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Groundwater Contamination Due to Municipal Solid Waste Disposal – A GIS Based Study in Erode City

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Abstract

Erode city, the head quarters of Erode District is located on the bank of Cauvery River in Tamil Nadu state. It lies between 11° 17' N and 11° 23' N latitudes and 77° 40' E and 77° 46' E longitudes with an approximate aerial extent of 120 km^2. The city depends on Cauvery River for its drinking water supply. In addition to Cauvery River water, people in this region also depend on the groundwater resources for their domestic, agricultural and industrial needs. Urbanization and improper disposal of solid wastes lead to contamination of groundwater and surface water resources in this region. Municipal solid wastes of the city are presently disposed as open landfills at three distinct sites namely Vendipalayam, Vairapalayam and Semur. The leaches of the open dump yards directly contaminate the groundwater and surface water resources leading unsuitability of water for drinking at many places. Hence, a detailed study has been carried out using Geographical Information System (GIS) to understand the spatial variation of surface water and groundwater quality. About forty three groundwater samples and seven surface water samples were collected during February, 2009 from the study region, and the samples were analyzed for various physical and chemical parameters such as pH, Electrical Conductivity, Total Dissolved Solids, Alkalinity, Hardness, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, CO_3^{2-}, SO_4^{2-}, NO_3^- and F^-. The concentrations of physical and chemical constituents in the water samples were compared with the Bureau of Indian Standard (BIS) and World Health Organization (WHO) standard to know the suitability of water for drinking. The study indicates that the water quality parameters exceed the permissible limits for drinking at many locations leading the water unsuitable for drinking. The spatial variation of groundwater quality parameters was also plotted using GIS.

Key words: Spatial variation, groundwater contamination, Geographical Information System

1. Introduction

Waste is a by-product of life. High standards of living and ever increasing population have resulted in an increase in the quantity of wastes generated. Municipal Solid Waste (MSW) is generally a combination of household and commercial refuse which is generated from the living community. Among the multitude of the environmental problem existing in the urbanizing cities of developing countries, MSW management and its impact on groundwater quality have become the most prominent in the recent years.

Erode city, the head quarters of Erode District is located on the bank of Cauvery River in Tamil Nadu state. It lies between 11° 17' N and 11° 23' N latitudes and 77° 40' E and 77° 46' E longitudes with an approximate aerial extent of 120 sq.km. Innumerable large towns and many mega cities derive a major component of their domestic, agricultural and industrial water supply from aquifers. Similarly, the major part of the living community in Erode city depends also on groundwater for their drinking, domestic, and agricultural needs. During the last two decades groundwater quality has emerged as one of the most important environmental issues confronting much of the world's populace. Due to lack of efficient solid waste management system and improper dumping of MSW as open landfills, the ground water and surface water in the Erode city is found to be contaminated in various places. In the study region, the municipal solid wastes are disposed as open landfills in three places i.e. at Vendipalayam, Semur and Vairapalayam (on the bank of Cauvery).

1.1 Study Area

Groundwater is a precious and most widely distributed resource of earth and unlike any other mineral source; it gets replenished from meteoric precipitation. Considering the fact that land is a finite resource and the burgeoning population, which requires more and more of it, an integrated landscape assessment is essential. In India, groundwater is the most precious natural resource to provide for the population at large during draught period. Considering the fact that population is increasing dramatically, an integrated landscape assessment is essential to compensate the rising needs due to Urbanization. Now-a-days quality of groundwater is more important than its quantity [8]. Studies on groundwater quality have not received attention that it [10] deserves. Erode city, the head quarters of Erode District Tamil Nadu, is located in the southern part of Indian subcontinent. The boundary of the study area consisting of villages, rivers and streams along with ponds, was digitized using the Survey of India [7] Toposheet 58 I (1:50000). Erode district is located between latitudes 11º 15' N and 11º 45' N, and longitudes 77º 00' E and 77º 40' E. The study area is located between 11° 17' N and 11° 23' N latitudes and 77° 40' E and 77° 46' E longitudes. The selected area for study is Erode city and the area taken for study is about 120 sq.km. The temperature variation in the city ranges from 39.6°C to 24.1°C in summer while in winter it is found to be 32.8°C to 20.5°C. The annual average rainfall in the study area is 700mm. In the study area, the MSW is disposed as open landfills in three points, of which the larger yard is located at Vendipalayam, around 4 km from Erode city. Another disposal yard is located at Semur, at the western part of the study area (Fig - 02). The third yard is located at the bank of river Cauvery, i.e. at Vairapalayam, the eastern part of the study region. The wastes are dumped in non-engineered [11] land fills which results in the contamination of surface and sub-surface water in the region considered for study.

