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SUB-SURFACE WATER QUALITY ASSESSMENT USING GIS TECHNIQUES IN SURAT-BHARUCH INDUSTRIAL REGION, GUJARAT, INDIA

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Abstract

Sub-surface water is essential for drinking, industries, irrigation and other domestic purposes. Demand for the sub-surface water is continuously increasing due to population growth which leads to over exploitation of water. The over-usage and industrial effluents may affect the quality of sub-surface water. The present study focuses on Surat-Bharuch industrial region that lies on the eastern flank of the Gulf of Khambhat, Gujarat. Based on 138 sub-surface water samples, collected from the region in May-June 2017, spatio-temporal analysis was undertaken. Physio-chemical parameters like pH, TDS, Calcium (Ca2+), Sodium (Na+) and Fluoride (F-) were analysed and a descriptive analysis was performed. Further, a mathematical model in terms of WQI was generated. WQI indicated that 7.97% of sub-surface samples were excellent for drinking, 15.94% were very good, 16.67% were good, whereas 14.49% were poor and 44.93% were unfit for drinking. The WQI classification shows that a significant part of the region had poor water quality making it, unfit for drinking.

Keywords: Sub-surface Water Quality, WQI, Spatial Distribution, Geographic Information System.

Introduction:

Sub-surface water is the most valuable resource on the earth and is currently of global concern (Villeneuve et al., 1990; Isa et al., 2012). It plays a significant role in water supply, ecosystem functioning and human well-being (Sheikhy Narany et al., 2014). Sub-surface water is one of the essential natural resources which have extensive usages. This resource is either inadequate or plenteous at times and is always very unevenly distributed, both over space and time. It is utilised for domestic, industrial and agricultural purposes. Its usage has recently increased and in the long run the trend would continue.

The physical and chemical composition of surface and sub-surface water changes throughout time and over space. It depends on factors such as atmospheric precipitation, in-land surface water, geological formation and anthropogenic activities (Ramesh & Elango, 2006; Vasanthavigar et al., 2010). All these factors jointly affect water quality which changes spatially and temporally.

Globally, sub-surface water is being exploited due to the rapid increase in industries, agriculture, irrigation and drinking. The over-exploration of the resource might be a more significant threat to water quality. In addition, excessive pumping, industrial and domestic waste disposal, inappropriate land use, air pollution and wastewater discharge adversely impact sub-surface water quality. Fashae et al., 2014 discussed the impact of anthropogenic effects such as municipal dumpsites and defecation sites on the shallow groundwater in Southwest Nigeria. Similarly, Solanki et al. (2010) studied the untreated domestic waste impact on water quality and contamination in the Andhra Pradesh. According to the study by Babiker et al., (2007), modern agricultural practices, industrial effluents and urban wastewater were increasing the soluble chemicals in groundwater which is a more significant threat to the water environment. Jassas & Merkel (2015) evaluated a study on hydrochemical assessment of groundwater quality for drinking and irrigation in Gomal Basin, Northern Iraq. They observed that the groundwater quality is mainly controlled by rainfall leaching processes (recharge), dissolution of carbonate minerals, alumina-silicate weathering and ionic exchange. Thus, sub-surface water quality is an important issue that needs to be monitored and evaluated for water sustainability and human health.

In India, few studies have been carried out on the sub-surface water quality: for instance, Gujarat (Prakash et al., 2016), West Bengal (Gupta et al., 2008) and other states of India (Shankark et al., 2011). Water Quality Index (WQI) is one of the most efficient methods for detecting and monitoring surface and sub-surface water quality. In addition, the WQI method has been widely used to indicate water quality for drinking and irrigation (Asadi et al., 2007). Jha et al., in 2010, performed GIS and statistical method of Water Quality Assessment. They represented the spatial distribution of sub-surface water quality in Tamil Nadu state through WQI based map.

The present work, assesses the sub-surface water quality in the Surat-Bharuch Industrial region, which has many industries (small and large scale). Therefore, it is assumed that industrial wastewater contains a significant amount of soluble inorganic and organic chemicals and their by-products.

Study Area:

Gulf of Khambat, Western Gujarat, comprises of Surat-Bharuch industrial region. 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. This region has been a vital hub for economic activities since ancient times. Many industries, such as oil, gas, cotton textile, dyeing, paper, chemical and petrochemicals and new installations are planned in the Hazira and Dahej industrial area (Fig.1).

