



Groundwater quality around municipal solid waste dump in Tiruchirappalli (South India)

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Received: 7 September 2017 / Revised: 7 October 2018 / Accepted: 9 October 2018 / Published online: 27 October 2018
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Abstract

Physicochemical analysis was performed on 32 groundwater samples around the municipal solid waste dump yard, Ariyamangalam, Tiruchirappalli. The dump yard is 12 km from the city dumping that is around 500 tons per day. The parameters such as TDS, turbidity, alkalinity, pH, Mg, NH₃, NO₃⁻, NO₂⁻, total hardness, Na, K, F, Cl⁻, SO₄²⁻, BOD and COD were tested using standard testing procedures according to IS 3025. The obtained values were compared with BIS 10500. The WQI has been calculated using AW method, and statistical analysis such as variance, standard deviation, correlation, histogram with its distribution and principal component analysis has been performed using SPSS 16.0. The spatial variation of the parameters has been interpolated by using geographical information system as a platform. Using GIS interpolation, the values at the location where the data are not known can be inferred with the known set of values. ArcGIS 9.3 software has been used as an effective tool for the spatial variation mappings. The results suggested the need for adjusting factors managing the solid waste that leads to reduce the leachate contamination of groundwater with repeated monitoring of groundwater quality and leachate percolation.

Keywords Leachate · Water quality · Dump yard · Solid waste

Introduction

The solid waste from the panchayats in villages and municipalities in towns is due to trash/garbage that consists of many items thrown away. This comes from residential places, schools, colleges, hospitals, businesses, etc., (Mudgal et al. 2011). In some places, municipal solid waste is openly dumped without any treatment, segregation or cover (Vasanthi et al. 2008; Akoteyon et al. 2011). In such a site, the product produced due to the biochemical changes in

the organic substances and due to moisture penetration is called leachate (Aderemi et al. 2011). When moisture penetrates the landfill, it converts the contaminants into liquid phase, and when the moisture is high, it initiates a liquid flow (Jhamnani and Singh 2009). Leachate is an organic/inorganic compound from landfills. Percolation of leachate contaminates the groundwater. The type of contamination from solid waste disposal becomes a big issue to the environment (Abu-Rukah and Al-Kofahi 2001).

‘Leachate is produced when moisture enters the refuse in a landfill, extracts contaminants into the liquid phase and produces moisture content sufficiently high to initiate liquid flow (Lo 1996). The presence of bore well at the landfill sites to draw groundwater threatens to contaminate the groundwater’. The Ariyamangalam garbage ground near Trichy is an open dumpsite for leachate collection (Nagarajan et al. 2012). Open dumps are unhygienic and generally smelly with many types of human waste, animal waste, medical, pharmaceutical waste, etc. (Akinbile and Yusoff 2011). In addition heavy metals in chemicals lead to bioaccumulation and bio-magnifications. The aim of this present investigation is (1) to study the chosen solid waste dump yard site (Ariyamangalam, Trichy, Tamil Nadu), (2) to analyse the

Editorial responsibility: M. Abbaspour.

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groundwater quality around the dumpsite for contamination caused due to leachate (Aderemi et al. 2007, 2011, El-Salam and Abu-Zuid 2014) and (3) to determine the possible impact of groundwater contamination on the environment. Water quality index, which is an indicator of water quality, has been calculated using arithmetic weighing method and collated between parameters (Terrado et al. 2010; Yisa and Jimoh 2010). The probability distributions (PD) and principal component analysis (PCA) have been computed through Statistical Package for the Social Sciences (SPSS) software. From the analysis the average rainfall is + 28%, evapotranspiration is + 28%, and average precipitation is 20%.

Study area

Geography of the study area

Trichy is a metropolitan city and has a population ~28 lakhs, 602 inhabitants per km². The temperature is 18.90 (min) and 37.70 (max) (Banar et al. 2006; Esakku et al. 2007). The location of the dump yard is 10,048'0"N and 78043'0"E and has an elevation of 75.87 m above MSL. The study was conducted outside the city about 12 km towards Tanjore (Trichy–Tanjore National Highway (NH 67)). The study area has alluvial type of soil (Data source: Public Works Department, Tamil Nadu, India).

Waste generation and characterization

The municipal solid waste in Trichy city is shown in Fig. 1 (yearly). The generation of waste is due to population, economic development, packaged foods, packaged water and other items and an average of 470 tons of waste per day on dumpsite (Shenbagaraj 2013). The total surface area of the dump yard is 193,035.1 Sq. met. and has been operated since 1967 (Mor et al. 2006). An area of 169,968 Sq. met. is filled with

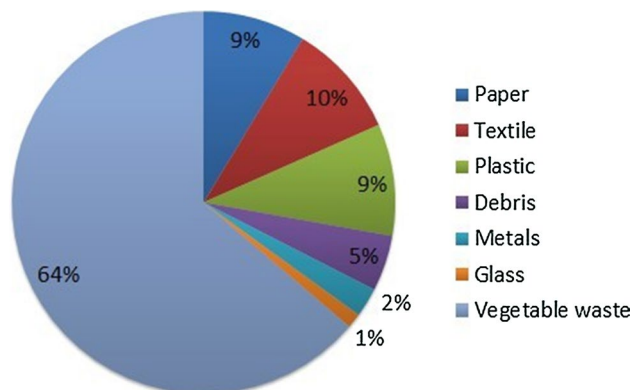


Fig. 1 Waste composition chart (Source: Trichy Municipal Corporation—2016 Nov)

garbage with height of 4.877 m. There are some industries' waste, boiler plants waste, vegetable waste (Gandhi market), etc., (Venkateswararao and Raju 2013). The minimum temperature is 31.1 °C and the maximum temperature is 36.1 °C.