The soil found in the study area is mostly red soil, some regions have coarse sand and some regions are found to have sand loamy. The entire study area is found to comprise gneissic complex type of geology. The geomorphology of the study area indicates that the region comprises of shallow pediments in the northern boundary region and also in some parts of southern boundary region. Most of the area in the study region is found to have deep pediments. Only very small area in the study region is found to have the shallow buried pediments. Figure - 01 shows the study area location in India.

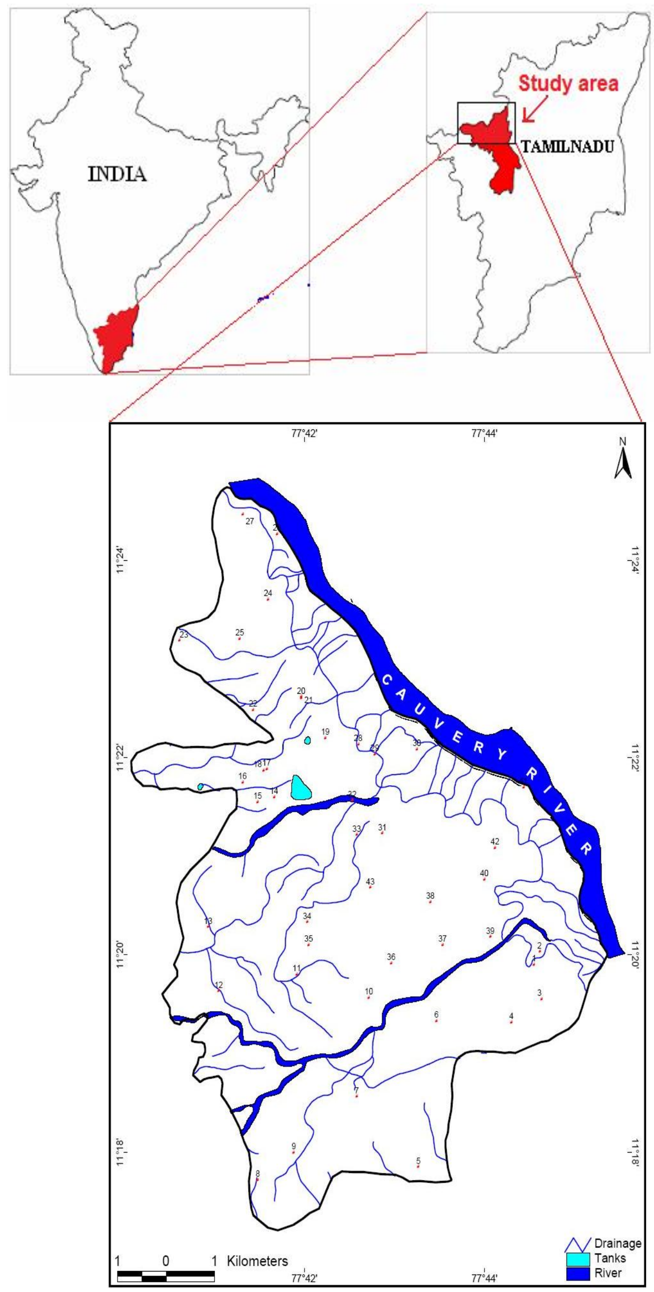

Figure - 01 Location map of study area

2. Materials and Methods

The Survey of India [7] toposheets (SOI) of 1:50000 scale were used for the preparation of base map, ground elevation contour map and drainage map. The Indian Remote Sensing Satellite - IRS 1D data of LISS III sensor [13] was used for preparing thematic maps such as geomorphology, lineament and land use by visual interpretation techniques. Geological Survey of India [7] map was used to get information about the geological formations. The locations of the MSW dump yards [16] in the region is identified and the locations are shown were identified. The major sources of MSW are shown in Table-01.