Rivers Narmada and Tapi intersperse this region and join the Gulf of Khambat. This region is divided into two significant plains: the northern part is Baroda plain and the southern part is Bharuch plain. Geologically, it consists of schists, phyllites and quartzites intruded by basic rocks, granites and pegmatites. The gradient slope is 23.5° north-east which gets reduced to 5° in the south and southwest. The region is endowed with numerous mudflats and marshy vegetation along the coast. The study area falls in the semi-arid and subtropical climatic regions. It receives tremendous annual rainfall from the southwest monsoon between June and September and the intervening month of October. The average annual rainfall ranges between 600 and 850 mm (District Census Handbook, 2011). In this region major aquifers are formed by alluvium with fine clay having silty sand at the top and Deccan trap basalt with moderate to high salinity and shallow water tables (Upadhyaya et al., 2014; CGWB, 2013).

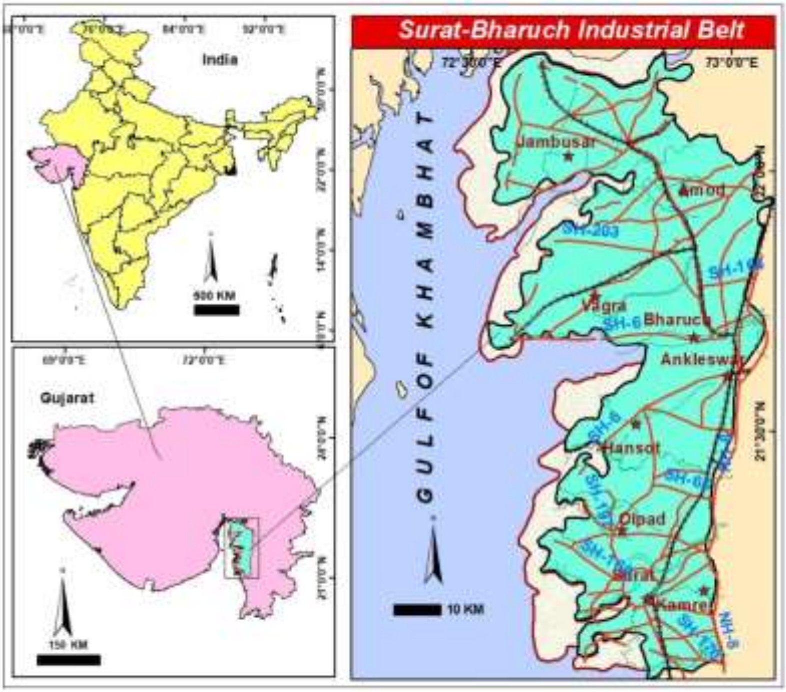

Fig.1: Location Map of the Study Area

The paper is undertaken because it is believed that the sub-surface water quality would be adversely affected by indiscriminate disposal of solid, liquid and gaseous waste from the industries. 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 generally prevalent in the industrial regions and their vicinity. The problem of contamination is more acute in industrial parts and their fringe areas. In this case, it has been inferred through observation, conducting interviews and applying PRA (Participatory Rural Appraisal) techniques.

Material and Methods:

Data Collection and Sample Analysis

Sub-surface water samples (138) were collected at various depths (<30 m) during pre-monsoon 2017. All samples were stored in plastic bottles and transported to the laboratory for physical and chemical analysis, which followed the standard procedure of APHA (1998). Before use, all glassware apparatus were thoroughly washed and rinsed with distilled water. Chemicals/reagents of analytical grade were used. The entire area of 4,200 sq. km. was gridded into a 5X5 sq. km. area and from each of the grids, at least one sub-surface water sample was collected and analysed (Fig.2). Sampling locations were marked by handheld GPS (Garmin GPSMAP 78S). The sub-surface samples were taken from the bore well and the hand pump, and physical parameters like pH and TDS were determined on-field by a portable instrument (Hanna Make, HI 98129). Esico Flame-Photometer (Model-1385) was used to assess calcium and sodium. Hanna-made Ion Selective Electrodes were used to detect fluoride (HI4110). Elico Double Beam UV- VIS Spectrophotometer (Model S1-210) was used to determine nitrate. All the laboratory work was performed in the laboratory of the Department of Geography, Faculty of Science, The M.S. University of Baroda.

