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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

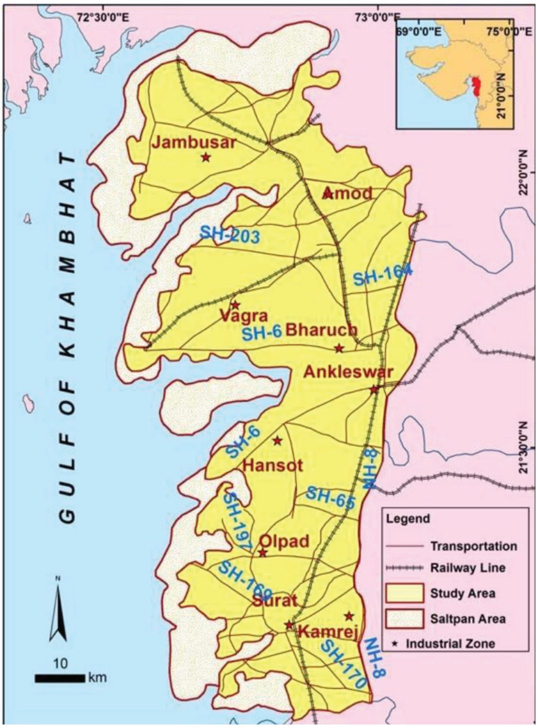


Figure 1. Location map of the study area

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

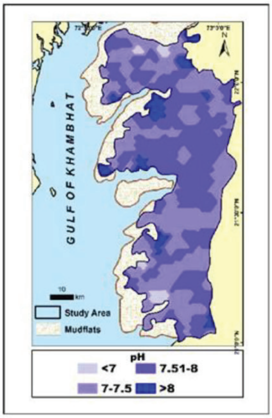


Figure 2. pH distribution of sub-surface water (Monsoon, 2016)

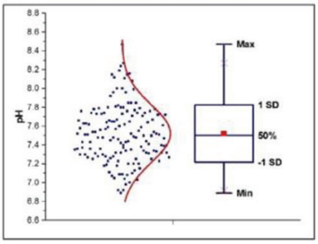


Figure 2.1

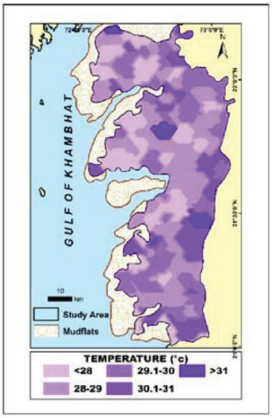
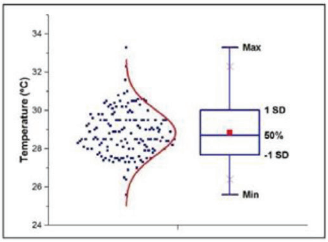


Figure 3. Temperature distribution of sub-surface water (Monsoon, 2016)



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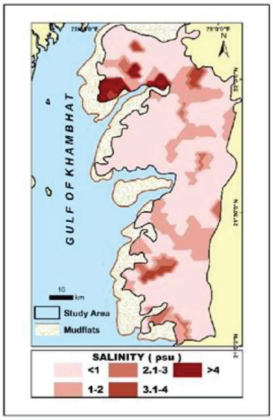


Figure 4. Salinity distribution of sub-surface water (Monsoon, 2016)

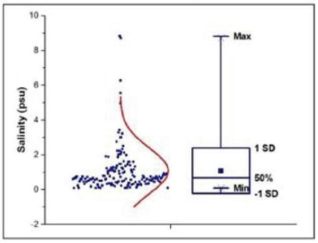


Figure 4.1

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.