Table - 01 Type and Sources of Solid Wastes

TYPES OFWASTE	SOURCES
Domestic waste	Glass bottles, rags, vegetable parts, residues etc,.
Commercial waste	Polyethylene bags, egg shells, cans, bottles, etc,.
Agricultural waste	Vegetable parts and residues
Construction waste	Rubbles, wood, concrete, etc,.

In order to know the ground water contamination due to leaching of wastes into ground, wells and surface water sources were selected and the water samples were collected to analyze its quality. Forty three open wells and seven surface water samples were collected from the study area and analysed for its physical and chemical characteristics as per standard procedure. Detailed well inventory survey was also carried out and the details such as well depth, well cross sections, subsurface lithology and groundwater level fluctuations were collected. Groundwater samples were also collected from 43 open wells (Fig-01) using water sampler during February 2009 for chemical analysis. Electrical Conductivity (EC) and pH were measured electromagnetically in the field using digital meters immediately after sampling. Samples were collected from the open wells around the municipal solid waste dumping yards also. The locations of municipal solid wastes dumping yards are shown in Fig-02.

Clean polythene bottles of one litre capacity soaked with 1:1 HNO_3 and washed using detergent was used for groundwater sampling. These bottles were rinsed with double distilled water before taking to the field. Then the sample bottles were rinsed two to three times in the field using the representative groundwater samples. Water samples were collected 30 cm below the water level in open wells using water sampler. Water level recorder was used to measure the water level in wells.

