

# Groundwater pollution due to sugar-mill effluent, at Sonai, Maharashtra, India

N. J. Pawar · G. M. Pondhe · S. F. Patil

**Abstract** Analyses of 126 samples collected from 18 dug wells in the shallow basaltic aquifer over a period of 7 months have revealed spatial as well as temporal changes in the chemical properties of groundwater. While the temporal changes have been attributed to dilution and concentration phenomena governed by climatic factors, the spatial variations in the geochemical characteristics of groundwater appeared to be related to pollution due to effluents from the Mula Sugar Factory. The cause of groundwater pollution is the effluent carried by a stream flowing through the area. Fluctuations in the groundwater table, influent water quality character of the stream, less capacity to accommodate large volume of effluent and occurrence of zero base flow (under natural conditions) in the stream are the factors favoring infiltration of constituents of waste water into the underlying weathered basaltic aquifer. Pollutants have entered into the shallow aquifer by downward percolation through the zone of aeration to form a recharge mound at the water table and, further, lateral movement below the water table. The plume of polluted groundwater has a lateral extent of a few meters in the upstream area and more than 400 m on either side of the stream in the downstream part. The zone of polluted groundwater has an areal extent of more than 3.5 km<sup>2</sup>. Groundwater is the only source available for drinking and agricultural purposes. It is recommended that the base of the lagoons and the stream used for release of

plant effluent should be waterproofed for the protection of groundwater in the Sonai area.

**Key words** Groundwater · Sugar mill · Basaltic aquifer · Pollution

## Introduction

The sugar industry in Maharashtra, India, is a key factor in the rural economy of the state. It has initiated developmental economic activities, like cooperative dairies, paper mills, and poultry farms, in their respective regions. Some of them have opened educational institutions and technical colleges and have been responsible for changing the social structure of rural areas. The growing demand for more sugar factories in all parts of the state is an indication of the importance of the industry to the rural development and general economic prosperity (Anand 1987).

In spite of the fact that the sugar industry is the backbone of the rural economy of Maharashtra, the need has arisen to review and recognize environmental problems associated with it. It is noteworthy that the rapid increase in sugar industrialization has led to unprecedented increases in urbanization and population and hence the degradation of environmental resources. The enormous quantities of wastes (solid, liquid, and gas) generated by these rural industries has led to problems of air, water, and soil pollution. The problems of water quality and water pollution are particularly severe in many sugar factory areas and are threatening the rural population. In the recent past, several studies (Manas 1976; Kundra and Purthy 1979; Handa 1981; Krupanidhi 1984) have reported that receiving water bodies are becoming increasingly contaminated due to domestic and industrial waste waters. However, few studies regarding the nature of groundwater pollution due to effluents from sugar mills have been carried out. Therefore, in this article groundwater pollution probably caused by the disposal of effluent from the Mula Sugar Factory is discussed.

Received: 30 April 1997 · Accepted: 23 September 1997

N. J. Pawar (✉)  
Department of Geology and Environmental Science,  
University of Pune, Pune 411007, India  
Tel.: 91 212 351195x2121 · Fax: 91 212 350087  
e-mail: njpawar@unipune.ernet.in

G. M. Pondhe · S. F. Patil, Vice-chancellor,  
North Maharashtra University Jalgaon (✉)  
Department of Environmental Science  
P.V.P. College, Pravarangan, Dist-Ahmednagar

## The Mula Sugar Factory

The Mula Sugar Factory is located at Sonai in Newasa Tahsil of the Ahmednagar district of Maharashtra. The village covers an area of 15.12 km<sup>2</sup> (inclusive of agriculture land) and is included in toposheet No. 47 I/15 of the Survey of India and lies between 19°22' to 19°24' N latitude and 74°49' to 74°51' E longitude (Fig. 1).

The Mula Sugar Factory is a cooperative sugar industry project, started in 1979 with an initial capacity of 1250 tons of crushed sugarcane per day (TCD), and expanded to 2000 TCD since 1987. Water consumption is nearly 1500 liters per ton of sugarcane crushed per day (L/ton/day). Due to internal processes, nearly 60% of this water is recirculated. The remaining 40% leaves as effluent from the boiling house, mill house, and filter cloth washing. The total effluent receives very little treatment; after lagooning it is discharged to a meandering natural stream flowing through an agricultural area for a distance of about 1.7 km and finally meets another stream, namely Panas Odha at the village of Shinganapur.

Further, there are monthly cleaning operations at the factory which release a great deal of effluent containing organic and inorganic matter. Due to the large volume of effluent and because of low carrying capacity, the stream floods at some places and effluent spreads over cultivated land. Nearby wells show adverse effects; also, soils in the area have become alkaline, with increased pH and salinity.

Groundwater in the area occurs under water-table conditions in the weathered basaltic aquifers. Occurrence and availability of groundwater in the basalt is controlled by

the degree of jointing, presence of vesicles, interconnection between vesicles by fissures and cracks, contact between lava flows and flow units, and several other factors (Pawar and Shaikh 1995). Groundwater is taken from large diameter wells that vary in shape and size. Depending on the thickness of soil cover and the depth of weathering, wells are fully or partly lined.

