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Environmental Impact of Sugar mill Effluent on the Quality of Groundwater from Sangamner, Ahmednagar, Maharashtra, India

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Abstract

Among the factors polluting the soil and groundwater, sugar mills certainly have a larger share in form of their discharges of the large account of wastewater as effluent. Increasing use of chemical fertilizers and pesticides in raising the sugarcane production has also resulted in the degradation of soil and groundwater quality. Taking this view into amount, the present study aimed at conducting a detailed investigation of the impact of sugar mill effluent on the ground water quality in the vicinity of sugar mills in Sangamner. Fifteen groundwater samples were analysed for various parameters like pH, EC, TDS, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3, SO_4^{2-}, PO_4^{3-}, NO_3^- and total hardness during the period of operation of sugar mill. The results revealed that there was significant variation in some parameters. The high values of Ca, Na, chloride, sulphates, nitrates and hardness in the samples which are located downstream suggest that sugar mill effluent is the source of soil and groundwater pollution. According to permissible limit suggested by Indian standard – drinking water specification -1991. During this study, it was found that the samples in flowing to the downward direction land located in the close proximity of stream of effluent are not suitable for either drinking or irrigation purposes. The investigation suggests that water quality management, an important issue for the sustenance of human civilization must become a major priority.

Keywords: Sugar mill effluent, groundwater quality, groundwater pollution, environmental impact, spatial variations, salinisation.

Introduction

Undoubtedly, water is the most essential requirement not only for life sustenance but for the economic and industrial development. At the same, it is a known reality that water is an important issue in the maintenance of our environmental balance with the rapid growth of population and acceleration in industrialization. In last few decades, the tremendous increase in the demand for freshwater has also been a matter of great concern. The release of treated and untreated industrial effluents in unplanned manner is one of the major causes of water pollution. The effluents released from sugar cane factory into land and into various surface water bodies not only affect the water quality and soil but also pollute the groundwater due to percolation of some water soluble pollutants[1].

Industrial and domestic waste water come into contact with natural water bodies. Such waste waters contain large amount of dissolved chemical constituents and many a times, microorganisms in them. In rural area small scale industries like dairy, poultry etc and large scale industries like sugar, distillery, paper etc. release the waste (solid and liquid) after partial treatments like lagooning or often without any treatment on the land surface or directly into the natural streams thereby admitting some hazardous chemicals. These waste material is also serving as a medium for growing bacteria, fungi or chemical minerals like Na^+, K^+, NO_3^-, PO_4^{3-} etc get in groundwater by percolation through the soil and thus contaminate groundwater. Disposal of industrial waste in the open space and abandoned dug wells have thus caused the pollution of groundwater in some parts of rural India. Industrial effluents often infiltrate upto the of pheratic zone of aquifer depending upon the porosity and the permeability of the medium of infiltration resulting in acceptable concentration of TDS, fluorides and iron resulting in severe contamination of the groundwater[2].

Sugar industry consumes substantial volume of water and chemicals in different processing units. All chemicals used wash away with the waste water discharged through industrial outlet. Thus effluents consist of all types of chemicals which contain toxic heavy metals. Effluents store pond is highly contaminated. Effluents moves along with heavy metals and reach in shallow water table by leaching processes and contamination may disperse in a wide range of the region. Contamination of soils of close areas occurs when the effluents or polluted water comes under contact of soil. The regular contact of polluted water with soil makes the sodic soils and alters the physico chemical characteristics, texture and profile of soil stratum[3].

India is widely known for its sugar industry; it has emerged as one of the largest sugar producing country in the world. In term of the economic development, sugar industry played a vital role in the Indian subcontinent. The industry particularly in Maharashtra holds a very important position in the economy and politics of the state. These sugar industries have initiated many economic activities by setting up dairies, distilleries, paper mills and poultries etc. in their respective regions. Besides, many of sugar industries run their own educational institutions to impart education at different levels e.g. from KG to PG and have started the technical institutions. Thus, contributing to the social change rural areas within their jurisdiction[4].

