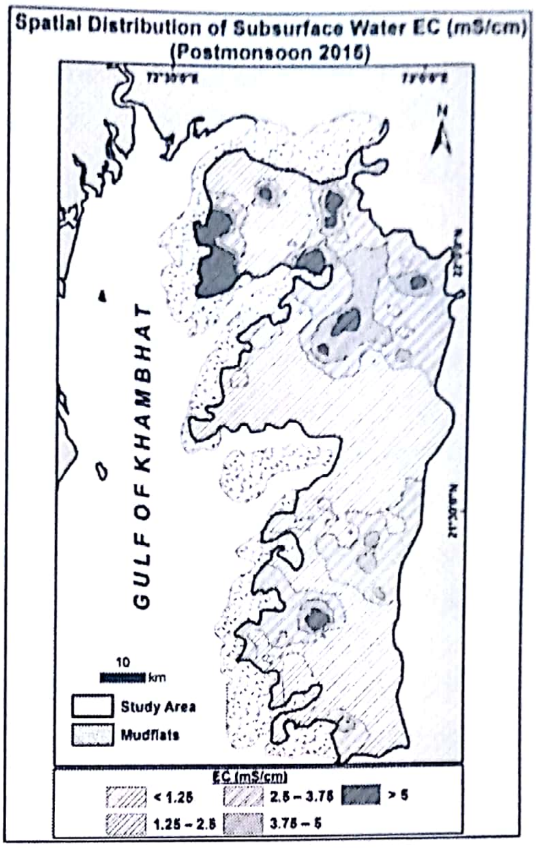

Fig. 7

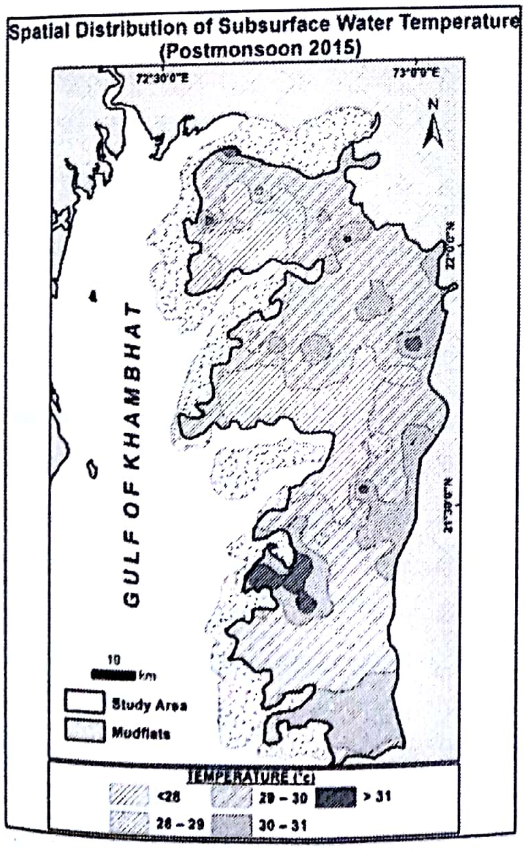

Fig. 8

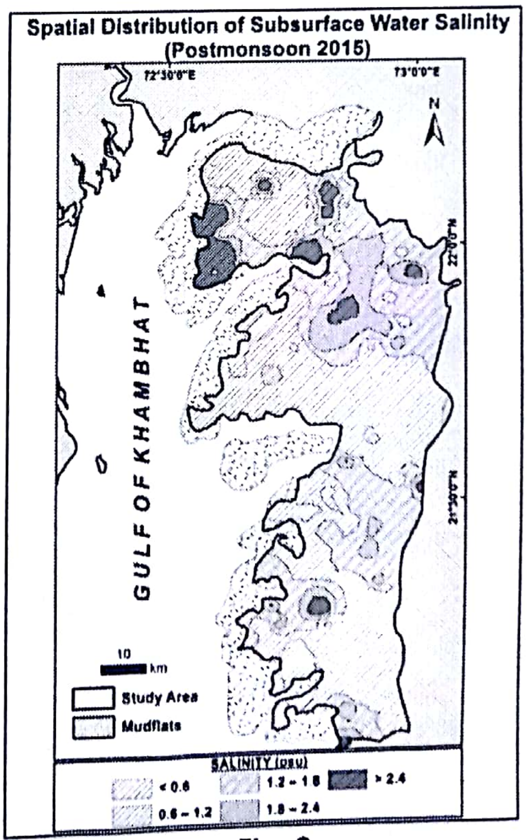

Fig. 9

relatively less level of sodium (Fig. 5). Majority of the region showed level of pH 6.8 to 7.6. Thus it can be said that, in the entire region the subsurface water was associated with slightly acidic condition to neutral type of water. Some of the patches of relatively higher pH (7.2 – 7.6) were observed. A small patch of higher pH was observed in the eastern and western portion. pH, <0.4 was found in the south central portion (Fig. 6). Other than a small portion in western segment the entire region showed pH value near to neutral that clearly depict the influence of slurces of surface water like rivers. The level of EC depicted relatively lesser concentration in the central and southern portion. In the northern segment of the region EC ranged between 2.5 to >5 mS/cm. Another patch of the higher level was also observed in the western part of region (>5 mS/cm). A small patch of higher level of EC was also found in the southern portion of the region (Fig. 7). The spatial distribution of temperature depicted varied condition throughout the space. The temperature varied between <28 °c to > 31 °c. The central most segment of the region showed lowest temperature while northern, eastern and southern portion showed relatively higher temperature. A patch of higher temperature was observed in the southern portion of the study area (Fig. 8). The level of salinity showed variable condition throughout the region the level of salinity of ranged between <0.6 to >2.4 psu. The salinity was relatively higher level in the northern portion of the study area. Smaller patches of higher salinity was observed In the northern south-central portion of the region. The salinity was relatively lesser in the central and southern portion of the region (Fig. 9).

Pearson Correlation