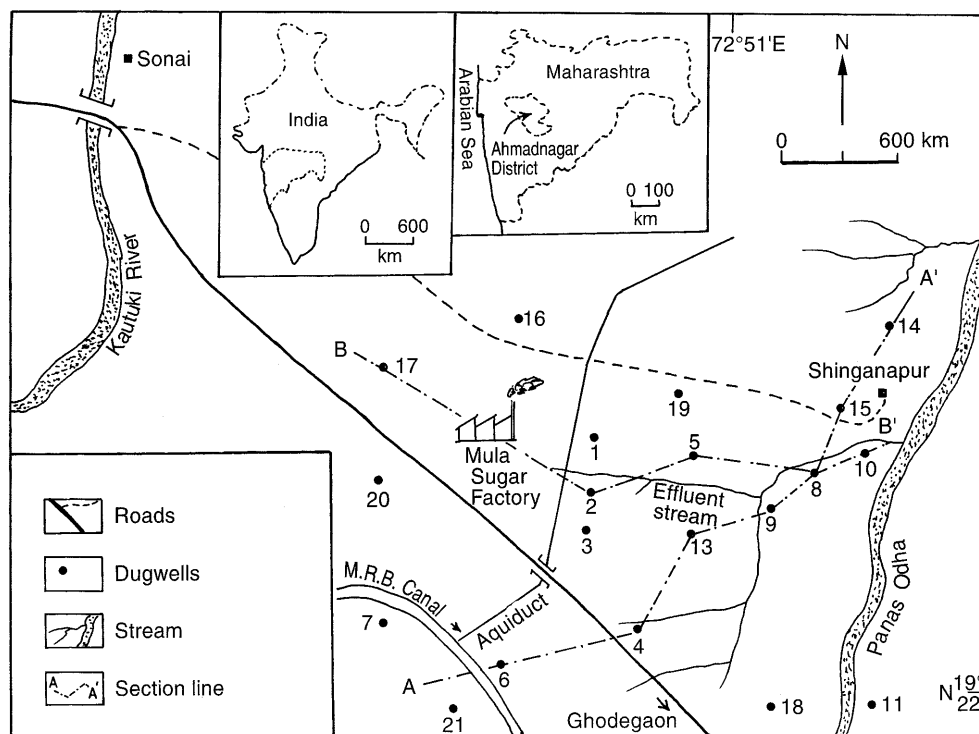
## Methodology

Eighteen dug wells penetrating the basaltic aquifer were selected in the study area with a view

1. to assess the impact of industrial activity on the chemistry of groundwater;
2. to determine the quality of groundwater in the natural state;
3. to delineate the sources and pathways of pollutants.

The first objective is met by establishing an impact station. In the present study, the impact station is considered to be a dug well in the vicinity of the source of pollution which has undergone contamination. The second objective is achieved by selecting a baseline station (i.e., away from the pollution source) and the third by choosing either of the first two, depending upon whether the pollutant is of natural or industrial origin. The sampling wells selected by adopting these criteria fall into three categories as:

- a. those which are serving as a source of water supply for drinking purposes;
- b. those from the agricultural area used mainly for irrigation;



**Fig. 1** Location map of the Sonai area showing sampling wells and the site of Mula Sugar Factory in Ahmednagar district, Maharashtra

c. the wells which are contaminated by sugar-factory effluent.

The sugar factory is seasonal; the schedule of operation varies from year to year depending on the occurrence of monsoon and availability of the sugarcane crop. In view of this cyclic operation, sampling was carried out to cover in part the period of operation of the factory and also the nonoperational period. By adopting this approach, it was possible to study the pollution during the operational period as well as pollution during the nonoperational period. Groundwater samples were collected monthly, in June, July, August, and September 1989 (nonoperational period) and in February, March (operational period), and October (nonoperational period) in 1990. Plastic containers of 2-l capacity were used for collection and storage of water samples. Some parameters, e.g., pH, electrical conductivity (EC), and total alkalinity, were determined in the field. Groundwater samples were brought to the laboratory for analysis of sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), chloride (Cl), sulfate (SO<sub>4</sub>), phosphate (PO<sub>4</sub>), nitrate (NO<sub>3</sub>), dissolved oxygen (DO),

biological oxygen demand (BOD), and chemical oxygen demand (COD). The methods used for these analyses were standardized as per the procedures given by APHA, AWWA and WPCF (1989).

## Results and discussion

Data obtained by carrying out chemical analyses on groundwater samples for the period of 7 months is presented in Tables 1 and 2. Table 1 summarizes 7-month averages and Table 2 summarizes monthly average.

### Temporal and spatial variations

Geochemical data collected from the study area is indicative of variations in groundwater chemistry with space and time. The major dissolved constituents of groundwater are Na, K, Ca, Mg, Cl, HCO<sub>3</sub>, and SO<sub>4</sub>. The concentrations of these ions are generally governed by the lithology, nature of geochemical reactions, solubility of differ-

**Table 1**

Physico-chemical characteristics of groundwater water from Sonai area, Ahmednagar, India. (N.B.: All concentrations are reported in ppm except pH, EC ( $\mu\text{s}/\text{cm}$ ) and Slc. Effl. = effluent.)