Increase in sugar industrialization along with high rate of urbanization and subsequent increase in population has led to unprecented increase in the environmental degradation of the resources. The damage to both aquatic and terrestrial ecosystems caused by the enormous quantity of waste released in the form of effluent produces is certainly alarming. These pollutants not only alter the physico chemical characteristics of the recipient aquatic bodies but also affect the aquatic flora and fauna. Similarly, the rural and semi-urban population, drinking water from streams or rivers and using it for agricultural and domestic purposes has undergo serious health hazards on account of the sugar mill effluents, being discharged into the environment. Farmers have been using these effluents unscientifically for irrigation and found that the growth, yield and soil health is reduced. Contaminants such as Cl^-, SO_4^{2-}, PO_4^{3-}, Mg^{+2} and NO_3^- are discharged with the effluent which creates a nuisance due to physical appearance, odor and taste[5]. In recent past various studies have been made on the impact of sugar mill effluent on groundwater quality[6-13].

Sangamner area is of particular importance because effluents from municipal sewage, agricultural runoff, sugar cane factory effluents and industrial waste are discharged into the Pravara River bringing out considerable change in the groundwater quality. However there exists negligible data and information available about the effect of sugar mill effluent on the quality of groundwater of this area. Considering these serious issues, the present study was carried out to find out the possible effects of such effluents on the quality of groundwater in the proximity of a sugar factory.

Sangamner Sugar Factory: The place of study is Sangamner sugar factory which is located at Ghulewadi, one of villages in Sangamner Tehsil of the Ahmednagar district of Maharashtra. It is included in the toposheet no 47/I/2 of the survey of India and lies between 18° 36' N to 19° 1' N latitude and 74° 1' W to 74° 56' W longitude (Figure-1). Sangamner sugar factory is located in the study area. It is a Co-operative Sugar factory started in 1966-67 with the initial capacity of 800 tons of sugarcane crushed per day (TCD). This initial capacity has been expanded two to three times and presently it is 3500 TCD (since 1989-90). The raw water requirement for the industry is about 1500-1700 lit/ton/day. The water goes through the internal processes, in the boiling house, mill house and filter cloth washing and comes out as an effluent. This effluent with very little partial treatment like lagooning goes through a zig - zag natural stream flowing through the agricultural area in the downstream part for a distance of about 5 km and finally meets the river Pravara at Sangamner. Geographical locations of lagoons are at higher elevation in the foothill zones where thickness of colluvial deposits is more, colluvium overlies on amygdaloidal/vesicular basalt that shows moderate degree of weathering. This has possibly favoured induced infiltration of effluent into the subsurface. In addition to this, while flowing through the natural stream the effluent infiltrates through the soils, leading to contamination and changes in chemical composition of water from nearby dug wells. It should be noted that water from this area was uncontaminated and was also of potable quality prior to installation of the sugar factory.

Methodology

The streams carrying effluent from sugar mills flows through the study area. The loss of some effluents envisaged due to percolation through the soil zone. This waste water is therefore, expected to reach the groundwater table. Hence it was essential to have the sampling sites near the stream and few meters away from the effluents stream. The groundwater composition is likely to vary from place to place due to the effect of mixing of effluent with natural groundwater. Hence representative water samples were collected from the wells close to the stream and progressively away from it. Thus fifteen sampling stations in the study area were selected (Figure-1) by adopting the above mentioned criteria. The wells which are used for drinking, irrigation and contaminated by sugar mill effluents were selected for sampling.

The wells located in platea top, hill slopes and valley floor areas spread over either side of Pravara River were included. By considering such an approach it should be possible to study the impact of sugar mill effluent on the groundwater quality. Considering the operational period of Sangamner sugar factory the groundwater samples were collected at appropriate time. The samples were collected in polyethylene bottles of one liter capacity. The care was taken to collect samples after pumping for some time. The pH, electrical conductivity (EC) and temperature were measured in the field. The analysis was carried out in the laboratory by using the procedures given by APHA[14]. Using titrimetric methods, the analysis of chloride (Cl), total alkalinity as $CaCO_3$, Calcium (Ca^{+2}) and total hardness as $CaCO_3$ (TH) was performed. While nitrate, phosphate and sulphate were analyzed by spectrophotometric methods (Hitachi-2000, UV-visible spectrophotometer), the alkali elements like sodium and potassium were detected by flame photometer (E1 850 A, Equiptronics). The data obtained through the chemical analysis of groundwater is presented in table 1.

Table-1
Physico–chemical Analysis for groundwaters from Sangamner area, Ahmednagar, (M.S.)