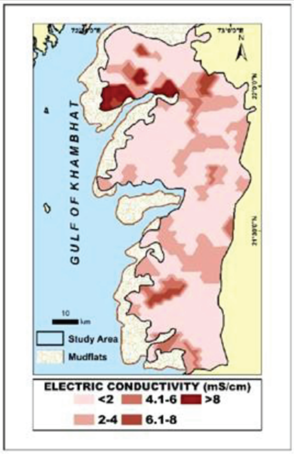


Figure 5. EC distribution of sub-surface water (Monsoon, 2016)

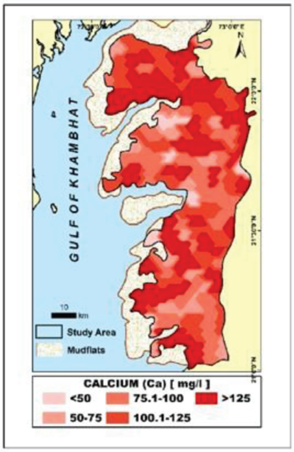


Figure 6. Calcium distribution of sub-surface water (Monsoon, 2016)

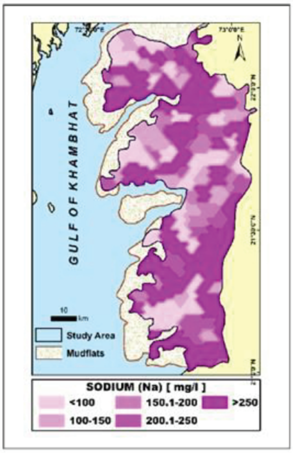
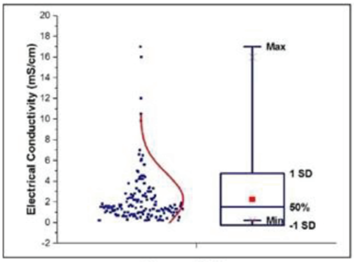


Figure 7. Sodium distribution of sub-surface water (Monsoon, 2016)



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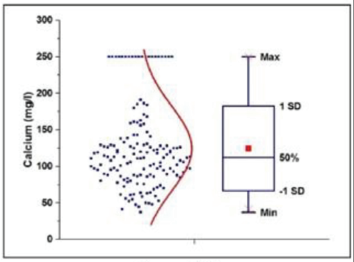

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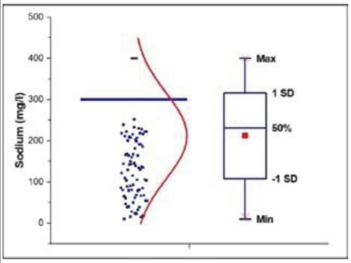


Figure 7.1

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

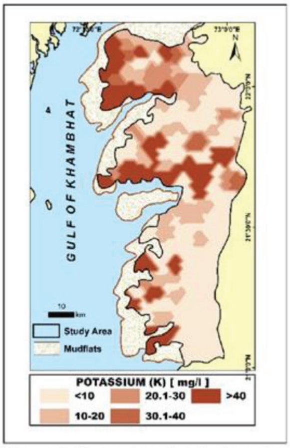


Figure 8. Potassium distribution of sub-surface water (Monsoon, 2016)

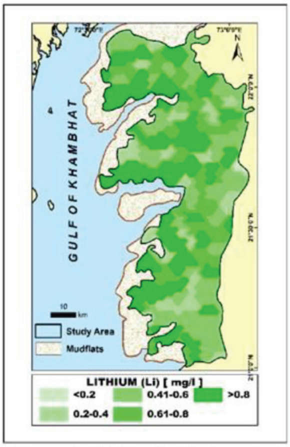


Figure 9. Lithium distribution of sub-surface water (Monsoon, 2016)

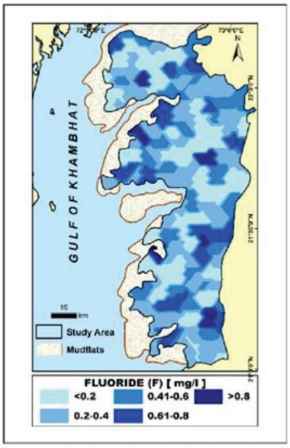
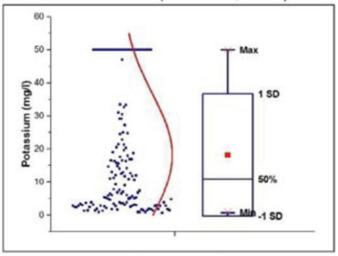


