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Ingress of Bhavnagar City (India)

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A preliminary survey of the coastal city-Bhavnagar was undertaken to assess salinity ingress probed through groundwater quality. Water samples from the wells and bores located in the study area were collected and analyzed. Bhavnagar City is found significantly affected by the seawater intrusion. The ground water showed very high values of SO_4^{-2}, Cl^{-1}, PO_4^{-3} and, Na^{+1}, K^{+1} compared to the permissible limits for drinking purposes. The quality of ground water in some of the areas was found highly saline and can not be used even for irrigation purpose. The results also indicated a gradual encroachment of seawater into the native ground water.

Key words : *Seawater intrusion, salinity ingress, Bhavnagar City*

Introduction

Problems related to seawater intrusion have seen a significant rise over the last decades[1]. Seawater intrusion related problems have been reported in various countries and are especially of great concern to Gujarat State in India, as it has the longest coastline of about 1800 km. However, environmental problems especially in the coastal areas have multiplied over the years because of rapid industrialization and excessive use of the natural resources. There has been an intensive use of the groundwater resources by various stakeholders for their individual benefit. In the absence of any concreted management plan, the groundwater quality has therefore seen a drastic deterioration in the recent years[2], which has resulted in to salinity ingress[2]. Coastal cities, especially in the low-lying areas are more prone to seawater inundation problems, as is the case of the study area.

The Bhavnagar city is situated in the south-east of peninsular region of Gujarat. The city has unique situation as it lays head of the Gulf of Khambhat on 21° 46' north latitudes and 72° 11' east longitudes. The total area of the city is approximately 48 sq. km[3,4].

Sources of water supply to Bhavnagar city are Shetrunji dam, Gaurishankar lake and Khodiyar lake. The city supply of 58 million liters per day (MLD) water from Shetrunji dam via Kankot-Chitra pipeline and 12 MLD water from the Khodiyar lake, is insufficient even for the domestic purpose.

Bhavnagar is a fast developing district in Gujarat state, contributing to its economic growth, but the city has a tremendous stress of supply of quantity and quality water to various sectors like domestic, agricultural and industries due to rapid industrialization and urbanization. It is quite reflected during a preliminary survey that over the years groundwater quality is found deteriorated. The present paper emphasizes on the salinity ingress and its pattern in the study area. This may lead to possible remedies to prevent salinity ingress in the Bhavnagar City.

Materials and methods

Selection of the sampling locations

A systematic study and planning was done before beginning the sampling. The planning involved, adequate literature survey, detailed survey of the city, discussions with local subject experts in the field ranging from geology, water works department, district industries centre, health department and other concerned individuals / organizations.

For the present study, the city was divided into three main stretches (denoted as A – the inner part, B -, the middle portion, and C- outer periphery) and four major zones (North [N] to East [E], East to South[S], South[S] to West [W] and West[W] to North[N]). These zones demarcation of the sampling spots helped in understanding the existing water quality status of an individual sampling spot as well as representing the surrounding areas of the city. Further, any patterns or changes existing in water quality parameters within each zone as well as between the zones were easily discernable.

The study focused on analyzing the changes in the water quality parameters across one complete hydrological cycle.

Methods of sampling

Procedure adopted for the present work was grab sampling, except for specific instances, e.g. for Gaurishankar (Bortalav) and Khodiyar lakes, where composite samples were collected.

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Methods of preservation and storage

The standard methods available in the liturature[5] were followed for the sample container material, sample volume and treatment given to the samples for their preservation.

Chemicals

All chemicals used in the investigation were of AR grade from E-Merck and from BDH. The stock solutions were prepared in double distilled water and used as and when required.

Experimental procedure

APHA[5] and IS-2430 analytical methods were selected for the analysis of various parameters. Some advance techniques were also applied to ascertain analytical results.

Results and discussion

Considering the distance from coast, depth factors, water use, population density, industrial and domestic waste and other local factors affecting the groundwater quality, the study area **(Fig.1)** was further divided into three stretches as [A] inner or central periphery, [B] middle region and [C] outer periphery, which was further divided into four zones :