S. No	pH	EC	TDS	Na	K	Ca	Mg	Cl	HCO_3	SO_4	PO_4	NO_3	TH
W1	9	860	559	12	1	88	51	45	302	18	0.6	27	429
W2	9	1650	1073	23	1	189	3	141	327	18	0.4	32	481
W3	9	3050	1983	41	0	181	84	325	306	28	0.4	35	797
W4	8	3060	1989	49	1	128	93	325	327	33	0.4	15	712
W5	9	2140	1391	67	0	72	117	182	468	23	0.4	37	662
W6	8	2510	1632	72	1	297	29	224	516	40	0.5	25	862
W7	8	6470	4206	182	1	413	183	875	504	66	0.3	97	1783
W8	8	3510	2282	184	2	208	20	280	617	63	0.3	42	2246
W9	8	4420	2873	174	0	236	95	397	665	87	0.3	110	982
W10	8	5840	3796	150	1	385	261	852	407	97	0.3	52	2043
W11	9	3500	2275	6	0	189	144	442	339	39	0.3	43	1062
W12	9	4370	2841	56	1	429	105	587	492	74	0.3	97	1504
W13	8	6440	4186	60	2	414	231	863	407	89	0.3	44	1984
W14	8	2270	1476	25	1	161	54	182	387	44	0.3	41	622
W15	9	1570	1021	23	1	160	7	161	141	59	0.3	81	430

(N.B.: All concentrations are reported in mg/l except pH and EC (μ/cm)

Results and Discussion

Spatial variations in the pH and EC: The pH of the groundwater from the study area varies from 8.1 to 9.1 indicating weakly to moderately alkaline nature of groundwater. Higher values of pH are related to higher ionic content of water. The higher values of pH have been obtained for samples (S. No. W1, W2, W3 and W5) which are close to the river channel and also in the downstream parts of Pravara River and near sugar factory region. These high values are indicative of the presence of higher amounts of carbonates and bicarbonates in the groundwater.

The conductivity measurement is an indicator of ionic concentration of water. It depends upon temperature and concentration and types of ions present[15]. The electrical conductivity of the groundwater varies from 860 to 6470 μS/cm. High EC is observed in the low lying alluvial part of the basin and near sugar factory area where stream is flowing along with effluents. Higher EC values suggest existence of highly mineralized groundwater. Mineralization is possibly due to higher residence time, sluggish movement of groundwater and intensive water – rock interactions in the alluvial aquifers. Low EC found for the samples (S. No. W1,W2,W3,W5,W6 and W15) are from upstream part along foothills or on the plateau top covered by non irrigated agriculture. Rolling topography, relatively higher gradient and higher rates of flushing of salts provide less time for water rock interaction leads to lower EC from the study area.

Spatial variations in the cationic constituents: Calcium and magnesium are the dominant cations in the groundwater from the study area followed by sodium and potassium. On the average Ca^{+2}+Mg^{+2} in equivalent units accounts for 75% of the sum of cations. On the individual basis, the values of Ca^{+2} range from 72 mg/l to 413 mg/l. Similarly, the values of Mg^{2+} range between 7 mg/l and 261 mg/l. In general, the Ca^{2+} concentrations have been found to be higher in the wells which are located in the downstream part and sugar factory region (S. Nos. W7, W10, W12, W13) than in the upstream part. The higher calcium concentration in the wells suggest that the effluent carrying stream and plagioclase feldspar as the dominant source[15]. The higher concentration of Mg in groundwater from some of the wells is due to the weathering of pyroxenes present in the basaltic rocks from the study area.

The concentration of Na^{+} varies from 6 to 184 mg/l and that of K^{+} from 0.2 to 1.6 mg/l. The values of Na^{+} increases in the downstream part of sugar mill effluent stream (S. No. W7, W8, W9 and W10). Sodium concentration in the groundwater is the result of chemical weathering of plagioclase feldspars present in the basalt. Apart from the natural sources, human activities i.e. sugar mill effluent have significant influence on the concentration of sodium in the groundwater[16]. In the study area however the higher Na^{+} concentration is the combined effect of geological source as well as evaporative concentration in the downstream part where water-table is at shallow depth. Higher concentration of sodium in the groundwater indicate that apart from contamination of groundwater from the effluent, the processes such as salinisation and/or alkalization of soils and groundwater due to excess irrigation are more important. The concentrations of K^{+} is negligible.