Figure 1 shows the types of waste and their percentage, and the sampling of 32 locations is shown in Fig. 2a graphically.

Materials and methods

Methodology

The work is started by collecting the literature pertaining to the chosen area of work. Then, the sampling procedures are studied (IS 3025: 2011, 1984). Sampling shall be carried out and tested for many physicochemical parameters and heavy metals (Kanmani and Gandhimathi 2013a, b). With the obtained results, special variation maps shall be generated using ArcGIS and a conclusion can be arrived with statistical analysis.

Sampling

Random sampling of groundwater has been done from 32 locations within an area of 10 km² and was labelled as S1 to S32 which were chosen on random basis of sources (Fig. 2b–f). The locations were noted through the hand GPS-GARMIN Etrex 30. The sampling was done in February 2016 after the rainy season. Eighteen hot spot samples were collected and tested to know the level of leachate contamination and control of groundwater to observe decreasing trend of contamination as the distance from the dump yard to the source.

Instrumental analysis

The analysis of the samples of pH, electrical conductivity (EC), turbidity and dissolved oxygen (DO) was performed in laboratory through portable meters (Systronics Limited, India). Total dissolved solids' (TDS) values were obtained by recalculation of the EC measurements. Further the alkalinity through acid base titrations, hardness through hardness titration (EDTA) procedure which are in BOGUE, and the ions are determined through spectrophotometer (SpectroDirect, Tintometer Ltd., Germany).

Water quality index (WQI)

The water quality index values of all samples are computed through the following formula:

$$WQI = \frac{\sum_{i=1}^n Q_i w_i}{\sum_{i=1}^n w_i} \quad Q_i = \frac{(M_i - I_i)}{(S_i - I_i)}$$