Figure 10. Fluoride distribution of sub-surface water (Monsoon, 2016)



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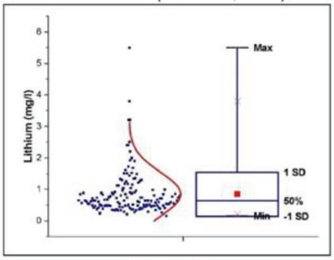

Figure 9.1

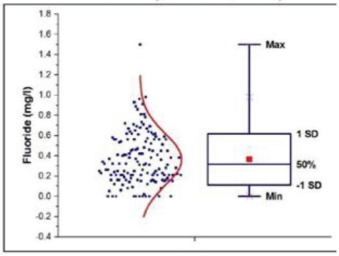

Figure 10.1

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 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.

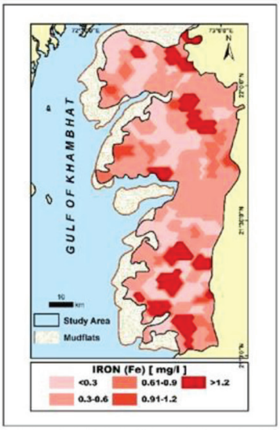

Figure 11. Iron distribution of sub-surface water (Monsoon, 2016)

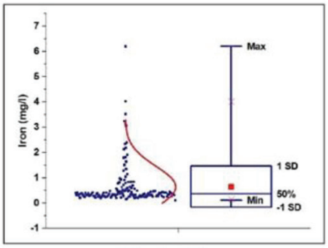

Figure 11.1

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,

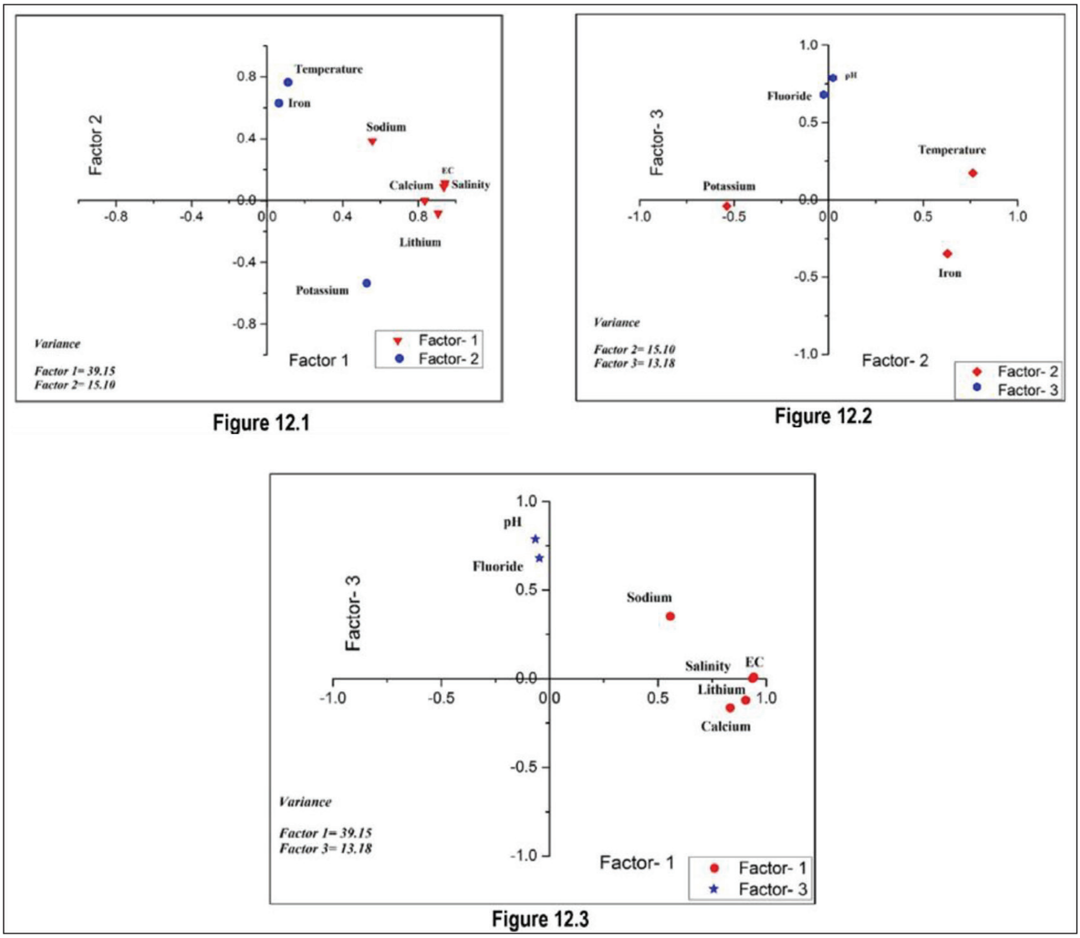

Figure 12. Interfactoral relationship. 12.1: factor 1 and factor 2; 12.2: factor 2 and factor 3, 12.3: factor 1 and factor 3.