Spatial Variations in the anionic constituents: Amongst the four major anions (Cl^{-}, HCO_3^{-}, SO_4^{2-} and NO_3^{-}), the chloride is found to be the most predominant anion followed by bicarbonate, sulphate and nitrate. The concentration of bicarbonate ranges from 141 mg/l to 665 mg/l. The high bicarbonate concentration observed in the downstream part of sugar mill effluent stream (S. No. W7,W8,W10,W11,W12 and

W13) is possibly due to flat topography, providing sufficient length of time for the aquifer material to interact with the groundwater[17]. Both silicate mineral weathering of basalt and dissolution of carbonate present in the alluvium and addition of effluent from sugar factory seem to be the potential sources of bicarbonates in the groundwater from the study area.

The chloride concentration in the groundwater ranges from 45 mg/l to 875 mg/l. The chloride concentrations are higher in the downstream part of the sugar mill effluent (S.No.W7, W10, W11, W12 and W13). There is no lithological source of chloride in the area. Hence higher concentration of chloride in the area close to sugar-mill and other industries indicate contribution of chloride could be due to mixing of waste waters and severe contamination of groundwater from the chloride rich effluent as the source.

The sulphate concentration in the groundwater of the area varies from 18 to 97 mg/l. The higher concentrations of sulphate is observed in the downstream part which could be due to excessive use of fertilisers or use of soil amendments (S. No. W6, W7, W9, W10, W12 and W13). The lower values of sulphate have been observed in the upstream part of the basin (S. No. W1,W2,W3 and W15) indicating negligible contribution from lithological sources.

The nitrate concentration varies between 15 to 110 mg/l. The high level of nitrate are observed in the downstream part and also around sugar factory area (S.No. W7,W9,W11 and W12). Around sugar mill there is mixing of effluent with the groundwater which is responsible for high orders of nitrate values. However, there does not seem to be any discernible pattern of distribution nitrate along the direction of groundwater movement. Thus, nitrate pollution in the area is the combined effect of agricultural activity, the mixing of sugar mill effluent and the animal wastes.

Groundwater quality for drinking purposes: Groundwater is the only source of drinking water for more than 80% of the population in India. As a part of this dependency, most efforts are directed in locating the groundwater reservoir ignoring the quality aspect. The seriousness of the chemical contamination remains often neglected as the toxic chemicals do not show acute health effects unless they enter into the body in appreciable amount. However, the adverse health effects may result through the cumulative poison formed in the body. Thus, the sugar factory continuing its operation without taking environmental precaution may cause serious health problems. Such health related problems are observed in the Sangamner sugar factory region where the people used to drink groundwater. In view of this, it was decided to study the impact of sugar mill effluent on the groundwater resources in the area. Table 2 shows the critical parameters exceeding the Indian standard – drinking water specification – 1996, permissible limit along with the permissible limit for these parameters[18].

It is observed that the pH of 5(33.33%) samples exceeds the permissible limit prescribed by drinking water standard. It is found from the Table 2 that the Ca of 7(46.67%) samples have exceeded the permissible limit specified by drinking water standard[18]. Therefore, constant use of such well waters for drinking purpose may lead to kidney stones or joints pains in population. In case of magnesium it is observed that 6(40%) samples have exceeded the maximum permissible limit (Table 2) prescribed by drinking water standard[18]. It is observed from Table 2 that the nitrate of 5(33.33%) samples from the study area have exceeded the permissible limit of nitrate prescribed by drinking water standard[18]. However, nitrates do not directly contribute to the problem. It is the bacteria present in the digestive tract converts the nitrate into highly toxic nitrites and this might lead into 'blue baby syndrome' (Methamoglobinema) in infants. Thus, the groundwater resources contaminated with high levels of nitrate prove be environmental hazards[19-21]. It is observed that wells from the irrigated agricultural surrounded by sugar cane field, close to cattle waste disposal areas and near sugar factory have been shown higher concentration of nitrate. This is possible due to leaching of organic and inorganic fertilizers from irrigated land and effluents from sugar mill.