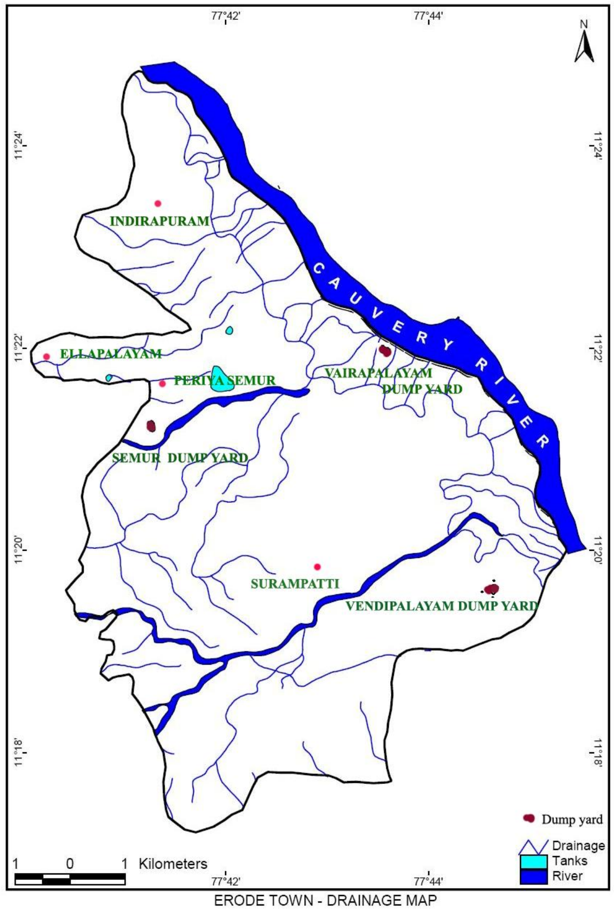

Figure - 02 Location of MSW dumping yards in study area

Groundwater and surface water samples collected in the field were transported to the laboratory on the same day. They were filtered using 0.45 mm Millipore filter paper and acidified with nitric acid (Ultra pure, Merck) for cations. Half-litre of each sample was stored below 4^{o} C for major anion studies. Then these samples were analysed for determining the concentrations of various chemical constituents such as sodium, potassium, calcium, magnesium, chloride, bicarbonate, carbonate, sulphate, nitrate, fluoride and total dissolved solids (TDS) in the laboratory using the standard methods (Table-02) as suggested by the American Public Health Association [2,3]. Ca^{2+}, Mg^{2+}, HCO_3^{-}, CO_3^{2-}, Cl^{-} and TDS were analysed by volumetric titrations. Concentrations of Ca^{2+} and Mg^{2+} were estimated titrimetrically using 0.05-N EDTA. Concentrations of HCO_3^{-} and CO_3^{2-} were determined using 0.01-N H_2SO_4. Cl^{-} was estimated using 0.05-N $AgNO_3$. Na^{+} and K^{+} ions were measured using flame photometer. SO_4^{2-}, NO_3^{-} and F^{-} were determined by spectrophotometric techniques. The accuracy of the chemical analysis was verified by calculating ion-balance errors where, the errors were generally around 10%.

Table - 02 Methods used for chemical analysis of groundwater

Chemical parameters	Methods
Ca^{2+} and Mg^{2+}	Titration using 0.05 - N EDTA
Na^{+} and K^{+}	Flame Photometer
HCO_3^- and CO_3^{2-}	Titration using 0.01 - N H_2SO_4
Cl^-	Titration using 0.05 - N $AgNO_3$
NO_3^-	Spectrophotometer
SO_4^{2-}	Spectrophotometer
SiO_2	Spectrophotometer
F^-	Spectrophotometer
B	Atomic Absorption Spectrophotometer

3. Results And Discussion

3.1 Groundwater Chemistry

Understanding the quality of groundwater is as important as that of its quantity as it is the main factor determining its suitability for drinking, domestic, agricultural and industrial purposes. Forty-three groundwater samples analyzed during February 2009 were used to classify the groundwater into various types based on its suitability for drinking and agricultural uses. Further, the data was used for understanding the spatial distribution of geochemical constituents over the Erode city.

The pH values in the study area vary from 7.0 to 8.2 suggesting alkaline nature of the groundwater. The electrical conductivity (EC) values were found to vary between 370 µmhos/cm and 3880 µmhos/cm. Physical and chemical parameters including minimum, maximum and average concentrations are reported in Table-02. The major ions are in the order $Na^+>Ca^{2+}>Mg^{2+}>K^+ = HCO_3^->Cl^->SO_4^{2-}>NO_3^->CO_3^{2-}$. High concentration of sodium and calcium in groundwater is due to weathering of silicate minerals. The lower concentration of potassium is, however, due to its greater resistance to weathering and its fixation in the formation of clay minerals [12]. Bicarbonate is the dominant anion in this region.

Table - 03 Minimum and maximum values of physical and chemical parameters of groundwater

Parameters	Units	Minimum	Maximum	Mean	Median	Mode
pH	-	7.1	8.2	7.63	7.6	7.5
EC	µmhos/cm	410	3830	1463.48	1290	1290
TDS	mg/l	267	2345	862.27	763.5	-
TH	mg/l	170	1070	441.4	410	345
P Alk	mg/l	-	-	-	-	-
T Alk	mg/l	210	675	383.6	381.8	345
Na^+	mg/l	0	437	142.37	104	92
K^+	mg/l	4	76	26.76	20	14
Ca^{2+}	mg/l	28	188	84.74	82	80
Mg^{2+}	mg/l	5	209	55.72	48.5	35
Cl^-	mg/l	28	759	201.76	124	71
HCO_3^-	mg/l	189	824	468.09	457.5	409
CO_3^{2-}	mg/l	-	-	-	-	-
NO_3^-	mg/l	0	47	7.93	4.5	2.0
SO_4^{2-}	mg/l	12	300	81.74	63	82
F^-	mg/l	0.14	1.5	0.80	0.9	1.3