Pearson correlation is one of the elementary statistical tool that can be used where both independent and dependent variable are either in interval or ratio scale (David and Sutton, 2004). To understand the probable relationship between multiple parameters at the same time, correlation analysis is considered to be vital. In the present study also there were eight parameters and it is necessary to depict the relationship between the parameters. Multiple correlations among the parameters were performed and the following results were obtained. Some of the important relations were obtained from the result where correction value was more than

0.50. The correlation value between calcium and lithium was (0.59) while it was 0.54 in between calcium and sodium. At the same time parameter like pH and temperature depicted higher concentration (0.67) while EC salinity both depicted similar correlation value with sodium (Table 2).

Table 2 : Correlation matrix of sub-surface water parameters

	Na	*K*	*Ca*	*Li*	*pH*	*EC*	*Temp*	*Salinity*
Na	1							
K	0.05	1						
Ca	**0.54**	0.08	1					
Li	0.41	0.22	**0.59**	1				
pH	0.05	0.09	0.01	0.06	1			
EC	**0.57**	-0.01	0.40	0.44	0.01	1		
Temp	-0.03	-0.02	0.01	0.06	**0.67**	0.16	1	
Salinity	**0.57**	-0.01	0.39	0.44	-0.01	1.00	0.14	1

Boldfaces are statistically significant values (e" 0.5)

The parameters like lithium, sodium, EC and temperature showed correlation values which are nearer to the significance level (0.50) (ranges from 0.41 to 0.44) while in the case of correlation between parameters like pH and all other parameters showed very low correlation value.

Factor analysis

Factor analysis was performed on the entire data set for extraction of the factors. The extraction method was principle component analysis using Kaiser Criterion. The depicted Eigen values more than 1 were retained. During the process variances rotation with Kaiser Normalization. Result obtain from the analysis showed the fact that first three components depicted 75.07 % of variances of entire data set which is considered to be statistically significant. The scree plot also showed the same result where Eigen value of the first three components was above 1 (Fig.10). The table that showed the total variance explained (Table 3) depicted the fact that first component explained 39.79 % of the entire data set while 20.75 % of the entire data set was explained by the second

