Bio-Statistical Model for Impact of Sugar Industry on Groundwater Quality in Malegaon (Tal. Baramati)

Shital K. Gadekar
Tuljaram Chaturchand College, Baramati,
District – Pune, Maharashtra, India

Vaishali V. Patil
Tuljaram Chaturchand College, Baramati,
District – Pune, Maharashtra, India

Neeta K. Dhane
Tuljaram Chaturchand College, Baramati,
District – Pune, Maharashtra, India

Abstract - Water is the precious gift nature to human beings. The groundwater of the sugar industry area (Malegaon) is going to be polluted day-by day. Although three-fourth part of earth is being surrounded by surface water but almost all the ground water in India is unfit for direct irrigation due to industrialization. Two hundred fifty six ground water samples were collected from different locations around Malegaon sugar factory. These ground water samples were collected and analyzed for their physio-chemical characteristics. In this paper, we develop the bio- statistical model of impact of sugar industry on ground water quality in Malegaon using statistical tools such as Cluster Analysis, Principal component analysis, etc. The quality of ground water samples are discussed using bio-statistical model for their suitability for irrigation purpose. This will be helpful to farmers for irrigation purpose.

Keywords: Water quality index, Multiple Linear Regression, Cluster Analysis, Principal Component Analysis

I. INTRODUCTION

The sugar industry in Maharashtra is a key factor in the rural economy of the state. Growing demand for the sugar industries in all parts of the state is an indication of the importance of the industry to the rural development. In spite of the fact that the sugar Industry is the backbone of the rural economy of the Maharashtra, the need has arisen to review and recognize environmental problems associated with sugar industry. The problems of groundwater quality are particularly severe in many sugar industry areas and are threatening the rural population. Sugar may be responsible for more biodiversity loss than any other crop, due to its destruction of habitat to make way for plantations, its intensive use of water for irrigation, its heavy use of agricultural chemicals, and the polluted wastewater that is routinely discharged in the sugar production process.

Sugar industry is basically seasonal in nature and operates only for 120 to 200 days in a year (early November to April). Significantly large volume of waste is generated during the manufacture of sugar and contains a high amount of pollution load particularly in terms of suspended solids, organic matter, and press mud, bagasse and air pollutants. Therefore an attempt will made to take an overview of waste management in sugar industry.

For over 40 years, about 60% of the existing land area in Baramati Taluka was covered with sugarcane plantation. Over these years, a large amount of pesticides and fertilizers have been used in order to achieve a high yield but as side effects, these agricultural practices have represented particular risks to water sources. The fertilizers and pesticides have been penetrating the ground water sources and runoff during rainfall, thus adding to the level of contaminants in the surface waters.

In addition, over the past two decades, several surface water bodies have been receiving industrial effluent discharges containing chemicals and trace of metals. Metal residues and textile slurries with high trace metal concentration have caused great deal of pollution. Hence there are strong reasons to believe that groundwater near the Malegaon Sugar Industry of Malegaon may possibly be undergoing degradation of the water quality arising from the presence of biological and chemical pollutants.

Realizing the importance of groundwater quality and its deterioration, we decided to study the impact of Malegaon Sugar Industry on groundwater level of the concern area.

Keeping in view the main objective of the present investigation is the evaluation of physiochemical aspects of ground water quality from the selected locations around Malegaon Sugar Industry, to specify accurately and timely information regarding the quality of river water at industrial effluent disposal point and both at upstream and downstream flow of water. The present findings may be helpful to shape sound public policy and to implement water quality improvement program effectively as well as efficiently.

In order to study the physiochemical activities in the groundwater near the Malegaon Sugar Factory of Malegaon, several studies have been performed and the levels of various metals, nutrients, physical and chemical parameters were recorded. These studies have shown the presence of the toxic metals. Since the water pollution is hazardous for the human beings it is important to find out whether the presence of toxic substances is significantly increasing due to the impact of industrial sewage. The aim of this paper is to develop and analyze a multifactor bio-statistical model to assess the extent of water pollution in the Malegaon Sugar Industry of Malegaon.

II. OBJECTIVES

This study found that the continuous disposal of industrial effluents on land, which has limited capacity to assimilate the pollution load, has led to groundwater pollution. The quality of groundwater surrounding the factory locations has deteriorated, and the application of polluted groundwater for irrigation has resulted in increased salt content of soils.