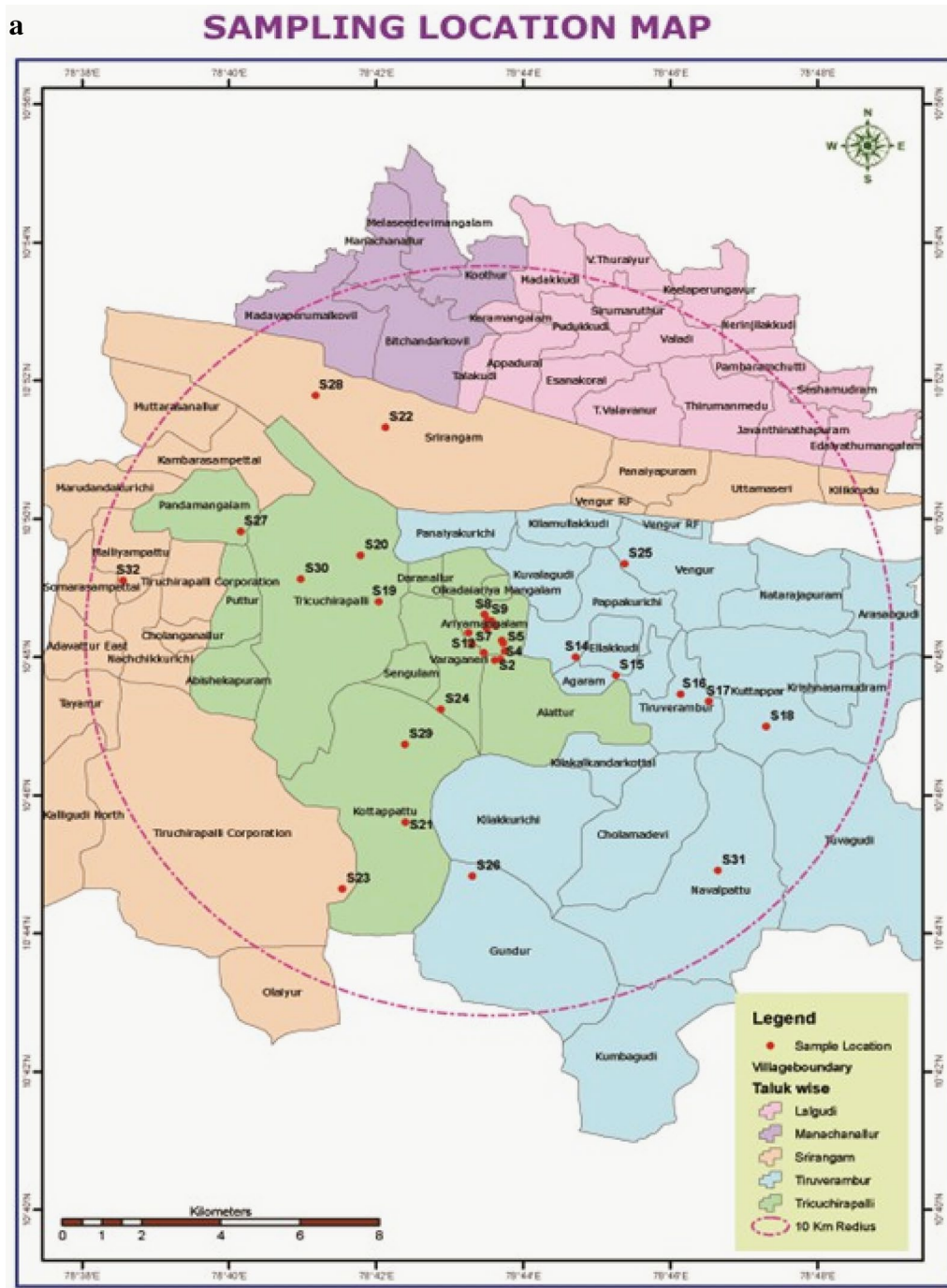


Fig. 2 a Geographical location of sampling (sample location map). b–f Sampling in fields



Fig. 2 (continued)

where M_i = laboratory-estimated values of the i th parameter, I_i = ideal value of the i th parameter, and S_i = standard value of the i th parameter.

Table 1 shows the quantity data of Ariyamangalam dump yard which gives information about the total area, area filled, maximum height of garbage, average height of garbage and current rate of dumping WQI of quality of water.

The same Table 1 shows the classification of quality based on WQI values. From the calculated WQI values compared with their specific locations reported in (Irena et al. 2016).

Spatial variation mappings

Spatial mapping has been done using the 3D analysis tool for raster interpolation modelling in IWD options in ArcGIS 9.3 software.

Statistical analysis

Basic statistics for the median, mode, variance and standard deviation has been found. The correlation matrix, histograms with their probability distributions, principal component analysis (PCA) and the scree plots have been obtained using SPSS (Statistical Package for the Social Sciences).

Results and discussion

Water quality index (WQI)

From the WQI of 32 groundwater samples, it was found that 34.37% has poor quality, 37.5%—very poor in quality, 12.5%—good in quality and better for human usage,

Table 1 Ariyamangalam dump yard details with values of WQI and classification

Land area	Value	Value (WQI)	Water quality (classification)	No. of samples	% of samples
Total area (sq. met)	190,202	0–24	Excellent	2	6.25
Area filled (sq. met)	169,968	25–60	Good	4	12.5
Maximum height of garbage (m)	6.096	51–74	Poor	11	34.37
Average height of garbage (m)	3.9624	75–100	Very poor	12	12.5
Current rate of dumping (MT/Day)	409	> 100	Unfit for drinking	3	9.37



6.25%—excellent quality and best for human usage in particular drinking purpose, and 9.37%—unfit for drinking and danger for human usage not only for drinking but also for washing purposes (Fig. 1). Table 2 shows the values of water quality index calculated using arithmetic weighing method.

The analysis suggested that more than 50% of the samples have poor quality including 12.5%—very poor and 9.37%—unfit for drinking.

Spatial variation of the parameters

From the obtained values of the laboratory analysis with respect to the location of sampling points, the spatial variation maps of the parameters have been plotted. This gives an overall idea about the contamination that has been spatially distributed in the chosen area. The process of spatial distribution is the points with the known values to estimate the values at the other points. From spatial interpolation, the values at the location where the data are not known can be inferred. The spatial interpolation and the range of distinguishing for the spatial mapping have been specifically set for each parameter. The minimum and maximum values of EC have been 694 and 4920, respectively (mic mho sec^{-1}), and all the samples have exceeded the acceptable limits of BIS10500 (Manoj and Pravin 2015). The minimum and maximum values of TDS have been 584 and 5644, respectively (mg/l), and all the samples have been found to be greater than the acceptable limits of BIS10500 (Fig. 3). The minimum and maximum values of fluoride have been 0.1 and 1.0, respectively (mg/l), and all the samples have been found within the acceptable level of BIS10500. The

minimum and maximum values of calcium have been 52 and 873, respectively (mg/l), and 93% of the samples have gone beyond the acceptable limits of BIS10500. The minimum and maximum values of chloride have been 85 and 3160, respectively (mg/l), and 31% of the samples have exceeded the acceptable limits of BIS10500. The minimum and maximum values of nitrate have been 10 and 58, respectively (mg/l), and 12.5% of the samples have exceeded the acceptable limits of BIS10500 (Fig. 4). The minimum and maximum values of total alkalinity have been 44 and 660, respectively (mg/l), and 28% of the samples have gone beyond the tolerance limits of BIS10500 (Fig. 5). The minimum and maximum values of sulphate have been 28 and 210, respectively (mg/l), and 3% of the samples have more than the acceptable limits of BIS10500. The minimum and maximum values of total hardness have been 190 and 3590, respectively (mg/l), and 96% of the samples have more than the acceptable limits of BIS10500 (Suratman et al. 2015; Aweng et al. 2011; Hussain et al. 2013). All the spatial variation values are depicted in Figs. 3, 4, 5, 6, 7, 8, 9 and 10.

Statistical analysis

The concepts of data reduction and descriptive statistics have been used in SPSS to produce the required statistical results. Factor analysis has been performed to find out the possible set of sources from the component and rotated component matrix. The 3D component plot has been obtained which can give a better idea of the statistical output by means of the statistical procedure as principal component analysis (PCA).