W. No	pH	EC	TDS	Na	K	Ca	Mg	Cl	HCO <sub>3</sub>	SO <sub>4</sub>	PO <sub>4</sub>	NO <sub>3</sub>	DO	BOD	COD	Slc
W1	7.09	501	326	69.56	3.16	23.82	8.56	81.40	149.70	30.97	0.72	0.65	5.70	4.00	10.44	-0.796
W2	7.65	676	440	74.70	4.79	56.85	8.80	102.00	237.14	37.28	0.66	0.10	6.52	5.60	12.94	-0.299
W3	7.16	781	508	128.99	2.35	42.70	6.99	115.28	285.50	32.85	0.22	0.56	5.47	6.50	13.77	-0.235
W4	7.29	693	447	129.28	3.71	32.33	6.71	142.58	272.40	45.28	0.22	0.08	6.70	5.40	10.90	-0.250
W5	7.55	830	540	82.99	7.27	34.42	9.85	76.85	224.50	26.11	0.40	0.01	6.80	9.10	18.85	-0.020
W7	7.23	645	419	102.14	3.10	33.85	5.71	109.37	209.40	36.11	0.31	0.13	6.52	6.90	14.42	-0.383
W8	7.28	3754	2414	390.20	7.25	79.42	13.70	535.10	370.10	62.68	0.29	0.01	4.70	11.50	22.74	+0.163
W9	7.06	3556	2310	419.00	7.75	90.42	10.00	495.74	411.14	90.10	0.33	0.29	4.40	9.40	21.40	+0.035
W10	7.30	1094	711	373.10	2.53	78.57	10.00	495.28	365.14	62.28	0.34	0.01	6.84	6.20	13.10	+0.179
W11	7.50	557	362	91.66	3.28	82.50	8.80	87.00	259.83	61.00	0.38	0.07	6.66	5.72	12.45	+0.328
W12	7.48	670	435	155.00	9.83	92.33	8.33	154.50	374.33	76.66	0.12	0.03	6.80	4.41	11.10	+0.479
W13	7.37	607	394	131.60	4.20	59.10	7.70	111.66	240.83	46.83	0.14	0.02	6.30	6.08	11.00	+0.031
W14	7.52	1024	665	151.16	3.90	28.33	5.66	53.83	384.66	41.16	0.40	0.08	5.30	6.10	15.33	+0.066
W15	7.88	1025	666	167.33	5.50	38.16	6.80	55.66	408.33	38.66	0.21	0.08	5.40	9.63	21.80	+0.563
W16	7.53	812	527	166.66	7.75	35.83	6.83	74.66	364.16	37.50	0.37	0.02	6.48	9.00	18.66	+0.149
W17	7.46	782	507	69.50	3.50	40.16	6.70	105.66	196.16	32.66	0.13	0.02	7.15	3.20	5.05	+0.101
W18	7.18	527	347	69.83	3.65	43.00	10.41	67.16	214.16	26.16	0.12	0.15	6.63	6.20	12.84	-0.309
Effl.	5.50	3175	2064	68.00	1.50	201.00	24.00	325.00	530.00	8.00	3.50	9.50	NIL	590.00	2245.00	+0.678

**Table 2**

Physico-chemical characteristics of groundwater from the Sonai area, Ahmednagar district, Maharashtra. [N.B. All the values of constituents except pH, EC ( $\mu\text{s}/\text{cm}$ ) are in ppm.]

Month	pH	EC	Na	K	Ca	Mg	Cl	HCO <sub>3</sub>	SO <sub>4</sub>	PO <sub>4</sub>	NO <sub>3</sub>	DO	BOD	COD
June 1989	7.18	1381	226	3.62	56.80	10.20	352	286	62.40	0.44	0.19	4.70	5.60	14.4
July 1989	7.53	1043	137	1.79	56.22	5.27	113	298	59.00	0.33	0.14	6.30	6.695	14.7
August 1989	7.48	2327	116	3.45	56.27	8.80	98	272	30.11	0.21	0.08	6.30	6.50	12
September 1989	7.43	992	105	6.40	52.40	6.10	85	244	36.20	0.29	0.10	7.10	6.42	11.9
February 1990	7.21	1172	208	8.19	59.00	11.11	257	319	38.60	0.39	0.14	6.00	8.50	16.9
March 1990	7.24	1077	217	6.50	58.60	11.53	244	326	43.00	0.36	0.12	5.90	8.70	17.6
October 1990	7.73	416	154	1.62	22.29	7.04	107	263	53.61	0.39	0.07	6.50	1.30	10.1

ent salts, velocity and volume of groundwater flow, and the role of human activities (Matthess and Harvey 1982; Bhatt and Saklani 1996). In order to evaluate the spatial and temporal changes in the concentrations of these constituents, the average chemical data (Table 1) for the wells located along two cross sections were considered. On the basis of this information and considering the groundwater flow direction, the cross section A-A' was taken in the NE-SW direction passing through well numbers W6, W4, W13, W9, W8, W15, and W14. Similarly, the cross section B-B' was taken in E-W direction across the well numbers W17, W2, W5, W8, and W10. The average chemical data (Table 1) for the wells along these two cross sections were plotted to show the spatial variations in the properties of the groundwater (Fig. 2). For this purpose the chemical parameters were divided into three groups on the basis of their concentrations and significance. These three groups are as follows:

1. major constituents (Na, K, Ca, Mg, HCO<sub>3</sub>, SO<sub>4</sub>, and Cl);
2. minor constituents (PO<sub>4</sub> and NO<sub>3</sub>);
3. indicator parameters (DO, COD, and BOD).