Most of the samples, due to contamination of spent wash, were found unsuitable for the irrigation purpose. Hence we set the following objectives:

- Study the pollutants in the groundwater.
- To identify factors important for establishing the bio-statistical model.
- Develop a Statistical index for impact of Sugar Industry on groundwater quality.

III. METHODOLOGY

3.1 Sample Collection

Baramati is located in the eastern part of Pune district of Maharashtra state, having geographical coordinates such as 18° 9' 0" North, 74° 35' 0" East. It lies between 74.82 Longitude and 18.31 Latitude. The Baramati city is located on the bank of river 'Karha' and Malegaon sugar factory is 7 Km away from Baramati. Baramati is a Taluka place.

The groundwater samples of 334 sites were collected from hand pumps dug wells and bore wells in and around different areas of **Malegaon around the Sugar Industry, Malegaon, Baramati, District Pune, Maharashtra state (India)** are selected randomly and analyzed for their physiochemical characteristics. The various physiochemical parameters such as PH, Electrical conductivity, Ca^{++} , Mg^{++}, Na^{++}, $HCO3^{-}$, Cl^{-}, $SO4^{2-}$ etc. were determined using standard procedures of APHA. The distance between two sampling sites was kept more than 200 meters. The depths of collected water from bore wells and hand pumps were in the range of 20 to 50 feet.

Water samples were collected in a good quality polyethylene bottle of one-liter capacity during period (October 2013 to January 2014) and analyzed on the same day or one day after the collection. The samples after collection were immediately kept in dark boxes and analyzed in laboratory for various parameters at earliest.

3.2 Physiochemical Analysis

Samples were analyzed in the laboratory by using standard methods of analysis (APHA,1998). High purity (A.R. grade) chemicals and double distilled water was used for preparing solution for analysis. Various physical parameters like pH, and EC were determined within two hours with the help of digital portable pH meter and Conductivity meter in the laboratory. Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Chloride (Cl^{-}), and Bicarbonate ($HCO3^{-}$) were determined by volumetric titration methods; while Sodium (Na+) and Potassium (K+) by Flame photometry as recommended by APHA. All parameters are studied in the laboratory within a one day after collection of samples.

The irrigation quality parameters like Sodium Absorption Ratio (SAR), Residual sodium Carbonate (RSC) were calculated with the help of Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Chloride (Cl^{-}), Sodium (Na^{+}) and Potassium (K^{+}) in mill equivalent per liter (Me/l). These (Me/l) values of respected cation and or anions were used in following calculations of respective parameter of irrigation quality for getting its index.

Sodium Absorption Ratio (SAR):

The index is used for predicting the sodium hazard of water in agriculture use. It is the concentration of sodium and the proportion of sodium to calcium and magnesium. SAR is given by SAR (Me/l) = $\frac{Na^{2+}}{\sqrt{(Ca^{2+}+Mg^{2+})/2}}$

Residual sodium Carbonate (RSC):

If the water contains carbonate and bicarbonate in excess of calcium and magnesium then this excess is denoted as RSC and was calculated by following formula.

RSC (Me/l) = $(HCO_3 - CO_3) - (Ca^{2+} + Mg^{2+})$

3.3 Statistical Approach

In this research, the water quality data has been collected over one and a half years so that sufficient sets of water quality data are available to increase the stability, effectiveness, and reliability of the final statistical analysis results. These data sets can be valuable references for managing, regulating, and remediating water pollution in the mentioned are.

Multivariate statistical approaches show that the polluted surface water is strongly influencing the quality of ground water in the study area of the data collected at 334 sites around the Malegaon Sugar Industry, Baramati.

Mathematical models, especially water quality models, will be play an important role for environmental study. We develop a Bio-Statistical Model of Impact for Sugar Industry on groundwater quality in Malegaon on the basis of major contaminants as nitrates, metals, inorganic constituents, organic components etc. in the groundwater in the concern area.

In this research paper we develop a water quality model with the help of statistical tools like correlation analysis, cluster analysis, principal component analysis etc. The model evaluate the status of water pollution correctly, the value of the water quality index given by model is all-around reflection of water pollution.