Table 2 Water quality index (WQI) data

Sample no.	WQI	Sample no.	WQI	Sample no.	WQI	Sample no.	WQI
1	25.4	9	89.49	17	42.2	25	56.95
2	66.49	10	65.19	18	54.03	26	54.81
3	64.43	11	18.9	19	99.75	27	88.08
4	102.15	12	49.9	20	98.4	28	107.4
5	76.52	13	82.6	21	56.2	29	45.88
6	94.14	14	101.2	22	63.27	30	61.21
7	98.2	15	23.35	23	64.27	31	77.05
8	86.7	16	72.16	24	89.8	32	87.25



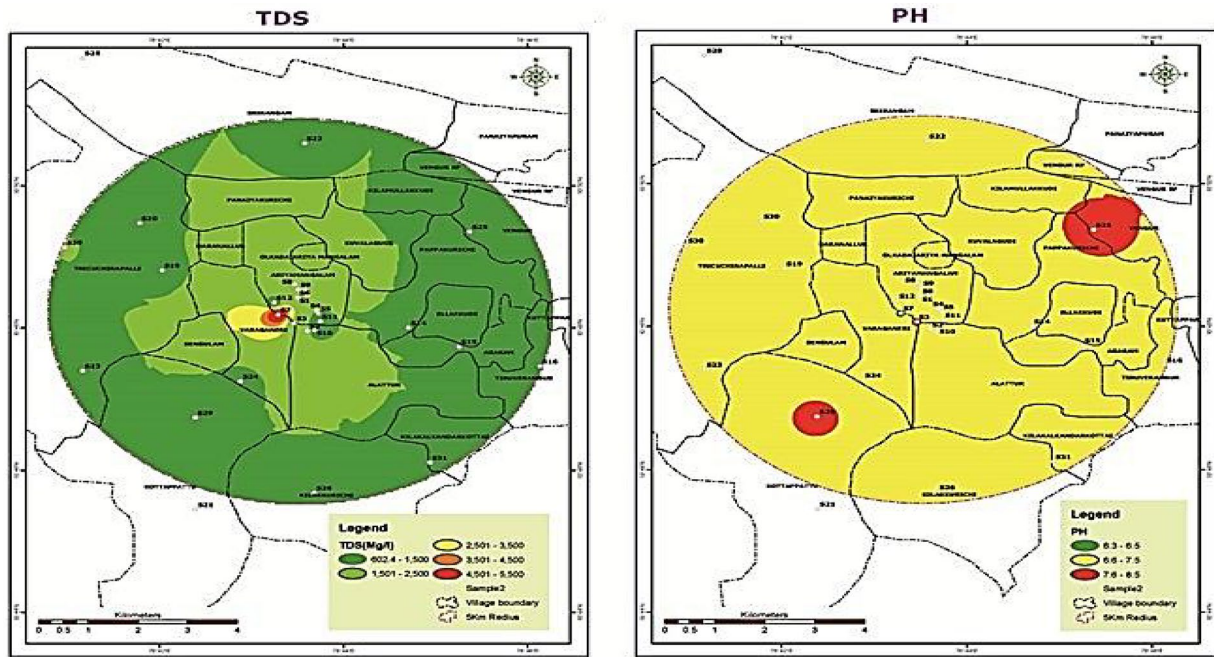


Fig. 3 Spatial variations of pH and TDS

These values are presented in Table 3, which contains the mean, median, mode, variation and standard deviation (SD) of the data of the various targeted parameters.

The 55% of the samples were almost of poor quality, out of which 12% were very poor and 9% were found unsuitable for drinking.

From the rotated component matrix, it is inferred that (component 1) hardness, calcium, magnesium, chloride,

sodium, EC and potassium are from the same source of leachate from the dump yard.

Fluoride, nitrite and nitrate (component 2) are from a similar source which can be fertilizers. BOD and COD (component 3) are from a common source, an improper disposal of industrial effluent (Table 4).