It is observed from Fig. 2 (i.e., cross sections A-A' and B-B') that the values of Na, K, Ca, and Mg increase markedly at wells W9 and W8 along A-A' section and at wells W8 and W10 along the B-B' section. These wells also show a sharp increase in concentrations of Cl, HCO<sub>3</sub>, and SO<sub>4</sub>. This is because these wells are located in a downgradient direction and are in the close vicinity of an effluent-carrying stream. Plant effluent shows high values of Ca, Mg, Na, K, Cl, SO<sub>4</sub>, HCO<sub>3</sub>, COD, and BOD. The contaminated wells are rich in the same chemical constituents that are high in the effluent. Therefore, there is apparent correlation of the contaminants in groundwater with the composition of plant effluent. The higher Ca, Na, K, HCO<sub>3</sub>, and Cl values in these wells suggest the effluent-carrying stream as the source.

The monthly averaged chemical data (Table 2) is also plotted to get an idea about the variations with time (Fig. 3). It is observed from the figure that Ca, Mg, K, and SO<sub>4</sub> show comparatively less variation in their respective concentrations with time. However, the Na, HCO<sub>3</sub>, and Cl trends clearly indicate the seasonal changes in the geochemistry of groundwater. The decrease in concentrations of these species from July 1989 to September 1989 is indicative of dilution effect possibly due to rising watertable in response to enhanced recharge to the aquifer from the infiltration of rainwater (rainy season). As against this, gradual increase in these constituents from September 1989 to March 1990 suggests the concentration effect as the rain-fed recharge ceases during the summer season. The plots of minor constituents, for example, PO<sub>4</sub> and NO<sub>3</sub>, with time indicate a dilution and concentration effect generally similar to the foregoing. However, spatial variations in the concentrations of PO<sub>4</sub> and NO<sub>3</sub> along cross sections (Table 1) do not follow the same trend as that of major constituents. Nevertheless, at some places the values of these parameters are higher than the background values. This suggests that some wells are polluted

due to closeness to the effluent disposal site. In the case of remaining wells the PO<sub>4</sub> and NO<sub>3</sub> values are variable possibly due to effective removal of these ions by the crops. Nitrogen and phosphorus are the chief nutrients required by plants. However, phosphate is less mobile than nitrate; it is sorbed onto the soil. On the other hand, nitrate is very mobile due to limited physical or chemical sorption; removal from water is predominantly by biological uptake. It is also possible that the nitrate is removed by the process of denitrification taking place in the presence of labile organic carbon and denitrifying bacteria (Starr and Gillham 1993).

Considering indicator parameters, organic pollution load increased from September 1989 to March 1990; BOD and COD values were high. As would be expected, DO shows exactly the reverse trend for this period. Since these months (September 1989 to March 1990) coincide with the winter and early summer seasons, it can be inferred that during these two seasons the input of pollution load is higher and dilution is less than that during rainy season, for which BOD and COD values are lower. The higher BOD and COD values in summer and winter may be considered indicative of a higher potential for pollution of groundwater. The BOD and COD variations with respect to space are consistent with the trends observed for major constituents. This is reflected in the higher BOD, COD, and lower DO values for well numbers W9, W8, and W15 (A-A' section) and W2, W5, W8, and W10 (B-B' section).