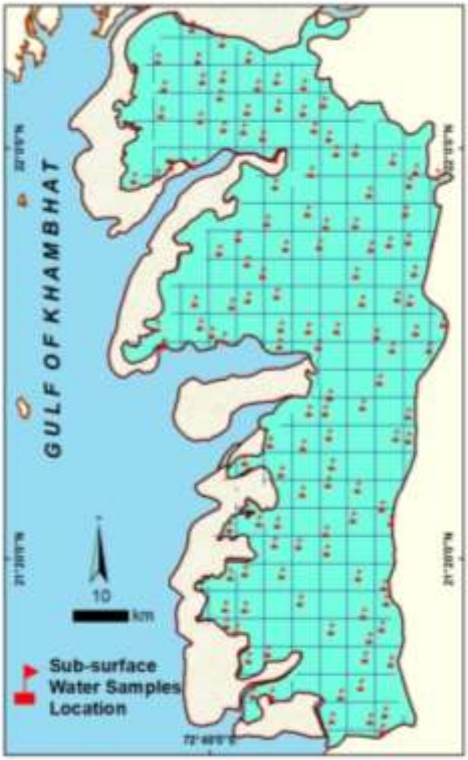

Fig.2: Location of Sub-surface water samples

Spatial Interpolation Method

GIS is a very effective tool for spatial analysis and interpolation methods. The Radial Basis Function (RBF) method produces thematic maps for major cations and anions in sub-surface water. This method followed the deterministic model approach in which the unknown points were computed based on the known points rather than the farthest point (Kawo & Karuppannan, 2018). Each basis function has a different shape and results and it can also predict values from below to maximum measured values (Gunarathna et al., 2016). This method helped categorise the values separately and gave a better visual illustration to understand the present water quality conditions. In the present study, water samples were collected, which were spread over the entire study area (12 talukas). Further, the geostatistical analyst tool generated parameter-wise interpolated surface maps/figures in the ArcGIS environment. For the graphical representation, ArcGIS 10.2 version was used.

Water Quality Index:

The Water Quality Index is an aggregate rating that reflects the composite influence of different water quality parameters (Horton, 1965; Şener et al., 2017). In other words, this method is a mathematical equation primarily used for data reduction of a large number of water parameters into a single number to evaluate the overall water quality at a specific location (Zhang et al., 2019). WQI provides simple and understandable information for decision-makers about water quality for drinking (Reza and Singh, 2010). It generates a score (zero to a hundred) illustrating the water quality status. The lower value of WQI indicates better water quality and the higher value reflects poor water quality. For drinking purposes, the Bureau of Indian Standards (BIS) was considered to interpret WQI.

WQI Calculation

The Water Quality Index was computed using the five measured parameters at each site. The Weighted Arithmetic Index method developed by Horton (1965) and Brown et al. (1970) was applied using the following equation:

$$\text{WQI} = \frac{\sum q_n . w_n}{\sum W_n}$$

Where, q_n = Quality rating of nth water quality parameter, W_n = Unit weight of nth water quality parameter.

The quality rating $(\boldsymbol{q_n})$ is calculated using this equation.

$$q_n = [(V_n - V_{id})/(S_n - V_{id})] \times 100$$

Where,

V_n = Estimated value of nth water quality parameter at a given sample location.

V_{id} = Ideal value for the nth parameter in pure water. (V_{id} for pH = 7 and 0 for all other parameters)

S_n = Standard permissible value of nth water quality parameter.

The unit weight (W_n) is calculated using the expression given in the following equation.

$$W_n = k / S_n$$

Where,

S_n = Standard permissible value of nth water quality parameter.

k = Constant of proportionality and it is calculated by using the expression given in the equation.

$$k = \left[1/\left(\sum 1/S_{n=1,2,..n}\right)\right]$$

Based on the above calculation, the ranges of WQI values were rated as excellent, good, poor, very poor and unfit for human consumption (Table 1).

Table 1 Different types of Sub-surface water and % distribution of samples using WQI (water quality index) range

Water Quality Index Range	Types of Water	% of Sample	% of Area	Probable usage
0-25	Excellent water quality	7.97	3.37	Drinking, irrigation, and industrial purpose
26-50	Good water quality	16.67	13.26	Drinking, irrigation, and industrial purpose
51-75	Poor water quality	14.49	16.98	Irrigation and industrial purpose
76-100	Very Poor water quality	15.94	20.44	For irrigation purpose
Above 100	Unfit for drinking	44.93	45.95	Proper treatment is required for any kind of usage

Source: Horton's Method (1965)

Results and Discussion

Descriptive Statistics

Descriptive Statistical analysis of sub-surface water specifications was developed to evaluate the ranges of Physico-chemical parameters and explore their deviation from BIS standards, as produced in Table 2 (Organisation BIS 2012).