The analytical results of physical and chemical parameters of groundwater were compared with the standard guideline values as recommended by the World Health Organisation [20, 21] for drinking and public health purposes (Table-04). The table shows the most desirable limits and maximum allowable limits of various parameters. The concentrations of ions, such as Ca^{2+}, Mg^{2+}, NO_3^- , SO_4^{2-} and F^- are within the maximum allowable limits for drinking. However, Na^+ and Cl^- ions exceed the maximum allowable limits for drinking purposes. The concentration of cation Na^+ is exceeding the maximum allowable limits at many places. The TDS and total hardness values are also found to exceed the maximum permissible limits at many places. Sodium ion concentration in the ground water varies from 0 to 437 mg/l with an average value of 142.4 mg/l. Ten samples out of 43 exceed the maximum permissible limit of 200 mg/l for drinking. The calcium ion concentration varies from 28 mg/l to 188 mg/l with an average value of 84.74 mg/l. All the samples are with the permissible limits. Magnesium and potassium concentrations are comparatively low. Bicarbonate, the dominant anion in the study area, varies between 189 mg/l and 824 mg/l (average 468.09 mg/l). Chloride varies from 28 mg/l to 759 mg/l (average 201.76 mg/l). Only at four locations, the chloride concentration exceeds the maximum permissible limit for drinking [20, 21]. All the other anions in groundwater including fluoride are well with in the permissible limits for drinking purposes.

To ascertain the suitability of groundwater for any purposes, it is essential to classify the groundwater based on their hydrochemical properties. The TDS values [4, 6] in the samples analysed are presented in Table-05. The values show that groundwater in the area is mostly fresh except for a brackish water occasionally and are suitable for drinking as per WHO standard.

Table - 04 Groundwater samples of the study area exceeding the permissible limits prescribed by WHO for drinking purposes

Parameters	WHO international Standard (1971 and 1983)		Wells exceeding permissible limits	Undesirable effect
	Most desirable limit	Maximum allowable limit	February 2009	
pH	7- 8.5	9.2	Nil	Taste
TDS (mg/l)	500	1,500	1, 2, 15, 37	Gastro -intestinal irritation
TH (mg/l)	100	500	1,2,6,9,10,11,15,23, 32,33	-
Na^+ (mg/l)	-	200	1, 2, 9, 10, 15, 24, 25, 27, 32, 37	-
Ca^{2+} (mg/l)	75	200	Nil	Scale Formation
Mg^{2+} (mg/l)	50	150	9	
Cl^- (mg/l)	200	600	1, 2, 9, 15	Salty taste
NO_3^- (mg/l)	45	-	1	Blue Baby
SO_4^{2-} (mg/l)	200	400	Nil	Laxative effect
F^- (mg/l)	-	1.5	Nil	Fluorosis

Table - 05 Nature of groundwater in the study area based on TDS values

TDS (mg/l)	Nature of water	Representing wells	Total No. of wells
<1000	Fresh water	3-5, 7,8,11-14,16-23,26,28-31,33-36,38-43	32
1000-10,000	Brakish water	1,2,6,9,10,15,24,25,27, 32,37	11

10,000-1,00,000	Saline water	Nil	Nil
>1,00,000	Brine water	Nil	Nil

Sodium Adsorption Ratio (SAR), an important parameter for determining the suitability of groundwater for irrigation purposes is defined (Karanth, 1987) as:

$$SAR = Na^{+} / \{[(Ca^{2+} + Mg^{2+})/2]^{1/2}\}$$

where the concentrations are reported in meq/l.

The SAR values in the samples range from 0.3 to 10.62 with an average value of 2.9. The 42 groundwater samples in the area fall under low sodium (S1) class and one sample fall under S2 class (Table-06) suggesting no alkali hazard. If the SAR values are more than 6, the water will have permeability problems [17].

Table - 06 Alkalinity Hazard

SAR	Alkalinity hazard	Water Class	February 2009	
			Representing wells	Total No. of wells
< 10	S1	Excellent	1-36, 37-43	42
10-18	S2	Good	37	1
18-26	S3	Doubtful	Nil	Nil
>26	S4	Unsuitable	Nil	Nil

The percent sodium (% Na) is calculated using the formula given below:

$$Na\ \% = (Na^{+} + K^{+}) \times 100/ (Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})$$

where the concentrations are reported in meq/l.