#### Sources of salts in the groundwater

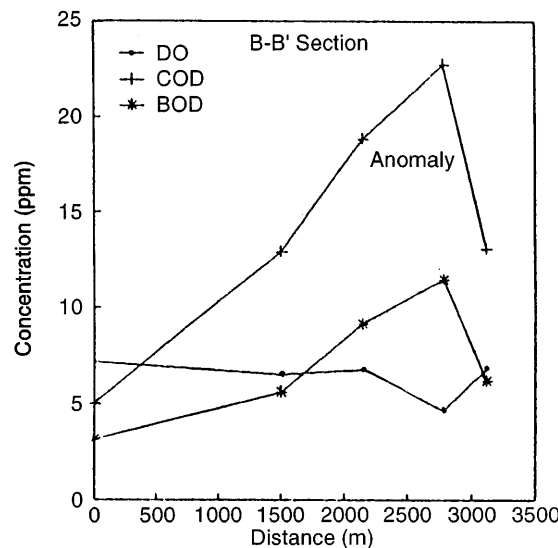
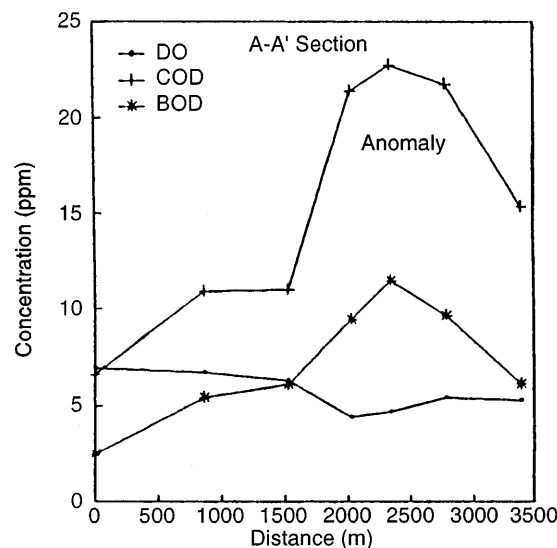
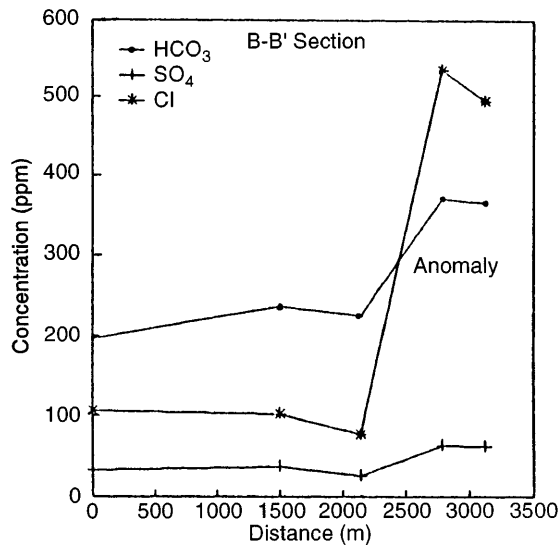
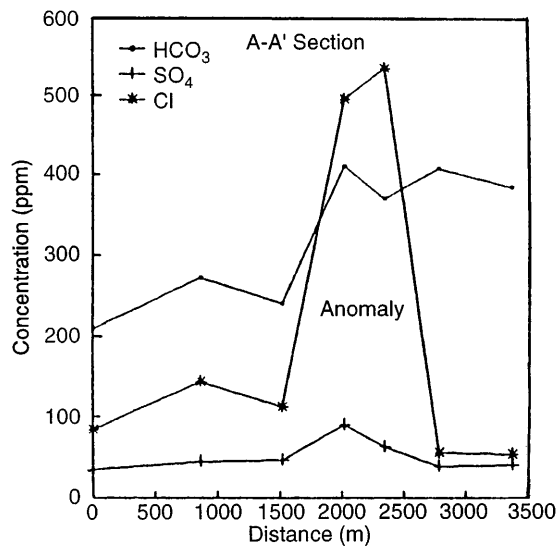
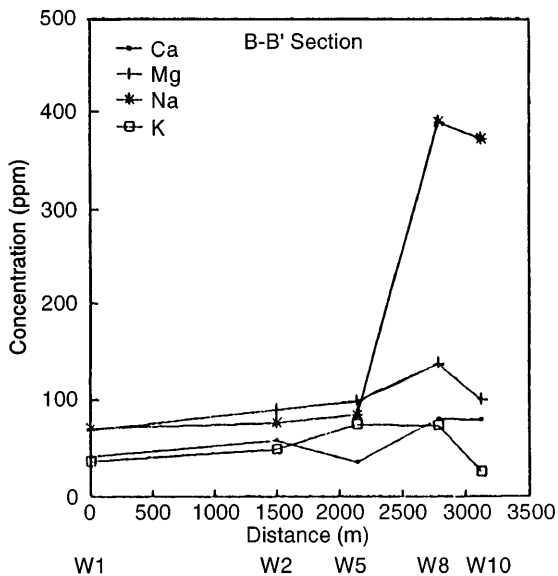
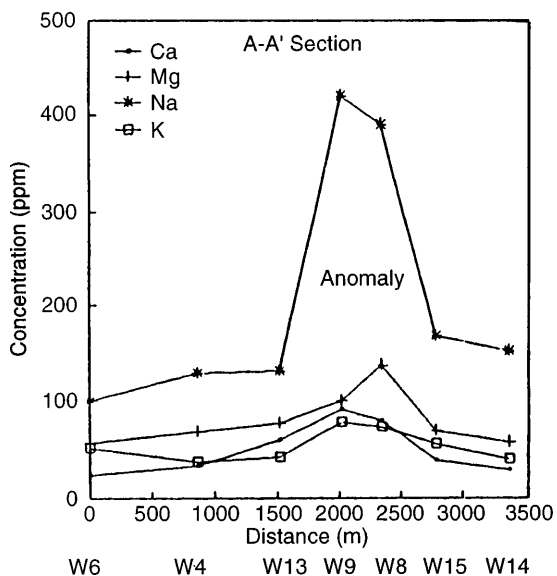
In a natural system, most of the dissolved constituents present in the groundwater reflect the nature of water-rock interaction taking place within the lithologic framework. The groundwater from the study area is found to contain the average total dissolved solids (TDS) ranging from 347 to 2414 PPM (Table 1). Values of TDS noted for well numbers W8 and W9 are higher than for the remaining wells. Effluent shows higher TDS than wells away from effluent-carrying stream. The natural basin groundwater from wells away from the effluent-carrying stream does not show elevated values of TDS comparable to those of the wells in the close vicinity of a stream. It is therefore essential to know what are the sources leading to the higher concentrations of dissolved constituents in some wells. First we consider natural sources.