IV. STATISTICAL ANALYSIS

Correlation

Table-1: Correlation Coefficient between Various Physiochemical Parameters of Ground Water Samples at Different Locations.

	pH	EC	% of Na	RSC	SAR	Ca^{++}	Mg^{++}	Na^{+}	$HCO3^{-}$	Cl^{-}	Mg^{++} to Ca^{++} ratio
pH	1	-.015	.220(**)	.124(*)	-.099	-.256(**)	-.179(**)	.062	.089	-.122(*)	.012
EC	-.015	1	.138(*)	.234(**)	.174(**)	.388(**)	.447(**)	.508(**)	.321(**)	.633(**)	.030
% of Na	.220(**)	.138(*)	1	.358(**)	.383(**)	-.324(**)	-.375(**)	.562(**)	.272(**)	-.17(**)	-.016
RSC	.124(*)	.234(**)	.358(**)	1	.153(**)	-.117(*)	-.071	.230(**)	.634(**)	.021	.058

SAR	-.099	.174(**)	.383(**)	.153(**)	1	-.077	-.128(*)	.359(**)	.135(*)	.001	-.005
Ca^{++}	-.256(**)	.388(**)	-.324(**)	-.117(*)	-.077	1	.399(**)	.124(*)	-.094	.622(**)	-.29(**)
Mg^{++}	-.179(**)	.447(**)	-.375(**)	-.071	-.128(*)	.399(**)	1	.192(**)	.110(*)	.584(**)	.297(**)
Mg^{++}	.062	.508(**)	.562(**)	.230(**)	.359(**)	.124(*)	.192(**)	1	.336(**)	.330(**)	.096
HCO3-	.089	.321(**)	.272(**)	.634(**)	.135(*)	-.094	.110(*)	.336(**)	1	.094	.105
Cl^-	-.122(*)	.633(**)	-.167(**)	.021	.001	.622(**)	.584(**)	.330(**)	.094	1	.035
Mg^{++} to Ca^{++} ratio	.012	.030	-.016	.058	-.005	-.297(**)	.297(**)	.096	.105	.035	1

** Correlation is significant at the 0.01 level , * Correlation is significant at the 0.05 level.
X_1:pH , X_2: EC , X_3:% of sodium,X_4:RSC, X_5:SAR, X_6: Ca^{++}, X_7: Mg^{++}, X_8:Na^+, X_9:HCO3--, X_{10}:Cl^-,X_{11}: $Mg^{++}$to Ca^{++} ratio.

Descriptive Statistics

Table-2: Analytical Results of Ground Water samples at different locations.

Variables	N	Range	Minimum	Maximum	Mean	Variance
PH (6.5-8.4)	334	2.38	6.56	8.94	7.833443	0.110229
EC (0-0.75)	334	7.23	0.18	7.41	1.505808	1.158062
SODIUM% (0-60%)	334	76.71	3.71	80.42	38.72249	203.4103
RSC (0-1.5)	334	18.4	0	18.4	5.02482	16.60852
SAR (0-1.8)	334	21.52	0	21.52	2.158413	2.707845
Ca++ (0-1.5)	334	9.8	0.2	10	2.010479	2.153466
Mg++ (1-5.0)	334	18.7	0.2	18.9	3.343293	5.341687
Na++ (0-4.0)	334	9.3	0.4	9.7	3.266617	2.718786

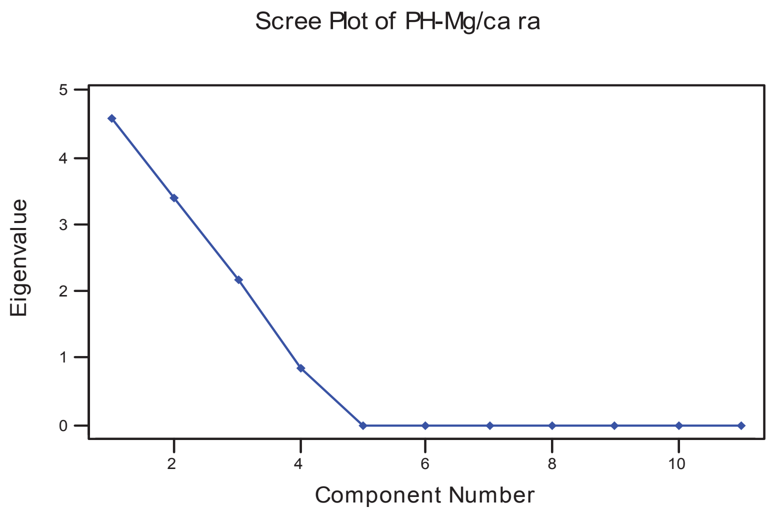
HCO_3 (1-8.5)	334	21.8	1.2	23	9.313174	13.15063
Cl (0-6.0)	334	58.2	1	59.2	6.06497	41.71958
Mg/Ca Ratio (0-3.0)	334	21.48	0.02	21.5	2.288144	7.486144

From the above table we observe that the maximum values of all parameters are too much greater than the permissible level of corresponding maximum values. Also we observe that, there is large variability in some parameters. Hence we classify the data into clusters using "Cluster Analysis" technique.