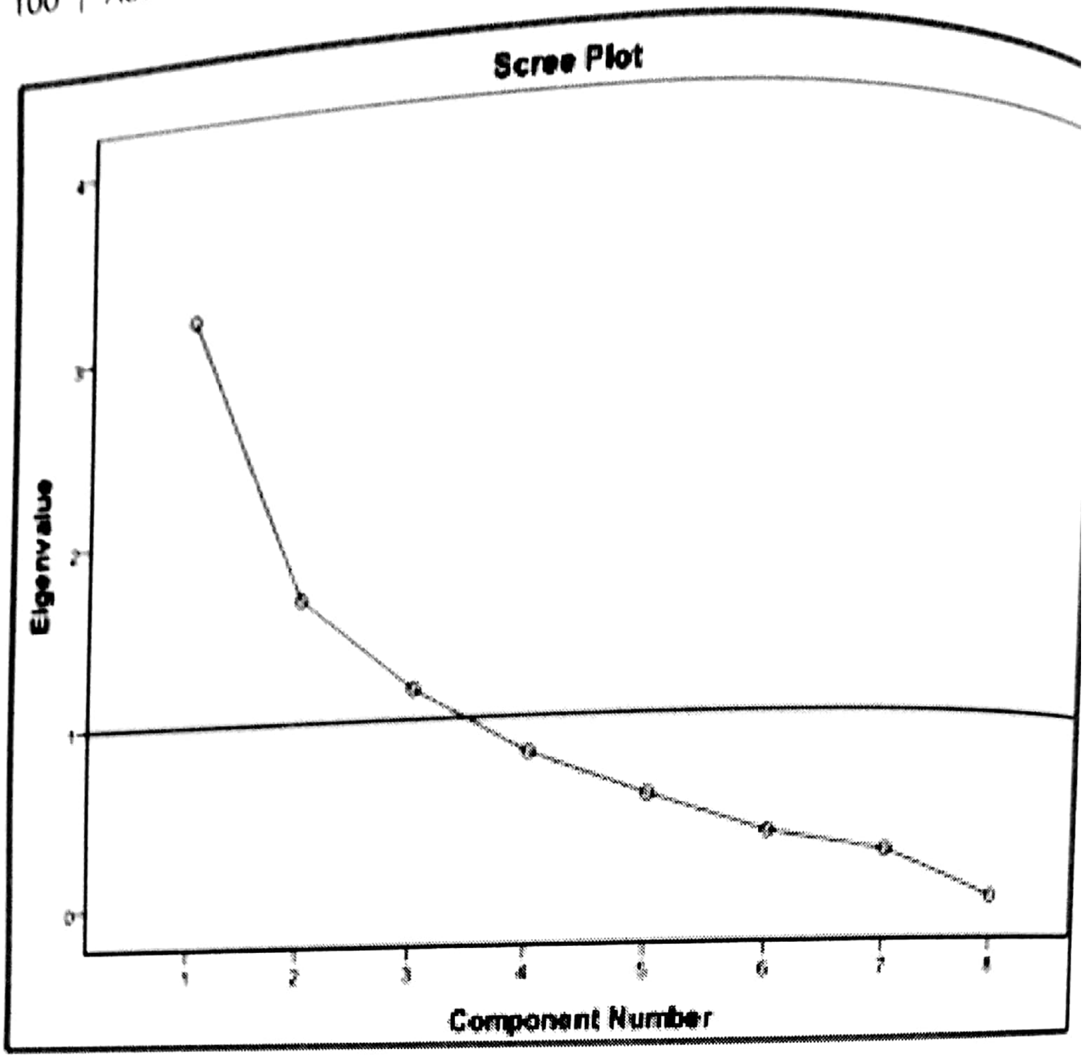

Table 3: Total Variance Explained

Component	Initial Eigen values			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.184	39.797	39.797	3.068	38.345	38.345
2	1.660	20.755	60.553	1.676	20.948	59.293
3	1.161	14.518	75.070	1.262	15.777	75.070
4	0.806	10.077	85.148			
5	0.569	7.116	92.264			
6	0.361	4.518	96.782			
7	0.255	3.188	99.970			
8	0.002	0.030	100.000			

Extraction Method: Principal Component Analysis.

Table: 4 Rotated Component Matrix[a]

Parameters	Component		
	1	2	3
Na	**0.753**	-0.038	0.179
K	-0.076	0.043	**0.818**
Ca	**0.629**	-0.047	0.446
Li	**0.598**	0.030	0.553
pH	-0.030	**0.905**	0.127
EC	**0.932**	0.085	-0.126
Temp	0.083	**0.916**	-0.077
Salinity	**0.930**	0.068	-0.129

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. [a] Rotation converged in 4 iterations.

component. In case of third component, it explained 14.51 % variances of the total data set. The rotated component matrix of the data set depicted the factor loadings where it was seen four components viz Na, Ca, Li and salinity with +0.75, +0.69, +0.59, and +0.93 respectively (Table.4). On the other hand, the second component was associated with pH and temperature. The factor loading of the parameters were +0.90 and +0.91 respectively. Finally the third component was associated with single component of K and the loading was +0.81. From the factor analysis it was observed that pH and temperature showed relatively higher factor scores and better relationship. On the other hand although the loading of K was higher but definite relationship with other parameters was not observed. In case of correlation also the same conclusion was there.

Conclusion

In the present study an attempt has been made to evaluate the characteristics of sub-surface water quality in the coastal industrial belt of south mainland Gujarat, comprising the districts of Bharuch and Surat. During post monsoon season of 2015, the samples were collected from the entire region and different physico-chemical parameters were analyzed and further statistical analysis were incorporated in the study along with spatial distribution of all the parameters. The result depicted the fact that the majority of the parameters showed wide variation in terms of the spatial distribution which clearly indicated the fact that the importance of the controlling factors. Further statistical analysis substantiated the results and also helped in depicting the probable association between the parameters.

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