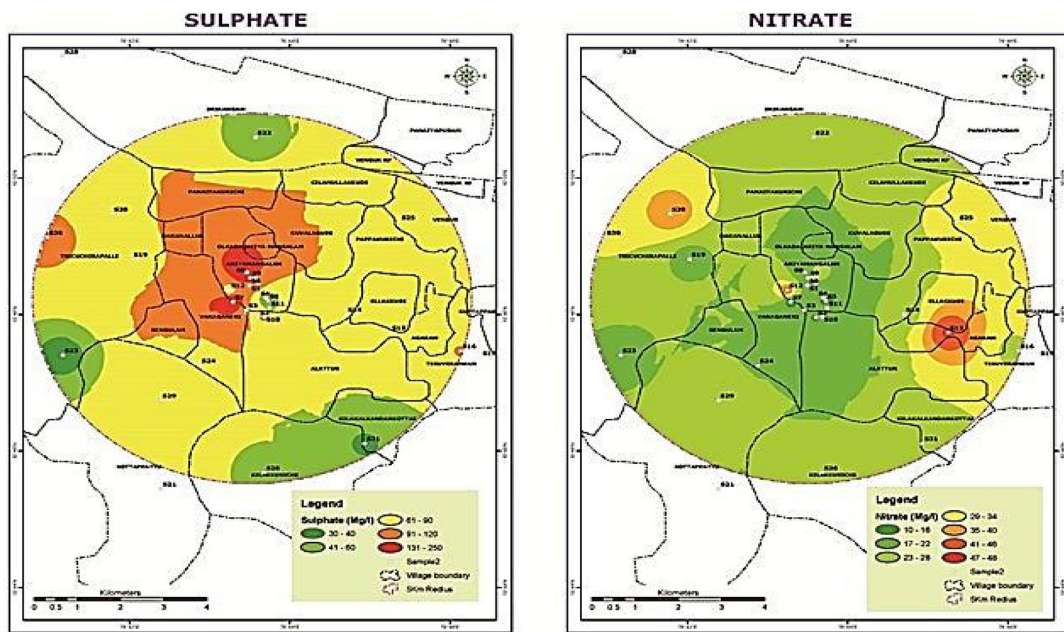


Fig. 4 Spatial variations of sulphate and nitrate

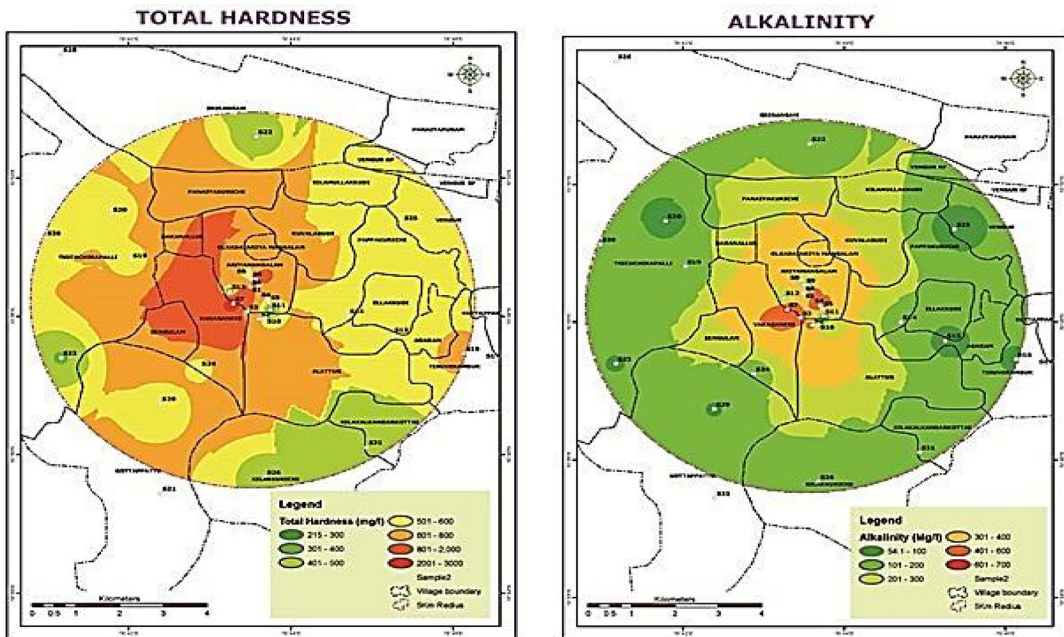


Fig. 5 Spatial variations of total hardness and alkalinity

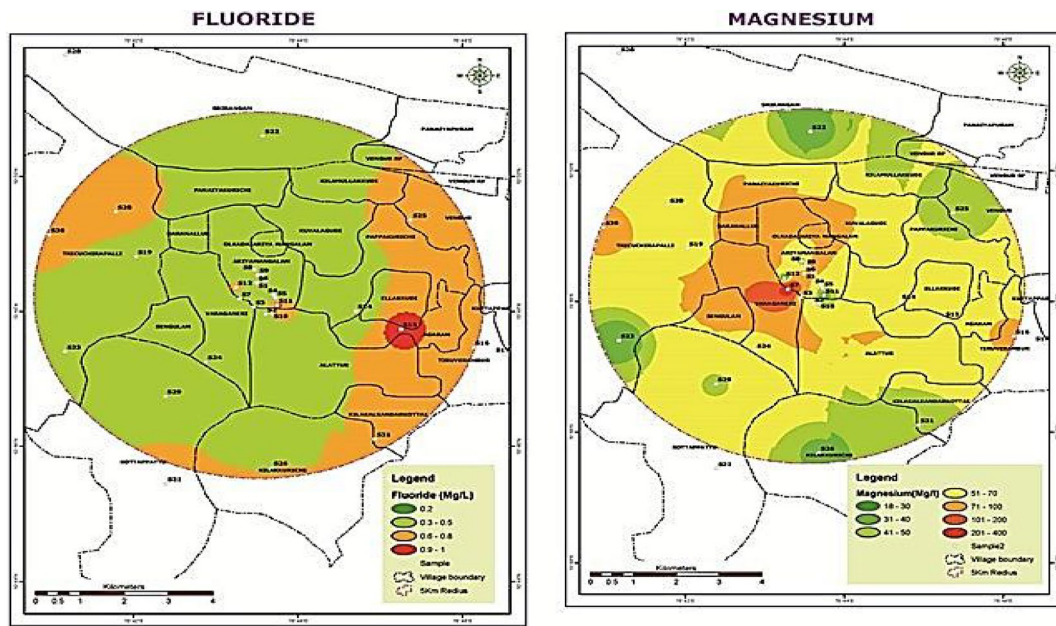


Fig. 6 Spatial variations of fluoride and magnesium

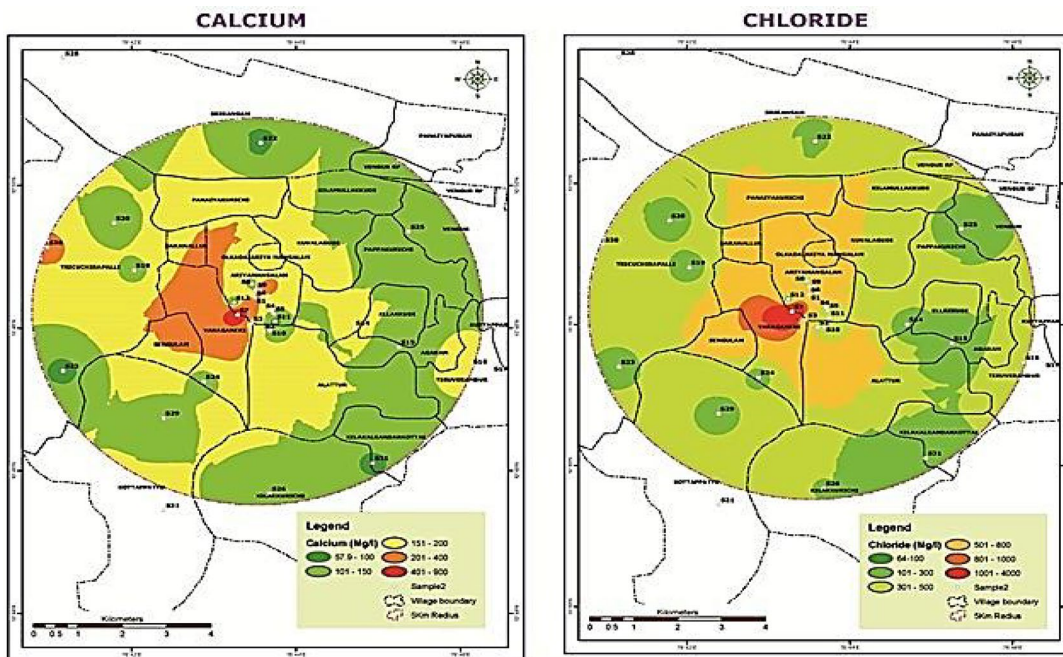


Fig. 7 Spatial variations of calcium and chloride



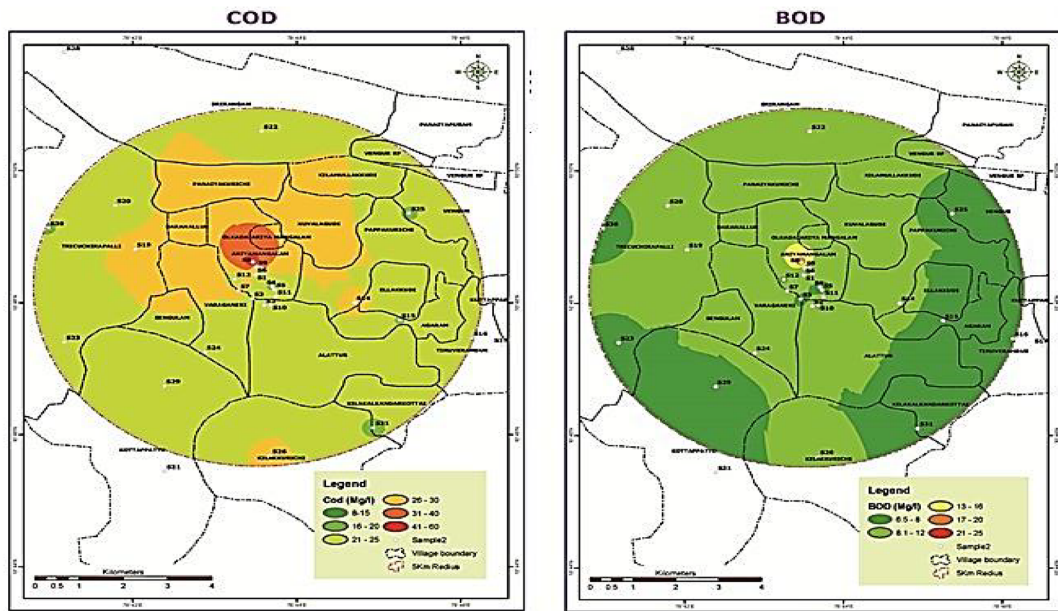


Fig. 8 Spatial variations of COD and BOD

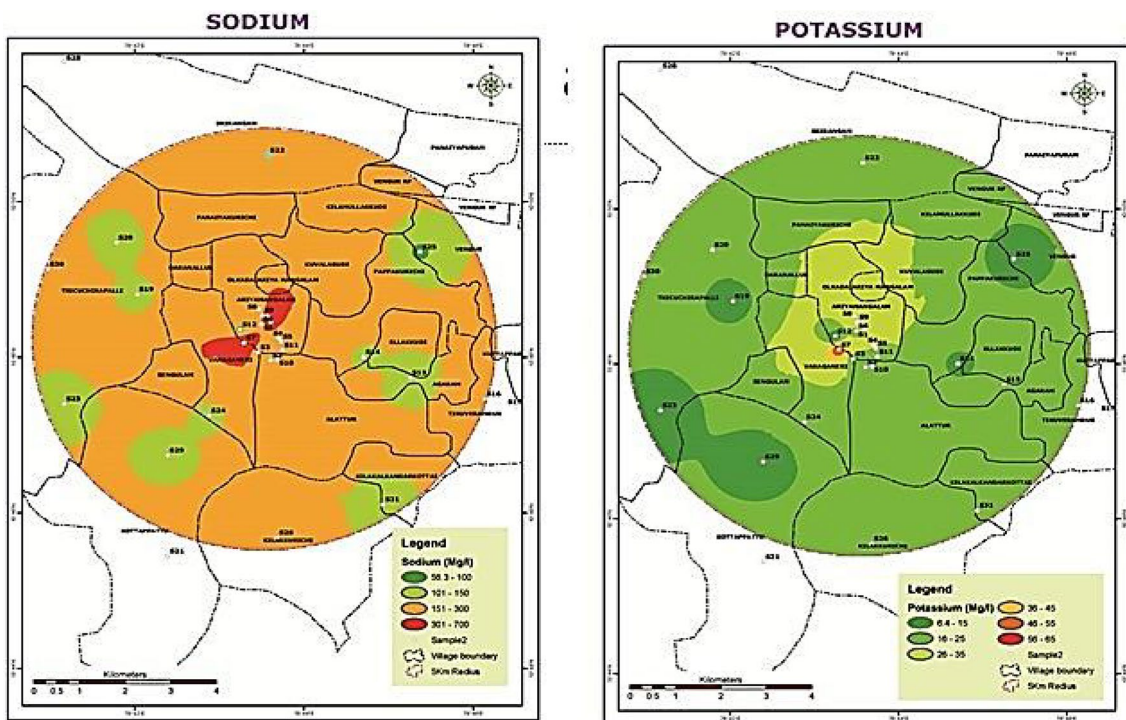


Fig. 9 Spatial variations of sodium and potassium

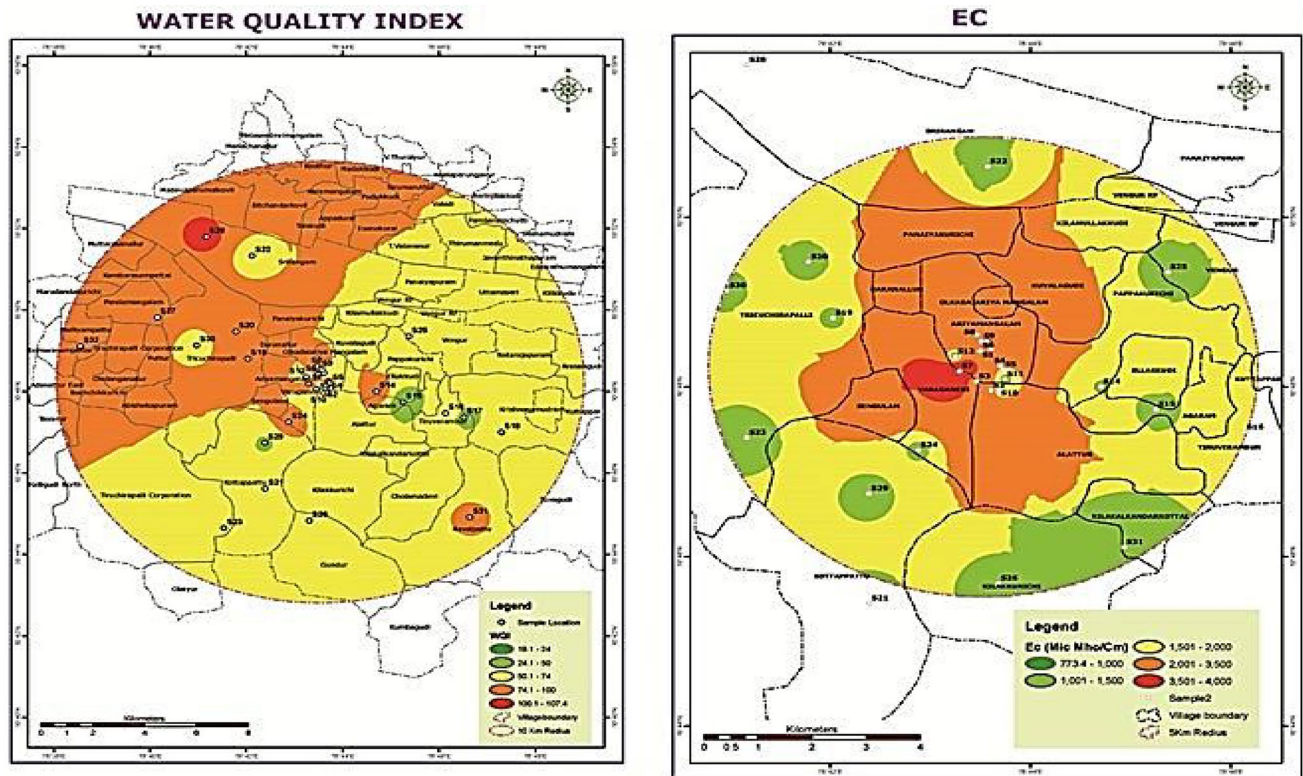


Fig. 10 Spatial variations of WQI and electrical conductivity

Table 3 Basic statistics of the data set

S. No.	Parameters	Mean	Median	Mode	SD	Variance
S ₁	Fluoride	0.45	0.45	0.60	0.227	0.52
S ₂	TDS	1.39	1.08	986	9.145	8.36
S ₃	pH	7.19	7.20	7.20	0.34	0.11
S ₄	Alkalinity	200.15	113	104	176.83	31,271
S ₅	Hardness	620.68	512	190	581	338,421
S ₆	Calcium	155.46	123.5	92	142.7	20,383.2