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

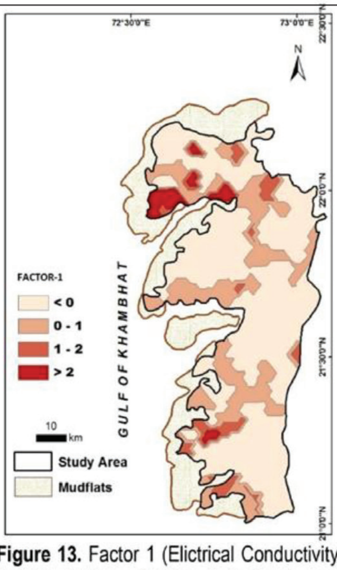

Figure 13. Factor 1 (Elictrical Conductivity, Salinity, Lithium, Calcium & Sodium) score distribution of sub-surface water (Monsoon, 2016)

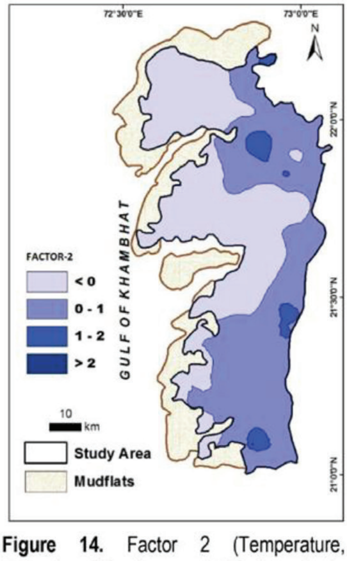

Figure 14. Factor 2 (Temperature, Potassium & Iron) score distribution of sub-surface water (Monsoon, 2016)

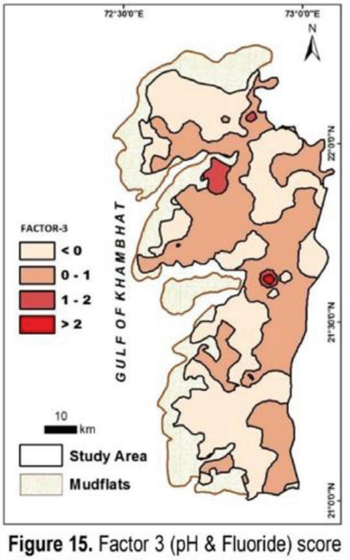

Figure 15. Factor 3 (pH & Fluoride) score distribution of sub-surface water (Monsoon, 2016)

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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