Table 2 Descriptive Statistics for Determined Sub-surface Water Parameters

Parameters	Min	Max	Average	STD	Skewness	Kurtosis	S_n (BIS, 2012)	k value	Unit weight
pH	6.05	9.45	7.921	0.463	-0.156	2.31	8.5	0.8619	0.1014
TDS	112.5	7865.4	1171.32	1243.88	3.2	12.77	500	0.8619	0.0017
Sodium (Na^+)	13.4	400	266.996	148.467	-0.406	-1.55	200	0.8619	0.0043
Calcium (Ca^+)	15.5	420	74.306	85.369	3.135	9.44	75	0.8619	0.0115
Fluoride (F^-)	BDL	2.86	1.043	0.723	0.546	-0.52	1	0.8619	0.8619
Nitrate (NO_3^-)	BDL	187.68	21.933	36.396	3.292	11.5	45	0.8619	0.0192

In the pre-monsoon season, the pH level varied between 6.05 and 9.45, indicating a slightly acidic to alkaline nature (Fig.3a). The mean pH in sub-surface water was 7.92, which depicted the normal condition. The standard deviation value was 0.46, Skewness was negative (-0.16), and kurtosis showed a positive value (+2. 31). The pH value (6.5-8.5) in the entire area was within the range of the drinking water guideline value of BIS (2012). This season, the TDS level ranged between 112.50 to 7865.40 mg/l (Fig.3b). The average value of the data set was 1171.32, with a standard deviation value of 1243.88. The skewness and kurtosis values were +3.20 and +12.77, indicating the data's positive skewness and leptokurtic characteristics. Approximately, 25% of samples in the study area had a TDS value of <500 mg/l, which fell under the freshwater group (Kawo & Karuppannan, 2018).

Calcium concentrations varied from 15.50 mg/l to 420 mg/l (Fig.3c), with an average of 74.31 mg/l. Before the rains, the standard deviation was considerably high (85.37). Both skewness and kurtosis both depicted positive and leptokurtic characteristics (+3.13 and +9.44). 73% of samples of calcium were <75 mg/l, which was within the drinking water guideline set by BIS (2012).

The range of sodium varied between 13.40 mg/l and 400 mg/l with a higher mean (267 mg/l) and standard deviation (148.47). Both skewness and kurtosis values were negative (-0.41 and -1.55 respectively). According to Ayenew (2008), the possible sources of sodium in the sub-surface water were weathering of acidic volcanic rocks and rock-water interaction (Fig.3d).

The fluoride concentration ranged from BDL to 2.86 mg/l (Fig.3e). The average fluoride was 1.04 mg/l and the standard deviation was 0.72 in the dataset. Skewness (+0.55) indicated a positively skewed distribution, whereas kurtosis (-0.52) depicted a low degree of peakedness. The primary source of fluoride in sub-surface water is fluoride-bearing minerals such as Fluorspar (Fluorite), Apatite (Fluorapatite) and Phosphorite, which are present in rocks and alluvium of the Deccan Trap aquifer (Prajapati et al., 2017). The nitrate concentration varied from BDL to 187.68 mg/l (Fig.3f). The mean and standard deviations were 21.93 mg/l and 36.40. Skewness (+3.29) and kurtosis (+11.50) showed positive skewness, flatter distribution and leptokurtic dataset. Nitrate contamination in sub-surface water is caused by agricultural field, waste disposal sites, industrial effluents and organic matter (Zhang et al., 2019).