S ₇	Magnesium	59.50	47.50	30	55.52	3082.5
S ₈	Chloride	429	289.5	218	528.03	27,882.5
S ₉	EC	1779.25	1401.5	694	944.6	892,278.3
S ₁₀	Sodium	2.02	1.70	120	1.24	1543
S ₁₁	Potassium	19.91	18	20	10.74	115.29
S ₁₂	Nitrite	24.25	21.5	21	1.04	108.90
S ₁₃	BOD	8.34	7.85	8.7	2.76	7.62
S ₁₄	COD	23.6	22.1	19.8	7.55	56.99
S ₁₅	Nitrate	24.6	21	21	1.04	108.9



Table 4 Correlation matrix

	Turbidity	TDS	EC	PH	Alkalinity	Total hardness	Calcium	Magnesium	Sodium	Potassium
Turbidity	1									
TDS	-0.05731	1								
EC	-0.05186	0.999709	1							
PH	0.028592	-0.53659	-0.53542	1						
Alkalinity	0.103987	0.570084	0.572443	-0.06688	1					
Total hardness	-0.05952	0.987119	0.98641	-0.54441	0.460661	1				
Calcium	-0.06627	0.983574	0.982374	-0.53787	0.444301	0.998962	1			
Magnesium	-0.07768	0.974057	0.972694	-0.5177	0.417831	0.99599	0.99171	1		
Sodium	-0.10571	0.906353	0.910798	-0.5756	0.499348	0.874903	0.874645	0.852306	1	
Potassium	-0.03521	0.862895	0.868299	-0.53629	0.509051	0.823416	0.821213	0.80202	0.947042	1