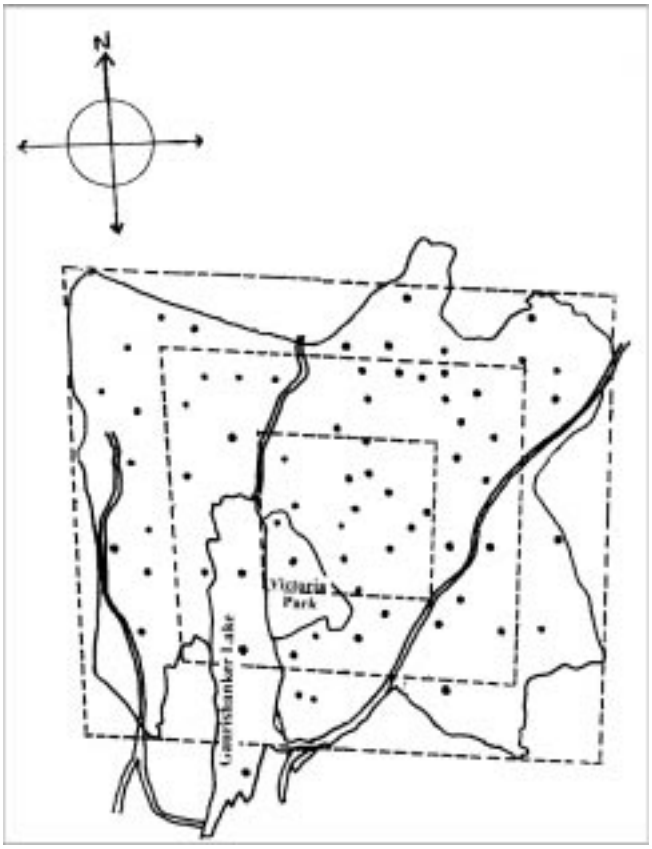

Fig.1 : The dots indicating the sampling locations in Bhavnagar city

Zone I : North : North - West to North - East

Zone II : East : North - East to South - East

Zone III : South : South - East to South - West

Zone IV : West : South - West to North - West

The water quality parameters were taken into consideration keeping in mind the intrusion effect of seawater along with the associated effect of industrial, and sewage pollution, and anthropogenic factors, if any

Stretch A

The average values of different parameters obtained after analysis for water samples taken from stretch-A are represented in the **Table 1**, In stretch -A, average value for conductivity was found 1100 µS, for hardness around 300 mg/L and the TDS value varied from 700 mg/L to 750 mg/L.

The results suggest that water quality of this stretch is potable with some exceptional areas, which show high salinity in comparison to permissible limits. The overall scenario in this region indicates that hardness is of temporary type having more concentration of Na, K, Ca and Mg along with Cl and SO_4, as their respective anions. These results suggest that only specific area of central part of the city is affected by the intrusion. This observation gets supported if the data available for geomorphologic conditions in this region is analyzed. It is mentioned in the geomorphologic data that there was seawater upto the central part of the city and gradually it was filled with slow sedimentation process. This phenomenon allowed penetrating seawater into the groundwater channels.

The results also indicate that the northern side, from where samples were collected in the central stretch

Table 1 : Average values for salinity parameters in Stretch- A

Area	Conductivity	Hardness	TDS	TS
1NA	352.39	105.55	225.53	245.53
16NEA	1229.25	361.83	786.72	794.72
30EA	253.92	68.98	162.51	174.51
31EA	483.25	119.01	309.28	317.28
32EA	1769.65	175.76	1132.57	1136.57
39SEA	1264.63	284.87	809.36	817.36
45SWA	980.75	334.34	627.68	639.68
46SWABC	345.51	72	221.13	277.21
50WA	360.48	135.86	230	238
51WA	2400	737.17	1393	1405
53NWA	2036.5	547.45	1303	1423

(stretch-A), shows good quality of water having low hardness, absence of organic pollutants as well as toxic heavy metals. The uniqueness of the obtained results is that the chloride and sulfate levels are present almost in equal concentration.

Stretch B

The average data of salinity parameters for stretch- B is given in the **Table 2**. Overall picture of stretch-B with respect to the salinity parameters is : conductivity varied from 2400mS to 5500mS, hardness levels ranged around 300 mg/L to 1200 mg/L and TDS varied from 1500 mg/L to 3400 mg/L.

Table 2 : Average values for salinity parameters in Stretch- B

Area	Conductivity	Hardness	TDS	TS
2NB	5460.57	1287.34	3494.77	3542.77
10NEB	724.6	74.86	463.75	479.75
11NEB	1030.01	148.37	659.2	671.2
12NEB	2301.23	222.41	1472.83	1492.83
13NEB	2406.25	232.39	1540.68	1552.68
14NEB	3042.98	743.06	1947.51	1999.51
15NEB	5516.4	744.51	3530.5	3542.5
23EB	1488.3	262.81	952.57	964.51
24EB	1731.39	272.3	1108.09	1116.09
25EB	2445.31	320.34	1557.57	1565.27
26EB	2712.17	423.38	1735.79	1743.79
27EB	3301.26	458.3	2112.81	2120.81
28EB	3497.04	585.94	2238.11	2250.11
29EB	3684.31	644.43	2357.96	2365.96
34SEB	833.93	52.34	533.72	537.72
35SEB	1879	178.56	1202.57	1202.57
36SEB	2674.54	309.08	1711.71	1719.71
37SEB	3389.12	373.7	2169.04	2181.04
38SEB	3686.4	463.25	2360.62	2368.62
41SB	1740.45	107.8	1113.89	1127.89
42SB	2873.68	489.63	1839.15	1847.15
46SWABC	345.51	72	221.13	277.21
48WB	772.7	215.07	1239.7	1249
49WB	3269.5	349.6	2092	2108