The percent sodium in samples ranges from 4.82% to 75.98% with an average value of with an average value of 39.80% suggesting that the groundwater of the study region falls under excellent to permissible limits for irrigation (Table-08). When the range of sodium is high, it will be absorbed by the clay particles, displacing Mg_2^{+} and Ca^{2+} ions [1]. The exchange process of Na^{+} in water for Mg_2^{+} and Ca^{2+} ions in soil reduces the permeability and eventually results in soil with poor internal drainage. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry [5, 17].

Table - 07 Suitability of groundwater for irrigation based on percent sodium

% Na	Water class	February 2009	
		Representing wells	Total No. of wells
<20	Excellent	7,11,12,17,18	5
20-40	Good	4,5,8,13,16,20,23,26,30,	14

		31,33,34,40,43	
40-60	Permissible	1,2,3,6,9,10,14,15,19,21 22,24,28,29,32,35,36,38 39,41,42	21
60-80	Doubtful	25,27,37	3
> 80	Unsuitable	Nil	Nil

3.2 Geospatial Variation Of Groundwater Quality Parameters

The groundwater of the area is fresh water except for a few samples which are brackish. To ascertain the suitability of groundwater for any purpose, it is essential to classify the groundwater depending upon their hydrochemical properties based on their TDS values [4, 6]. Most of the groundwater samples are within the maximum permissible limit for drinking as per the WHO international standard, except 4 samples of February 2009. The TDS zonation map of February 2009 (Fig-03) was prepared by setting the most desirable (500 mg/l) and maximum allowable (1500 mg/l) limits. The map shows that eastern and southwestern part of the study area contains more soluble salts in groundwater which cannot be used for drinking.

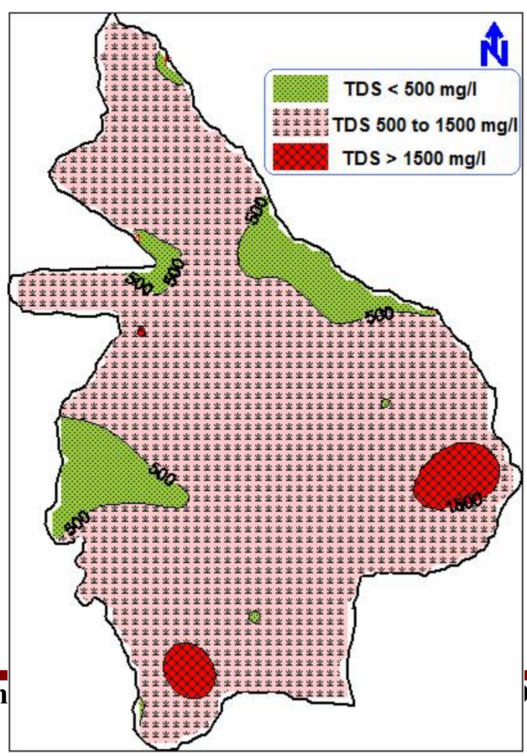

Fig - 03 TDS Zonation map of February 2009

The spatial variations of various geochemical elements in groundwater were plotted using GIS. Higher concentrations of sodium and chloride ions were noticed in the eastern and western parts of the study area (Fig-04) leading the groundwater unsuitable for drinking. Increased trend of nitrate and fluoride concentrations (Fig-04) were also noticed in the spatial variation diagrams of February 2009. Disposal of Municipal Solid Waste in the eastern part of the basin might have affected the groundwater quality.