Iron	0.962461	-0.07355	-0.06956	0.055807	0.124345	-0.09452	-0.10239	-0.11356	-0.13318	-0.05309
Ammonia	0.480319	0.074024	0.071987	0.016221	0.013747	0.03973	0.045944	0.037644	0.067651	0.148894
Nitrite	-0.25732	0.197179	0.195102	-0.10755	0.410307	0.154183	0.146466	0.1484	0.202857	0.010568
Nitrate	-0.29372	-0.2462	-0.24228	0.024619	-0.65148	-0.14568	-0.1397	-0.11667	-0.20257	-0.1988
Chloride	-0.07014	0.993219	0.991785	-0.57405	0.514933	0.987859	0.983385	0.97562	0.884283	0.833856
Fluoride	-0.15266	-0.31646	-0.31731	-0.17045	-0.67087	-0.22687	-0.23199	-0.19427	-0.32622	-0.33645
Sulphate	0.056736	0.616988	0.61778	-0.26505	0.350075	0.559846	0.554642	0.546952	0.557745	0.583771
Phosphate	-0.17541	-0.28376	-0.28582	0.239354	-0.54322	-0.2193	-0.22131	-0.17969	-0.32632	-0.29565
BOD	0.482998	0.205392	0.208181	-0.2731	-0.015664	0.172757	0.172837	0.150996	0.2778881	0.311578
COD	0.448995	0.168191	0.170242	-0.26941	-0.10992	0.152122	0.155977	0.135922	0.256486	0.285418