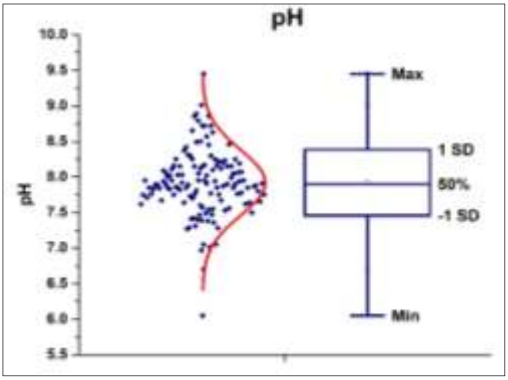

Fig. 3a

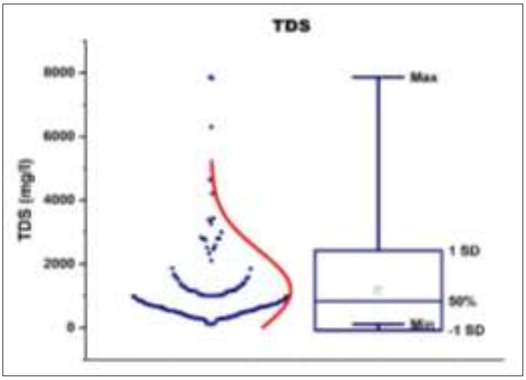

Fig. 3b

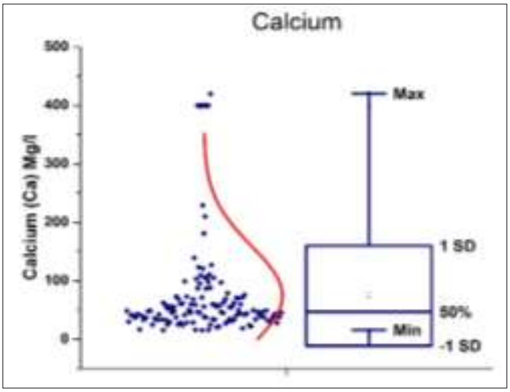

Fig. 3c

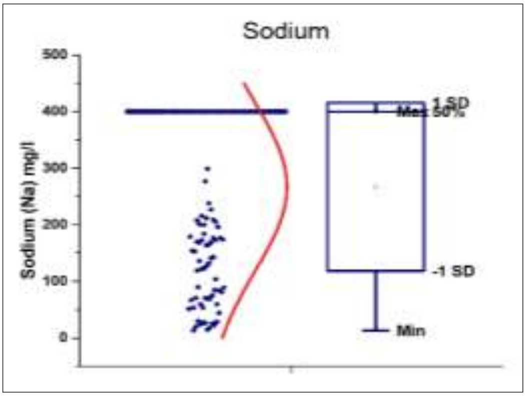

Fig. 3d

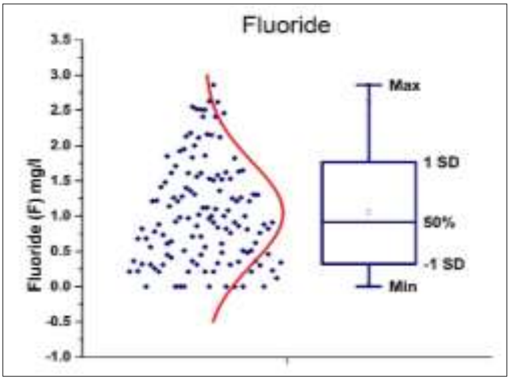

Fig. 3e

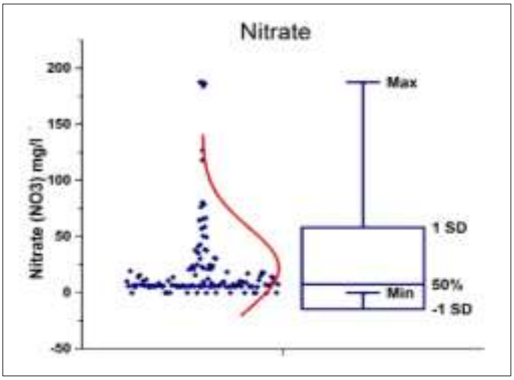

Fig. 3f

Fig. 3(a-f). Distribution of parameters pH (3a), TDS (3b), Calcium (3c), Sodium (3d), Fluoride (3e), and Nitrite (3f)

Spatial Distribution of Sub-surface Water Parameters:

Samples with a pH of >8 were 38.64% and they were spread over an area of 1517.4 sq. km. The western part of the region essentially had >8 of the concentration. Specifically, Vagra taluka in the Bharuch district had the maximum level. pH value (7.51 to 8 range) was observed in 46.21 % of the samples, covering an area of about 48.78 %. These were spread over the entire study area. The concentration range of 7 to 7.5 was noted in 12.88% of the samples, which dispersed across 12.14% of the region. It was seen in small pockets in the southern portion.