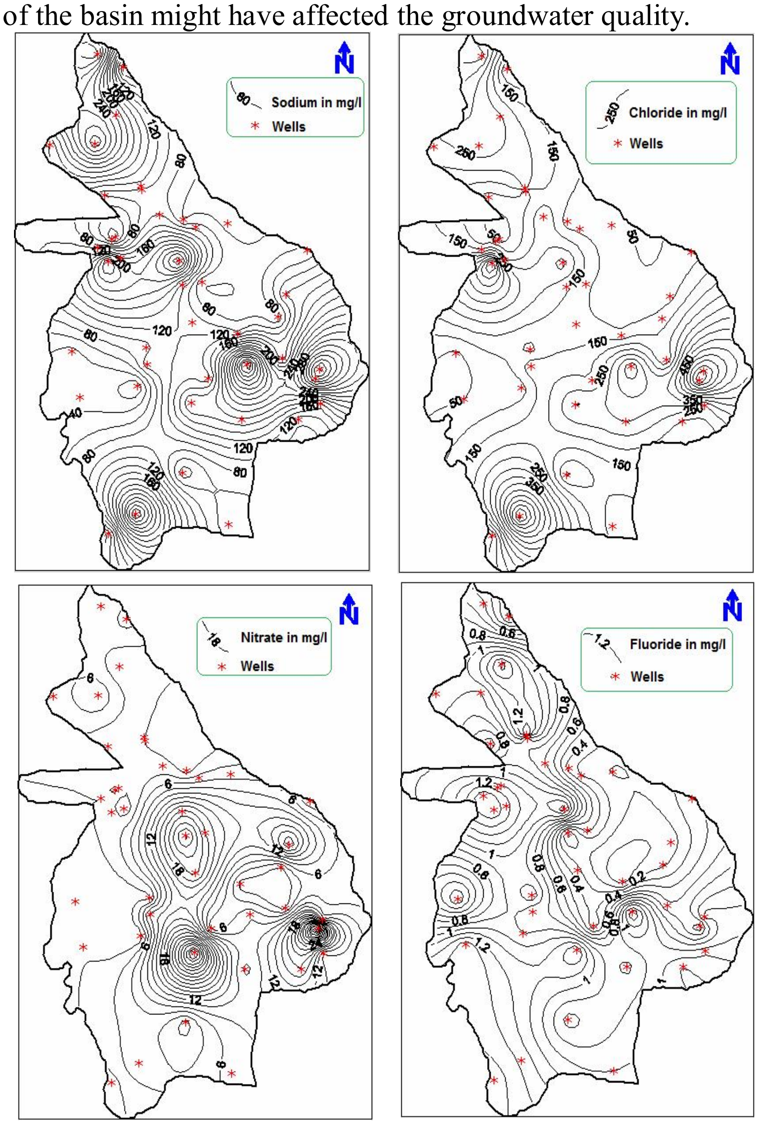

Fig - 04 Spatial variation of ions in groundwater

3.3 Surface Water Chemistry

There is no single or simple measure of water quality. Surface water in nature contains a wide variety of substances, and human activities inevitably add to this mixture. Scientists have, therefore, developed specialized approaches to measuring quality. Surface water samples were collected from the study area at 7 locations during February 2009 and analyzed for its major ions. The analytical results are presented in Table-08.

Due to the dumping of municipal solid wastes in non-engineering landfills with in the study region, the surface water in the study region is found to be contaminated. The pH values of the groundwater samples vary between 7.0 and 7.8. The average pH in the area is 7.41. The electrical conductivity of the surface water in the study area varies from 440 µmhos/cm to 3880 µmhos/cm. The minimum, maximum, average, median and mode values of the physic-chemical parameters are given in Table-08. There is considerable impact of the solid waste on the surface water quality. The TDS value is also found to be more in some samples and it is varying between 273 mg/l to 2512 mg/l.

Table - 08 Minimum and maximum values of physical and chemical parameters of surface water

Parameters	Units	Minimum	Maximum	Mean	Median	Mode
pH	-	7.0	7.8	7.41	7.4	-
EC	µmhos/cm	440	3880	1100	630	-
TDS	mg/l	273	2512	720	369	-
TH	mg/l	155	460	262.1	250	155
P Alk	mg/l	-	-	-	-	-
T Alk	mg/l	135	650	305	270	-
Na^+	mg/l	28	748	165	53	-
K^+	mg/l	4	53	18	16	4
Ca^{2+}	mg/l	30	80	46.3	42	-
Mg^{2+}	mg/l	16	63	35.6	35	-
Cl^-	mg/l	43	915	190	50	43
HCO_3^-	mg/l	165	793	372	329	-
CO_3^{2-}	mg/l	-	-	-	-	-
NO_3^-	mg/l	1	53	12	7	-
SO_4^{2-}	mg/l	13	53	26	22	22
F^-	mg/l	0.01	1.66	0.77	1.1	-

The quality of the surface water samples are compared with World Health Organisation standards (Table-09) and most of the values are within the permissible levels except in some samples. The TDS is more than the permissible limit in sample S3 which is in the Erode town region. Na^+, Cl^- and NO_3^- are found to exceed the permissible limits in sample S4. The F^- exceeds the drinking water quality limit in the sample S1 which is also used by the local community for domestic and drinking purpose.