Cluster Analysis: The number of observations clustered in first, second, third, fourth and fifth cluster are 5, 166, 69, 70 and 24 respectively.

Cluster wise Principal Component Analysis

Principal Component Analysis for first Cluster



Eigen analysis of the Correlation Matrix			
Eigen value	4.5866	3.3883	2.1592
Proportion	0.417	0.308	0.196
Cumulative	0.417	0.725	0.921
Variable	PC1	PC2	PC3
PH	-0.430	0.167	0.007
E.C	0.293	0.415	0.101
SODIUM %	-0.382	0.242	0.244
R.S.C	0.438	-0.087	0.207
S.A.R	-0.151	-0.480	-0.215
Ca ++	0.396	0.044	-0.339
Mg ++	0.378	0.172	-0.318
NA++	-0.124	0.503	-0.149
HCO3	0.158	0.281	0.508
Cl	-0.072	0.295	-0.204
Mg/ca ratio	-0.154	0.228	-0.551

Since there are 11 predictors, there are 11 Eigen values and corresponding 11 principle components. Eigen values are expressed in descending order. We consider principal component is significant if Eigen value > 1.

For the first cluster three Eigen values > 1 and explain 92.1% information. Therefore we select first three principal components.

To group 11 predictors into disjoint groups we consider absolute value of load > 0.30 is significant. Using this criterion we have the following grouping of variables and corresponding to each principle components, scores are computed as a linear combination of loads and respective selected predictors.

Z1 =	$-0.43X_1 - .382X_3 + .438X_4 + .396X_6 + 0.378X_7$
Z2 =	$0.415X_2 - .48X_5 + .503X_8 + 0.295v$
Z3 =	$0.508\,X_9 - 0.551\,X_{11}$

Using these Principal components we develop multiple linear regression model to construct water quality index.

Water Quality Index 1=0.452769 Z1+0.334419Z2+ 0.212812 Z3

Water quality index in terms of original variables

$$WQI\_1 = -0.19469\,X_1 + 0.138784\,X_2 - 0.17296\,X_3 + 0.198318\,X_4 - 0.160521\,X_5 + 0.179297\,X_6 + 0.171147\,X_7 + 0.168213\,X_8 + 0.108108\,X_9 + 0.293\,X_{10} - 0.117259\,X_{11}$$

. The similar analysis is done for the remaining four clusters. Water quality indices for these clusters are given in conclusions.

V. RESULT AND DISCUSSION

Suitability of Ground Water for Agricultural Purpose

Physiochemical properties of ground water samples from different locations are shown in Table 2.

5.1 pH

The pH of natural water is important index of hydrogen ion activity and it is resulting value of the acid - base interaction of a number of mineral and organic components in water. A pH is an important ecological factor and is a term used and universally to express the intensity of the acid and alkaline condition of the water samples. Most of the water samples were slightly alkaline due to the presence of carbonates (CO3’’) and bicarbonates (HCO3’). pH-value determines the equilibrium between free CO2, HCO3’ and CO3’’.It is clear from the table 2 that the pH value of water samples were varying from 6.56 to 8.94 and these values are within the prescribed limits.

Electrical Conductivity (EC)

Electric conductivity is caused due to presence of electrolytes which dissociate in to cations and anions. It is a measure of water capacity to convey electric current. It is an indicator of the degree of mineralization of water. The EC is correlated with total dissolved solids. In the present investigation the EC values of water sample during monitoring periods ranged in between0.18 to 7.4 mmhos/cm and indicate the presence of some ionic matter such as Ca, Mg, Cl, SO4, CO3, HCO3 and some trace elements.

5.2 % of sodium

In the present investigation the sodium % values of water sample ranges between 3.71 to 80.42%, which shows in some cases sodium % is above permissible level. Also it has more variability.

5.3 Residual Sodium Carbonate (RSC)

In our study, we observe that RSC is ranges between 0 to 18.4 meq/l and its maximum permissible level is 1.5meq/l. It shows reduction of water quality.