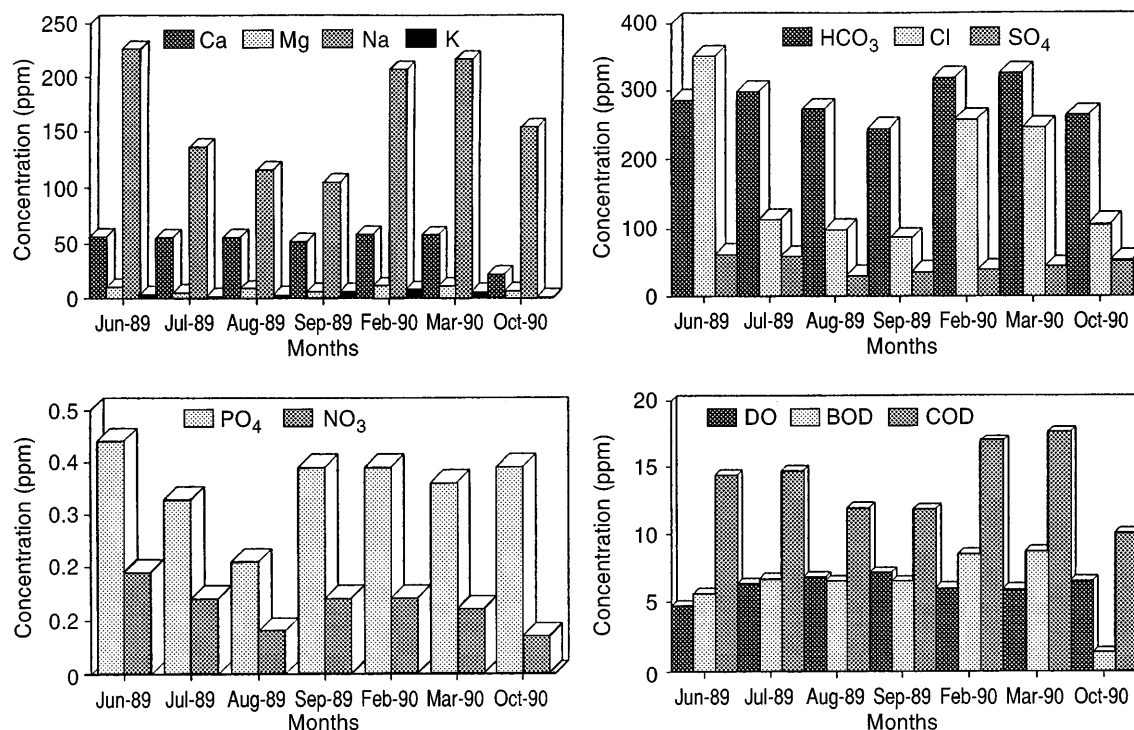
#### Natural sources

It is important to consider the mineralogy and chemistry of aquifer materials. The basalts constituting aquifers in this area are made up of two important silicate phases, for example plagioclase feldspars (labradorite) and pyroxenes (augite). As plagioclase feldspar forms a solid solu-

**Fig. 2**

Spatial variations in the major and indicator parameters along cross sections A-A' and B-B', Sonai area, Ahmednagar district, Maharashtra

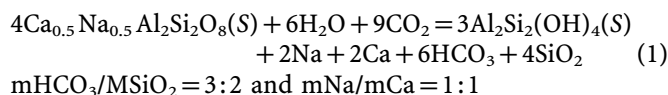




**Fig. 3**

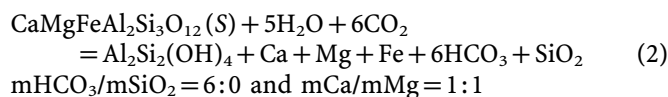
Temporal variations in the major, minor, and indicator parameters for the groundwaters from Sonai area

tion series between anorthite (An) and albite (Ab), the mole ratios of different cations in the groundwater depend on the An content of the plagioclase (Garrels 1967). In labradorite, An content varies from 50% to 70% and the chemical reaction for plagioclase with 50% An content can be given (Raymahashay 1986) as:



This reaction suggests that, in response to the natural water-rock interaction process, the groundwater in the area will acquire Na, Ca, and  $\text{HCO}_3$  in specific proportions, besides  $\text{SiO}_2$ .

Another important mineralogical constituent of the basalt is the pyroxene group mineral, augite. The chemical reaction for the dissolution of augite can be written as:



From reaction (2) it can be inferred that the release of Ca, Mg, and  $\text{HCO}_3$  ions is governed by interaction of groundwater with augite. These two reactions suggest that plagioclase and augite are the two chief sources of supply of major cations (Ca, Mg, and Na) and  $\text{HCO}_3$  as an anion to the groundwater. There is no apparent source of  $\text{SO}_4$  and Cl in the basalt. However, rainwater and anthropogenic activities of man can be important

sources. In a highly irrigated area, heavy use of fertilizers is possibly responsible for high background values of chloride and sulfate in groundwater (Pawar and Shaikh 1995).

#### Sugar-mill effluent as a source

As noted, there is no lithological variation in the area. Therefore, under natural conditions there should be no occurrence of anomalous values of ionic constituents in the groundwater. Instead, systematic variation in the ionic constituents along the flow paths of the groundwater would be expected. Elevated values of ionic constituents, obtained for a few wells, can be interpreted as being due to contamination and mixing of foreign waters with natural groundwater. Wells W8 and W9 have higher values of dissolved constituents in comparison with the background groundwater. As these wells are in the close vicinity of the effluent-carrying stream and are located in the downgradient direction, the high values of certain parameters can be related to the mixing of the effluent with background groundwater. This can be investigated with the help of ion concentration ratios, i.e., Na/Ca, Ca/Mg, and Cl/ $\text{HCO}_3$ .

To evaluate sugar-mill effluent as a source of groundwater contamination, wells from the area were classified into two groups: (1) wells upgradient of the effluent source and (2) wells downgradient of the effluent source. Six wells (W6, W7, W11, W16, W17, and W18) fall into group a and the remaining wells belong to group b. The average values of molar ratios for the two well groups are given in Table 3.