Table - 09 Surface water samples of the study area exceeding the permissible limits prescribed by WHO for drinking purposes

Parameters	WHO international Standard (1971 and 1983)		Samples exceeding permissible limits	Undesirable effect
	Most desirable limit	Maximum allowable limit	February 2009	
pH	7- 8.5	9.2	Nil	Taste
TDS (mg/l)	500	1,500	S3	Gastro -intestinal irritation
TH (mg/l)	100	500	Nil	-
Na^+ (mg/l)	-	200	S4	-
Ca^{2+} (mg/l)	75	200	Nil	Scale Formation
Mg^{2+} (mg/l)	50	150	Nil	
Cl^- (mg/l)	200	600	S4	Salty taste
NO_3^- (mg/l)	45	-	S4	Blue Baby
SO_4^{2-} (mg/l)	200	400	Nil	Laxative effect
F^- (mg/l)	-	1.5	S1	Fluorosis

The surface water sample quality has been studied and it is classified based on the TDS values. Table-10 shows classification. All the samples are found to fall with in the fresh water type except the sample S4 which falls in the type of brackish water. Some of the industrial discharges and the sewage from the town are discharged into this drain. This may be the major cause for the pollution.

Table - 10 Nature of surface water in the study area based on TDS values

TDS (mg/l)	Nature of water	Representing samples	Total No. of samples
<1000	Fresh water	S1-S3, S5-S7	06

1000-10,000	Brackish water	S4	01
10,000-1,00,000	Saline water	Nil	Nil
>1,00,000	Brine water	Nil	Nil

The classification of surface water based on alkalinity hazard (Table-11), and suitability of the same for irrigation based on percent sodium (Table-12) has been done and almost all the samples are found to fall under permissible limits.

Table-11 Alkalinity Hazard

SAR	Alkalinity hazard	Water Class	February 2009	
			Representing samples	Total No. of samples
< 10	S1	Excellent	S1-S3, S5-S7	06
10-18	S2	Good	S4	01
18-26	S3	Doubtful	Nil	Nil
>26	S4	Unsuitable	Nil	Nil

Table-12 Suitability of surface water for irrigation based on percent sodium

% Na	Water class	February 2009	
		Representing samples	Total No. of samples
<20	Excellent	Nil	Nil
20-40	Good	S2, S5	02
40-60	Permissible	S1, S3, S6, S7	04
60-80	Doubtful	S4	3
> 80	Unsuitable	Nil	Nil

4. Conclusion

The groundwater in the study area is mainly alkaline in nature. The abundance of major ions are in the following order $Na^+ > Ca^{2+} > mg^{2+} > K^+ = HCO^{3-} > Cl^- > SO_4^{2-} > NO_3^- > CO_3^{2-}$. The concentrations of cations such as Na^+ and Mg^{2+} exceed the maximum allowable limits for drinking water at some locations which are near to the MSW dumping yards in the study area. Ca^+ concentrations in the groundwater, however, are within the permissible limits in February 2009. The anions such as SO_4^{2-}, NO_3^- and F^- are well within the permissible limits for drinking except at one location which is near to the area of location of tanneries. Only at four locations out of which three are very near to the MSW dump yards in the study region, the chloride concentrations are found to exceed the permissible limits during February 2009.

The zonation map indicates that TDS in 2/3 of the study area is between 500 to 1500mg/l. This indicates the presence of soluble salts in some samples of groundwater, which has to be treated before using it for drinking. So, there is a considerable impact on the groundwater within the study area because of dumping of MSW in non-engineered land fills.

The surface water in the study area is also alkaline in nature. Most of the samples are found to be within the permissible limits except one in which the industrial discharges and sewage from the study region are getting mixed.

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