Table-2
Critical parameters of drinking water exceeding the Permissible limit in the study area

Parameter	Indian Standard drinking water – specification IS 10500 -1991 (Reaffirmed 2009)		No. and locations of the samples exceeding permissible limit
	Desirable Limit	Permissible Limit	%
pH	6.5 to 8.5	No relaxation	W2,W3,W5,W11 and W15 = 5 (33.33%)
TDS, mg/L	500	2000	W7,W8,W9,W10,W11,W12,W and W13 = 7 (46.67%)
Ca, mg/L	75	200	W6,W7,W8,W9,W10,W12 and W13 = 7 (46.67%)
Mg, mg/L	30	100	W5W7W10W11W12 and W13 = 6 (40%)
Cl, mg/L	250	1000	Nil
SO_4, mg/L	200	400	Nil
NO_3, mg/L	45	No relaxation	W7,W9,W10,W12 and W15 = 5 (33.33%)
TH, (as $CaCO_3$) mg/L	300	600	W3,W4,W5,W6,W7,W8,W9,W10,W11,W12,W13 and W14 = 12 (80%)

Hardness of groundwater and groundwater quality for drinking purposes: The study shows that the hardness of groundwater of 12(80%) samples have exceeded maximum permissible limit (table 2) prescribed by drinking water standard[18]. Therefore, it is found in the study area that majority of the samples in the sugar factory area and wells along the path of sugar mill effluent is not suitable for drinking purposes.

On the basis of hardness, groundwater can be classified into four categories[15]. These are

i. Very hard : <300mg/l. ii. Extremely hard class I : 300-600 mg/l. iii. Extremely hard class II : 600-1200 mg/l. iv. Extremely hard class III : >1200 mg/l.

In the study area, the groundwater has been categorized as per above classification. It is observed that the groundwater can be described as 3(20%) samples show extremely hard class I, 7(46.66%) shows extremely hard class II and 5 (33.33%) belong to extremely hard class III. Therefore it is observed that sugar mill effluent has the impact on groundwater quality in the study area and it can be categorized as very hard to extremely hard type.

Groundwater pollution due to sugar mill effluent: To evaluate the sugar mill effluent as a source of groundwater contamination, the wells from the study area are selected along the cross section from Chandanapuri Ghat to Karhe Ghat (figure 1). Out of 15 wells, 3 wells (S. No. S1, S2 and S3) from southern part penetrate predominantly through basaltic aquifers. Similarly from northern part through 7 wells (Sr. No. W15, W14, W13, W12, W11, W10 and W9) pierce though basaltic aquifers. All these wells both from southern and northern part of the valley section represent recharge areas of the basin. The remaining wells (S. No. W8, W7, W6, W5 and W4) displaying composite lithosection consisting of alluvium and basalt represent discharge area. Some of the wells (S. No. W7 and W8) located close to river bank show higher thickness of alluvial aquifers. In contrast, the wells which are situated close to the base of hills in Ghat section pierce through colluviums and basaltic lithology (S. No. S1, S2, S3 and S15). The groundwater flows from water divides on either sides (Chandanapuri Ghat and Karhe Ghat) to the central part of the valley where Pravara River is flowing. This is to say that groundwater flow is clearly associated with physiographic setup of the area. Although the main Pravara valley is in the E-W direction, the slopes on northern part (Karhe Ghat) and southern part (Chandanapuri Ghat) of the vally have been eroded by numerous small to medium sized tributaries of the Pravara River. This has developed local valleys and water divides thereby affecting the regional flow pattern. As a result of this hydrogeomorphic and hydrogeological set up, the groundwater is flowing from southern part i.e. Chandanapuri Ghat towards the vally and similarly from northern i.e. Karhe Ghat where sugar factory is located to central part i.e. towards Pravara river (figure 2).

Mechanism of groundwater pollution in the area: As sugar processing is a seasonal activity the samples for the groundwater pollution were to be collected only during the period of operation in the sugar factory. 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 winter months is minimum i.e. 2.5 m. During this period, the stream remains dry and factory operation recommences. The operational period of sugar factory corresponds with the major part of winter and early part of summer season in the area. The average depth to groundwater during early summer month is 4 m. During the period of operation of the factory, waste water percolates through porous and permeable soil and weathered basalt to reach the aquifer. Then the aquifer creates waterlogged conditions in the downstream reaches over confluence of Pravara River, favoring induced infiltration of waste water. This leads to salinisation of groundwater (figure 2). The primary cause of contamination of the shallow aquifer apparently seems to be the infiltration of effluents through the soil and weathered basalt. It is the downward percolation through the zone of aeration allows the pollutants to enter the shallow aquifer. This percolation forms a recharge mound at the water table and further lateral movement below it. The effluents, draining downwards and reaches the water table and get mixed with the groundwater and then becomes the part of a lateral flow.