The wells of group a representing background groundwater have lower Na/Ca, Ca/Mg, and Cl/ $\text{HCO}_3$  ratios as compared to group-b wells representing groundwater in

**Table 3**  
Average ionic ratios for well groups and the effluent

well groups	Na <sup>+</sup> /Ca <sup>2+</sup>	Ca <sup>2+</sup> /Mg <sup>2+</sup>	Cl <sup>-</sup> /HCO <sub>3</sub> <sup>-</sup>
group 'a'	3.03	4.04	0.69
group 'b'	3.32	5.12	0.99
effluent	0.29	5.10	1.05

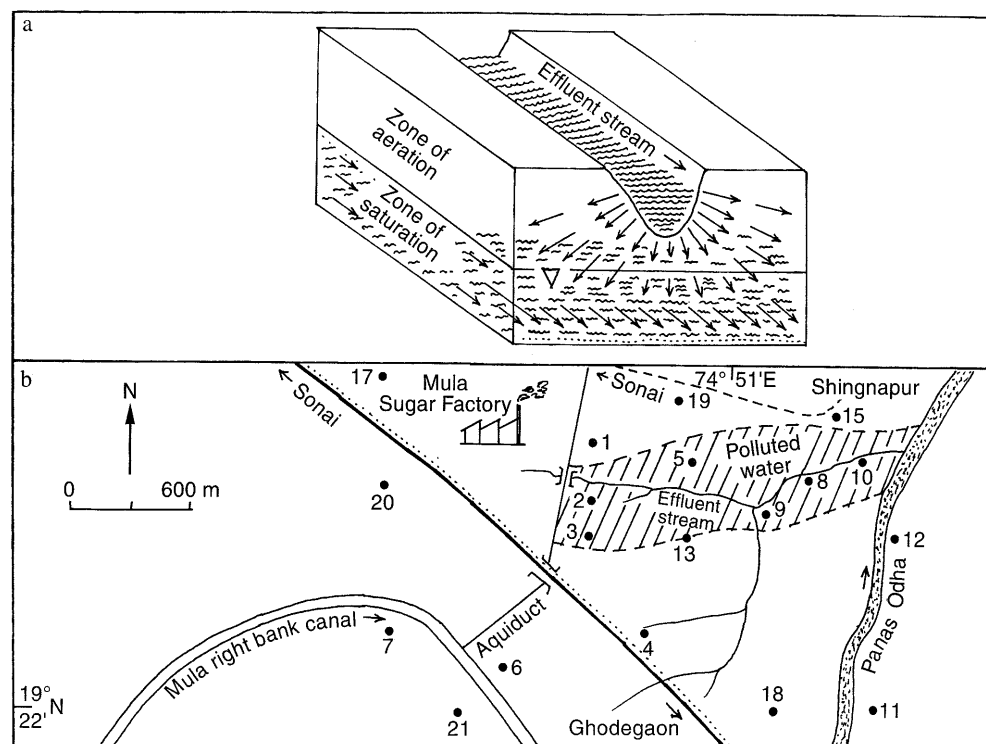
the downstream direction of the effluent-carrying stream. The ratios for the effluent are comparable to the average ratios for the group-b wells except for the Na/Ca ratio. The values of the Ca/Mg and Cl/HCO<sub>3</sub> ratios for the effluent and the group-b wells are almost the same, suggesting that most of the wells are receiving ions in solution from groundwater mixing with effluent. Higher values of Na/Ca for both well groups are suggestive of precipitation of calcium carbonate from groundwater (Pawar 1993). The precipitation of CaCO<sub>3</sub> can be considered as an important sink for calcium in the groundwater. However, the increase in the Ca/Mg ratio for group-b wells possibly indicates that the rate of addition of Ca from the effluent is greater than the rate of precipitation from groundwater. The precipitation of CaCO<sub>3</sub> accompanies the positive values (Table 1) of saturation indices for calcite (SIc). The higher Na/Ca values obtained for the background and polluted groundwater support this inference.

#### Mechanism of groundwater pollution

Geoenvironmental conditions of the area have a marked influence on the mechanism of groundwater pollution. It must again be noted that sugar processing is a seasonal

industry. Hence, the source of groundwater pollution, for example the effluent-carrying stream, flows only for the period of operation of the sugar factory. In addition, the stream under consideration is very small. This implies that there is no flow of natural water, i.e., base flow, throughout the year except for surface run-off during rainfall events. Further, the artificial flow generated by the release of effluent also ceases for a couple of months when the factory closes in the rainy season. Subsequent to the rainy season, the average depth to groundwater in the winter months is minimum, i.e., average depth to water table  $\cong$  2 m. During this period, the stream remains dry and the factory operation recommences. The operational period of the sugar factory corresponds with the major part of the winter and early part of the summer season in the area. The average depth to groundwater during the early summer months is 3.6 m.

A large quantity of industrial waste water is released into the stream. The degree of dilution of waste water is governed by the base flow of the stream (Blair 1972); however no base flow exists. This makes the stream influent to the aquifer in the area, at least for the period of operation of the factory. Under such conditions, the waste water percolates through porous and permeable soil and weathered basalt to reach the aquifer. Furthermore, the aquifer in the area is in direct hydraulic contact, as evidenced by nearly waterlogged conditions in the downstream reaches near the confluence with the Panas Odha, favoring induced infiltration of waste water. In addition, in the immediate vicinity of the stream, groundwater from the shallow basaltic aquifer is abstracted continuously for agricultural use. In effect, the effluent from the stream is drawn into the aquifer rapidly.