The results suggest that water quality of this stretch is not potable with some exceptional areas, in which low salinity is observed. The hardness is of temporary type having more concentration of Na, K, Ca and Mg along with Cl, SO_4 and PO_4. The water deficiency in this region leads to over utilization of the groundwater, which causes more saline water at middle depth level around 100-200 feet from the zero level.

Stretch C

The overall average picture of stretch-C is given in the **Table 3**, which is the outer most periphery of the city. This region is surrounded by industrial areas, i.e. GIDC, Chitra along with salt-farms and low-lying coastal areas. The results of this stretch have shown randomness due to geomorphologic conditions in this area. Some of the areas in which salinity parameters are found very high, are not comparable at all with the results obtained from other stretches of Bhavnagar City. The conductivity varied from 3000 mS to 55800 mS, hardness between 200mg/L to 4700mg/L and TDS from 900 to 35700 mg/L. The results indicate that this region is highly affected by seawater intrusion and industrial activities. In some areas, which are nearer to industries, the COD values are found very high upto 190 mg/L showing deep influence of industrial waste effluent discharge to zero level that penetrate and reach into the existing groundwater channels. This can be attributed to geomorphologic conditions of this stretch, which allowed penetration of seawater and other pollutants.

Some of the major important features of the study are listed below :

- The south, southeastern part and southwestern part seems to be under the influence of Gaurishankar (Bortalav) lake, the water quality in this region was found good enough in respect of all water quality parameters like hardness, salinity factors, cations and anions, organic pollutants and

Table 3 : Average values for salinity parameters in Stretch-C

Area	Conductivity	Hardness	TDS	TS
4NEC	572.57	27.98	366.45	372.45
5NEC	1499.09	30.65	959.42	1093.22
6NEC	3576.57	111.09	2289.98	2301.98
7NEC	3871.87	209.81	2478	2484
8NEC	4727.2	329.23	3025.41	3031
9NEC	4769.2	1102.33	3052.29	3064.29
17EC	1729.33	108.61	1106.77	1146.77
18EC	2991.92	463.56	1914.83	1922.83
19EC	3596.47	464.85	2301.74	2314.21
20EC	3603.45	516.19	2306.21	2343.74
21EC	4869.9	663.13	3116.74	3152.74
22EC	6601.45	1195.8	4224.93	4256.93
33SEC	9300	455.52	3511.69	3523.69
40SC	1408.56	216.51	901.48	909.48
43SWC	626.45	174.51	400.92	404.92
44SWC	1710.75	450.43	1094.86	1118.86
46SWABC	345.51	72	221.13	277.21
47WC	4449.81	237.7	4802	4972
52NWC	55848	4784.2	35743	35749

Note :

In the above tables, capital letters “A”, “B” and “C” represent three different stretches, while numerical and capital letters “N”, “E”, “W” and “S” indicate different areas along with different directions from where samples were collected.

heavy metal levels, which were found well within the permissible levels.

- By and large, the organic pollutants were in the lower range. These varied from BDL to 190 mg/L. The high values were found in the northeastern portion of the city while the eastern, southeastern, southern, southwestern and to some extent, the western regions showed very low COD, BOD and TOC values irrespective of stretches.

- The heavy metals were found well within the permissible limits. Toxic metals, like mercury and arsenic, were found below the detectable limits in all the samples. No visible trend was noticed along stretches A, B and C., i.e. inspite of high conductivity levels from inner portions of the city to the outer portions, the metal concentrations were not found to increase beyond the permissible levels. Lead varied between 0.009 mg/L to 0.030 mg/L, Cadmium varied from 0.002 mg/L to 0.0074 mg/L and Chromium found between 0.0073 mg/L to 0.1699 mg/L. Copper was found around 0.0042 mg/L and zinc was around 0.0074 mg/L. Iron was found relatively higher compared to other metals and ranged around 0.150 mg/L to as high as 3.194 mg/L. The outer periphery of the city has relatively higher concentration of metals in comparison to the middle and interior regions.

- The results indicated that the overall groundwater quality is only influenced by salinity parameters and not by other factors like organic pollutants, toxic heavy metals, fluoride and permanent hardness. Therefore, emphasis should be given to the salinity factor, which is actually affecting the water quality of the city and this needs further statistical support to estimate the salinity ingress and remedial steps too.

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