On the basis of TDS, salinisation of groundwater is defined by Mehta et al[22]. The waters with TDS content ranging from 400 to >3000 mg /l have been designated as saline water. Hem[15] classified water into four categories based on the TDS values. They are slightly saline (1000-3000 mg/l), moderately saline (3000-10,000 mg/l), very saline (10000 to 35000 mg/l) and brine (>35000 mg/l). By using the same criteria, the wells along the cross section of Pravara basin were classified. It is observed that in the recharge zone (S. No. W1) wells belong to fresh water class (TDS<1000mg/l), the wells (S. No. W2, W3, W4, W5, W6, W8, W9, W11, W12, W14 and W15) which are in the intermediate part between recharge and discharge areas, belong to slightly saline water class. The wells (S. No. W7, W10, and W 13) are situated on the both sides of river representing discharge zone are moderately saline in character. The wells (W15, W14, W13 and W12) located in the recharge zone near Karhe Ghat are expected to represent fresh water class. However, interestingly, all of them show slightly saline and moderately saline water characters (figure-2). This is possibly due to contamination of the wells by mixing of sugar mill effluent. These wells are located in the down gradient direction of the effluent storage pond (lagoons) of sugar factory besides being in close proximity to the effluent carrying stream. Due to mixing of effluents into the wells, saline water characteristics have been developed. As mentioned earlier the ground water is slightly to moderately saline in character in the discharge zone. This is possible because of alluvial lithology, flat topography and intensive irrigation practices that have lead to the problem of salinization. The observations further show that the area with

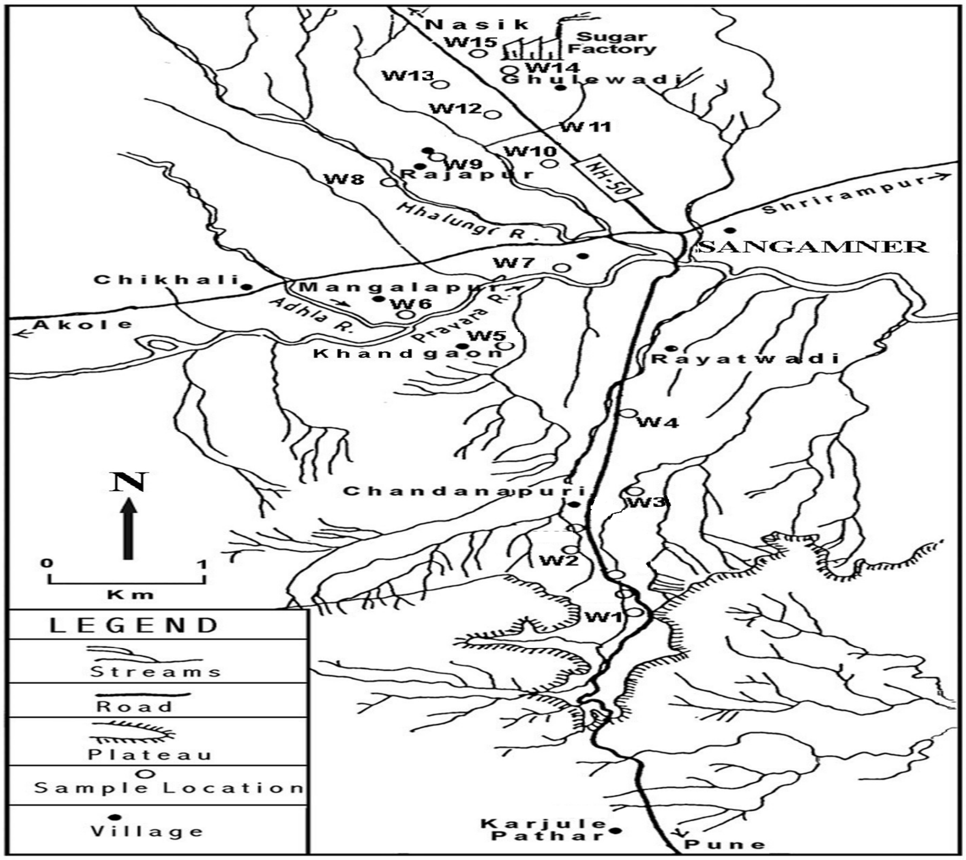

Figure-1
Location map of study area showing sugar factory in Sangamner, Ahmednagar, Maharashtra