**Fig. 4**  
a A block diagram showing the mechanism of groundwater pollution in the Sonai area, Ahmednagar district, Maharashtra. b An illustration showing the lateral extent of polluted groundwater plume in the Sonai area

Infiltration of effluent through the soil and weathered basalt is probably the primary cause of contamination of the shallow groundwater aquifer. Entry of pollutants into the shallow aquifer is due to the downward percolation thorough the zone of aeration to form a recharge mound at the water table and further lateral movement below the water table (Fig. 4a). Effluent draining downward to the water table mixes with groundwater and undergoes lateral flow. Pollutants in the saturated zone have formed a plume of polluted groundwater extending in the downstream direction. It has been possible to delineate the lateral extent of pollution plume by considering the area of anomaly. In Fig. 2, the geochemical data for the wells along the cross sections A-A' and B-B' are plotted for the major and indicator parameters. It is observed that along the cross section A-A' elevated values of ionic constituents were obtained for the wells situated between W13 and W15. Similarly, wells W5, W8, and W10 along cross section B-B' also show elevated values. Thus, the area of the anomaly was considered to represent the lateral extent of a plume of polluted groundwater on either side of the effluent-carrying stream. Since the depth of the water table is minimum, i.e., average 2.0 m during the period of operation of factory as compared to the maximum water-table depth (3.6 m) during summer, the pollution plume has spread laterally over a distance of more than 100 m to nearly 400 m on both sides of the stream (Fig. 4b). The zone of polluted groundwater has an area of nearly 3.5 km<sup>2</sup>.

## Summary and recommendations

On the basis of chemical analysis of groundwater samples it is possible to establish that sugar-mill effluent is a source of pollution of groundwater in the area. In India, more than 80% of the population is dependent on groundwater as the only source of drinking-water supply. Most efforts are focused on locating the groundwater reservoirs to satisfy drinking water needs and the quality aspect is often neglected. As stated earlier, the sugar factory is a rural industry and continued operation of this industry, without environmental precautions, may lead to serious health problems in the area. In the Ahmednagar district alone, there are 13 such sugar factories with several types of allied units associated with them. Moreover, in majority of villages there is no organized water-supply facility. Instead, the rural population is dependent on traditional sources of water supply, e.g. the fetching of water directly from rivers, springs, canals, community dug wells, and recently taken bore wells in some areas of water scarcity. Many of these water-supply sources are unfit for human consumption and rural populations suffer epi-

demics throughout the year. Water-quality management is an issue that must be given top priority.

The following measures have been recommended for the protection of groundwater.

1. Lining the stream course used for waste disposal and waterproofing the base of the lagoon (i.e., effluent storage ponds) and the stream bed to prevent infiltration of the effluent.
2. Treating the effluent to meet the standards established by Indian Standards Institution for releasing the waste into the stream.
3. Launching public-awareness programs and convincing the authorities to undertake groundwater protection measures.

**Acknowledgements** The authors gratefully acknowledge the facilities provided by the School of Environmental Sciences and Department of Geology, University of Pune. Thanks are also due to anonymous reviewer for many useful comments.

## References

- ANAND M (1987) Impact of Sugar Policy. *J Bhartiya Sugar Dir* 1:213–221
- APHA, AWWA and WPCF (1989) Standard Methods for the examination of water and waste water. American Public Health Assoc, Washington DC
- BHATT KB, SAKLANI S (1996) Hydrogeochemistry of the Upper Ganges River, India. *J Geol Soc India* 48:171–182
- BLAIR H (1972) Hydrogeological factors in groundwater pollution. The Water Research Assoc, Medmenham Bucks, England
- GARRELS RM (1967) Genesis of some groundwaters from Igneous rocks. In: Abelson PH (ed) *Researches in geochemistry*, v. 2, Wiley, New York, pp 405–420
- HANDA BK (1981) Hydrochemistry, water quality and water pollution in U.P. Tech Report Central Ground Water Board (CGWB), Ministry of Irrigation
- KRUPANIDHI KVJR (1984) Mechanism of ground water pollution in village wells. *J Geol Soc India* 25:301–302
- KUNDRA R, PURTHY S (1979) Sugar industry and pollution. In: Deshbandhu R, Bharatdwaj V (eds) *Ecology and development*. Indian Env Soc, New Delhi, pp 178–190
- MANAS C (1976) Water pollution in textile, leather and paper industry water. *Ind Chem Man* 14(3):13–14
- Matthess G, Harvey JC (1982) *The properties of groundwater*. Wiley, New York
- PAWAR NJ (1993) Geochemistry of carbonate precipitation from the groundwaters in basaltic aquifers: an equilibrium thermodynamic approach. *J Geol Soc India* 41:119–131
- PAWAR NJ, SHAIKH IJ (1995) Nitrate pollution of groundwaters from basaltic aquifers, Deccan Trap Hydrologic Province, India. *Environ Geol* 25:197–204
- RAYMAHASHAY B C (1986) Geochemistry of bicarbonate in river waters. *J Geol Soc India* 25:466–470
- STARR RC, GILLHAM RW (1993) Denitrification and organic carbon availability in two aquifers. *Groundwater* 31:934–948