Three of the 132 samples had a pH of 7.5, with Amod taluka having the lowest pH value (6.05) (Fig.4a). 2.14% of the region. It was seen in small pockets in the southern portion. Three of the 132 samples had a pH of 7.5, with Amod taluka having the lowest pH value (6.05) (Fig.4a).

TDS value of >2000 mg/l was observed in a small area of the northwestern region. This TDS range encompassed the villages of Tankaria, Nada, Islampur, Devla, Khanpur and Kalak (Jambusar taluka). Only three samples, covering 2.48% of the total area, exhibited concentration ranging between 1500 to 2000 mg/l. The following category of 1000 mg/l to 1500 mg/l included 8.33 % samples, spanning the same region. They were seen in isolated concentrations in the north and south. 500 to 1000mg/l of TDS had 34 samples which covered 27.10% area and were well distributed over the entire study area. 59.85% of samples covering the same percentage of the area had <500mg/l of TDS in sub-surface water. Except for a few pockets, this lower range was observed throughout the entire study region (Fig.4b).

Calcium concentrations above the BIS standard was noted in 78.79% of samples. 56.06% of samples had <50 mg/l calcium, spread over 51.77% of the area. They were distributed over the entire region, particularly in parts where the maximum area is agricultural land. A slightly higher range (50 mg/l to 75 mg/l) was observed in a few segments. It was more pronounced in Amod taluka (Bharuch district) and a long narrow tail was noted along the National Highway. On the other hand, 6.06% of the samples in the Dahej Industrial Region were distributed throughout an area that made up around 4.20 %, with concentrations ranging between 75.1-200 mg/l. 6.06% samples and 12% samples were noted in 100.1 to 125 mg/l and >125 mg/l range. Both ranges were observed in the form of patches in Jambusar, Amod, Vagra and Hansot talukas (Fig.4c).

The sodium concentration in the sub-surface water was <100 mg/l in approximately 19% area and 21.37% of samples. They were observed in the talukas of Vagra, Bharuch and Ankleshwar (Bharuch District) as well as in the city of Surat. It was more prominent in the central to the northern portions of these areas. The sodium content of 100 to 150 mg/l was noted in 9 samples which were spread over 8.76% area. This range was observed over the entire study area in isolated pockets. A higher concentration of sodium (150.1 to 200 mg/l) was found in 15 samples covering 434.05 sq. km of area. 6.11% of samples covering 7.17% of the area had a concentration of 200.1 to 250 mg/l. Whereas, >54.20% of sub-surface water samples had a sodium content of >250 mg/l that were dispersed over a large area of 55.13%. This belt was observed in two segments: one each in the northern and southern parts and another in the centre, in a small pocket near the Dahej industrial area (Fig.4d).