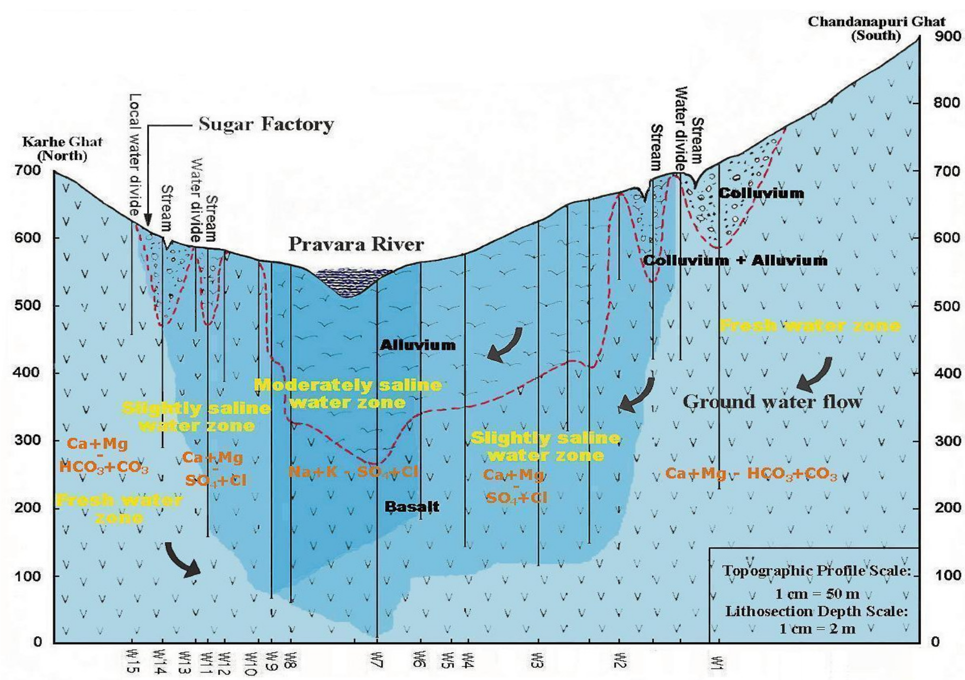

Figure-2
Mechanism of groundwater pollution due to sugar mill effluent in the study area

TDS below 1000 mg/l lies in the recharge zone, which is predominantly non-irrigated agricultural region and located on the plateau and hilltop. Therefore, absence of saline waters or presence of fresh water in this part is possible due to the faster circulation of ground water attributable to physiography. On the contrary, in the discharge zone, flat topography responsible for sluggish groundwater flow conditions has lead to higher residence time and greater rock-water interactions. In addition to this, intensive irrigation and excess use of fertilizers have lead to higher salinity in the area.

Conclusion

On the basis of chemical analysis of groundwater samples, it is possible to study the effect sugar mill effluent as a source of pollution of groundwater in the area. Sugar industries in India are mainly located in the rural parts. The study reveals that the sugar industries through their continued operation, without taking the environmental precaution may cause serious health problems to the rural population residing in the proximity. Comparison of data with the water quality standard indicated that the parameters like TDS, Ca, Mg, TH and nitrate have exceeded the prescribed limit in the majority of the samples particularly from the sugar mill effluent area. TDS of groundwater indicate slightly saline to moderately saline groundwater properties which suggests that the quality of groundwater from sugar factory area is almost unsatisfactory for drinking purpose. Majority of samples from sugar factory area have exceeded the permissible limit of nitrate. It is clear that the groundwater becomes polluted due to sugar industry effluent from surrounding area. Hence it is not suitable for human consumption without prior treatment. The following measures have been recommended for the protection of groundwater. i. Lining the store pond and water proofing at the base of lagoon. ii. Treatment to effluent releasing from sugar factory is essential to meet the required standards established by Indian standards institutions. iii. Arranging public awareness programme and there is a need for periodic testing of groundwater in the vicinity of sugar factory. This information should be provided to farmers for maintenance of soil and groundwater quality.

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