5.4 Sodium Absorption Ratio (SAR)

Increase of SAR of the irrigation water had an adverse impact on water infiltration for all soil types. As per standards it’s range is in between 0-1.8, above 1.8 they consider water quality is savior. We observe that, the SAR for our sample observations varied from 0 to 21.52 and it shows that water quality is very low as per SAR concern.

5.5 Calcium (Ca^{++})

In the present investigation the calcium values of water sample ranges between 0.2 to 10 meq/l, which shows that calcium is present in large amount.

5.6 Magnesium (Mg^{++})

In our study, we observe that Magnesium is ranges between 0.2 to 18.9 meq/l and its maximum permissible level is 5 meq/l. It shows lowering of water quality.

5.7 Sodium (Na^{+})

Sodium levels in ground waters vary widely; depends upon geological formation. In surface water generally the sodium concentration ranges in between 1 and 300 ppm depending upon the geographical area. Excessive intake of sodium chloride causes vomiting. In the present investigation the sodium concentration of the water samples were found in between the ranges of 0.4 to 9.4 meq/l, this indicates the more concentration of sodium in the industrial effluent point due to the chemical combination of compounds leads to change in the quality of water.

5.8 Bicarbonate ($HCO3^-$)

Alkalinity of water is acid neutralizing capacity of the water to predestinated pH. Alkalinity in water is mainly due to CO3'' HCO3' and OH- content. Borates, phosphates, silicates or other bases if present also contribute for alkalinity. In the present study, Bicarbonate concentration is varying from 1.2 to 23 meq/l which is above permissible level.

5.9 Chloride (Cl^-)

The chloride concentration serves as an indicator of pollution by sewage, industrial effluents. Chloride occurs in all ground waters widely in varying concentration. Excessive chloride in potable water is not particularly harmful. Chloride in excess imparts a salty taste to water. In the present investigation the chloride values ranged from 1 to 59.2 meq/l.

All Physiochemical parameters have maximum average in cluster 4 except pH, EC and sodium percentage. It shows that water quality of cluster 4 is severed.

VI. CONCLUDING REMARKS

The overall concluding remarks about water quality index are as follows:
The cluster wise water quality indices are given below:

$$WQI\_2 = 0.074013\,X_1 - 0.13486\,X_2 + 0.116708\,X_3 + 0.074645\,X_4 + 0.093764\,X_5 - 0.13232\,X_6 + 0.072611\,X_7 + 0.047511\,X_8 - 0.15172\,X_9 + 0.151043\,X_{10} + 0.099745\,X_{11} \quad (6.1)$$

$$WQI\_3 = 0.085958\,X_1 - 0.21572\,X_2 + 0.087286\,X_3 - 0.11081\,X_4 - 0.06837\,X_5 - 0.17822\,X_6 - 0.09733\,X_7 - 0.21815\,X_8 - 0.0778\,X_9 - 0.19867\,X_{10} - 0.11809\,X_{11} \quad (6.2)$$

$$WQI\_4 = 0.106592\,X_1 + 0.158574\,X_2 + 0.085245\,X_3 + 0.136892\,X_4 + 0.078458\,X_5 - 0.10767\,X_6 + 0.138752\,X_7 + 0.169901\,X_8 + 0.131711\,X_9 + 0.163176\,X_{10} + 0.121965\,X_{11} \quad (6.3)$$

$$WQI\_5 = 0.112354\,X_1 + 0.145308\,X_2 + 0.146329\,X_3 + 0.147696\,X_4 + 0.076983\,X_5 + 0.086869\,X_6 - 0.09492\,X_7 - 0.09361\,X_8 + 0.131286\,X_9 + 0.105952\,X_{10} - 0.11914\,X_{11} \quad (6.4)$$

In general, in this study we observe that water quality index for study area ranges from 0 to 25.
If quality index is ranges below 10 then water quality is good for irrigation.
If quality index is ranges between 10-15 then water quality is moderate for irrigation.
If quality index is ranges above 15 then water quality is severe.

We observe that water quality indices near to the Malegaon sugar factory water samples are high and it is ranges between 18 to 22. These samples are included in cluster 4. The overall groundwater quality of the study area is not good. To improve or to keep the quality of water at the effluent discharge point, the industrial waste should be treated properly before disposal into the river stream. Therefore should be continuous monitoring of the pollution level.

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