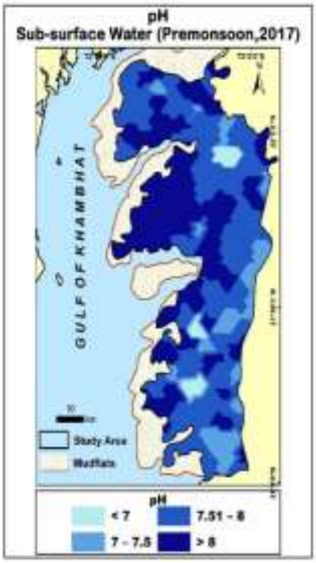

Fig. 4a

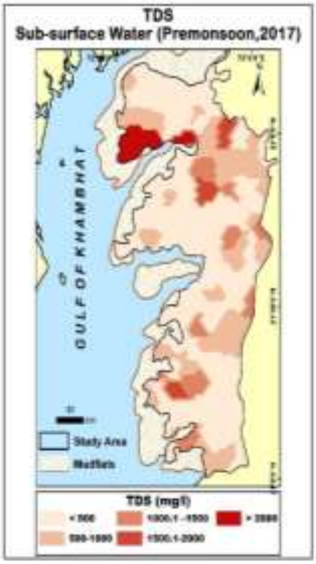

Fig. 4b

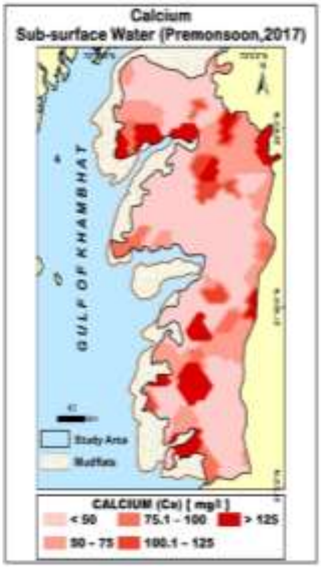

Fig. 4c

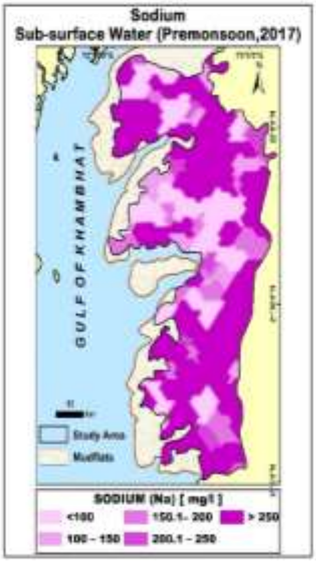

Fig. 4d

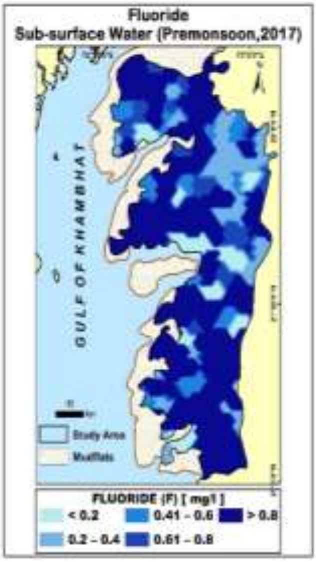

Fig. 4e

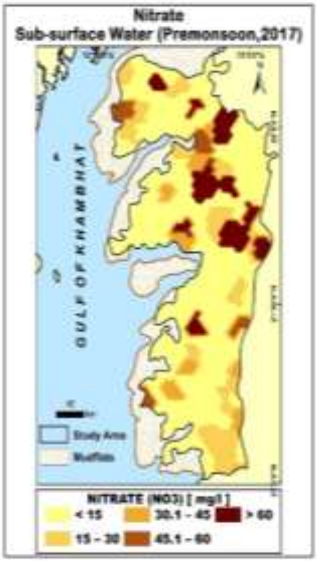

Fig. 4f

Fig. 4(a-f). Spatial distribution of parameters pH (4a), TDS (4b), TDS (4c), Sodium (4d), Fluoride (4e), and Nitrite (4f)

Fluoride concentrations were less than 0.20 mg/l in 8.40% of the samples. It covered 6.76 % in distinct places scattered over the whole region. Whereas, fluoride values of 0.20 to 0.40 mg/l were observed in 20 samples from the northeastern section, which accounted for 13% of the overall region. 439 sq.km area with 11 samples had fluoride content between 0.41 to 0.60 mg/l. 9.16% of samples spread over a 10.73% area had 0.61 to 0.80 mg/l of the element. They were in isolated scattered pockets near Jambusar, Bharbhut and Mangrol villages (Bharuch District). >0.8 mg/l concentration was identified in 60% of the samples and it was found in almost the same percentage in the industrial zones of Dahej, Vagra, Bharuch, Ankleshwar and Surat (Fig.4e).

The concentration of nitrate in sub-surface water was higher in the northeastern part. In 12 samples, a maximum range of >60 mg/l of the element was observed, accounting for about 10.52% of the total area. In comparison, just 4 samples exhibited nitrate concentration of 45.1 and 60 mg/l, accounting for 5.32% of the area. This range was also found in the form of isolated pockets near Panchppila, Devla and Intola villages (Jambusar taluka). In 9 samples, nitrate concentration ranged from 30.1 to 45 mg/l, accounting for 8.29% of the total area. On the other hand, nitrate values ranging from 15 to 30 mg/l were found in 16.10% of the samples and they were dispersed over 19.35% of the region. Lower nitrate concentrations (15 mg/l) were identified in 62.71% of the samples, which covered around 56.51% of the total study area. (Fig.4f).

WQI Results and Evaluation

In this study, WQI values ranged from 5.51 to 255.22. WQI values ranging from 0 to 25 were found in 7.97% of samples dispersed throughout 3.37 percent of the region. This range was discovered in the villages of Asnera and Nahier in Amod taluka and Manad in Bharuch taluka. Both talukas are located in northeastern and central parts of the study area. 26-50 WQI range was noted in 16.67% of samples, spread over 13.26% of the area.

This range was also recorded in the villages of Wadia, Adwala, Buva, Ranada, Kelod, Ora and Kolavana in the Amod taluka and Kapuria, Bakarpore and Nadiad in the Jambusar taluka. 20 samples and 16.98% of the region under study had WQI values ranging from 51 to 75, indicating "Poor Water Quality." This range was predominantly found in the Bharuch district in the talukas of Jambusar, Amod, Vagra and Bharuch. According to BIS, this water quality may be used for industrial and agricultural purposes. The WQI range of 76-100 labeled as "Very Poor" water quality was observed in 15.94% of samples and spread over 20.44% area. It was seen in the northeastern part of Jambusar taluka, north-western part of Amod taluka, western part of Vagra, north-central part of Ankleshwar taluka in Bharuch district and central part of Olpad taluka in Surat district. 58 samples were in the range of >100, suggesting that they were "Unfit for Drinking" (Table 1). It encompassed 45.95% of the study area (Fig.5). According to the WQI-based spatial variation map, this range was largely seen in the southern talukas of Hansot, Olpad, Surat and Kamrej, as well as in the central portion of Jambusar taluka, the eastern half of Vagra and the southern part of Ankleshwar Taluka (Fig.6). The increased levels of sodium, calcium, nitrate, fluoride and total dissolved solids in the sub-surface water at these sites were the reason for the increased WQI values. Leaching of ions, water-rock interaction and anthropogenic activities such as excessive pumping, industrial effluents, irrigation and domestic uses can be the probable reasons for the same (Reza & Singh, 2010).

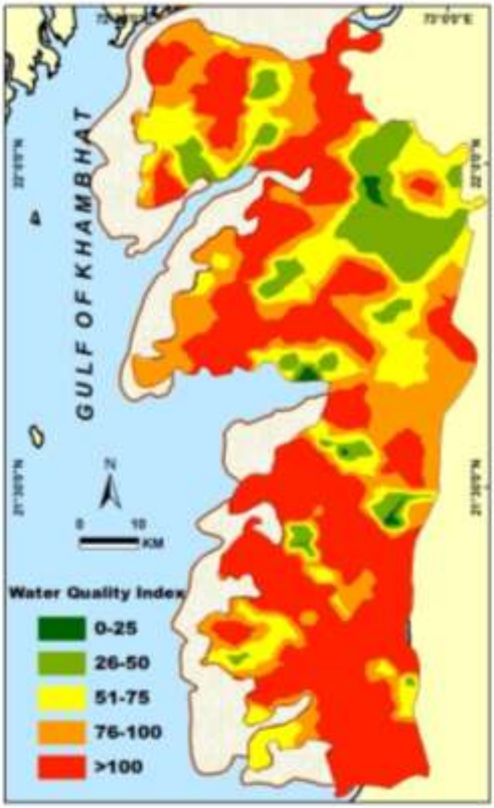

Fig.5: Water Quality Index (WQI) of Surat-Bharuch Industrial Region

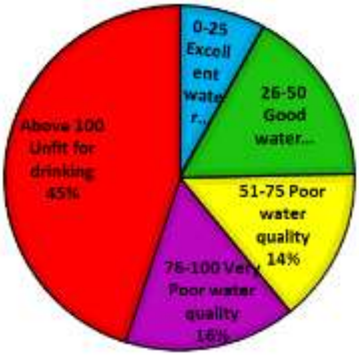

Fig.6: Pie chart showing the WQI category-wise percentage of distribution

Conclusion:

The WQI classification of sub-surface water quality in the Surat-Bharuch Industrial region of Gujarat shows that a significant part of this region has poor water quality - 'Unfit for Drinking'. In this region, natural (sub-surface water influenced by ion leaching process, weathering, percolating and movement) and anthropogenic sources (over pumping, agriculture and domestic use) played a significant role in affecting sub-surface water quality. In general, the highly industrialized and agricultural-based area had an impact on the sub-surface water chemistry of the study area. The investigation suggests that the sub-surface water in these areas requires considerable treatment before use. Some techniques for improving the water quality include- treating industrially contaminated water before discharging it into rivers or ponds, regular monitoring of water quality, revising fertilizer limits for agricultural operations and altering the policy for dumping industrial effluents. The northeastern portion of the research region had acceptable water quality suited for all purposes (drinking, residential, irrigation and industrial).

Acknowledgments

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