	Iron	Ammonia	Nitrite	Nitrate	Chloride	Fluoride	Sulphate	Phosphate	BOD	
Turbidity										
TDS										
EC										
PH										
Alkalinity										
Total hardness										
Calcium										
Magnesium										
Sodium										
Potassium										
Iron	1									
Ammonia	0.667159	1								
Nitrite	-0.20417	-0.16745	1							
Nitrate	-0.34921	-0.21823	-0.30864	1						
Chloride	-0.08684	0.056076	0.176968	-0.22258	1					
Fluoride	-0.1709	-0.20432	-0.16251	0.610966	-0.2355	1				
Sulphate	0.198119	0.552127	0.128166	-0.36326	0.600754	-0.37038	1			
Phosphate	-0.14876	-0.06283	-0.24487	0.446803	-0.21517	0.748592	-0.22892	1		
BOD	0.634736	0.9053	-0.07223	-0.11476	0.191566	-0.12608	0.581729	-0.13945	1	
COD	0.587098	0.891455	-0.15947	-0.01271	0.16063	-0.06791	0.524981	-0.0871	0.986098	

Table 5 Strongly correlated parameters

Parameter	To which it is strongly correlated
TDS	EC, hardness, calcium, magnesium, potassium
Iron	Turbidity
EC	Calcium, magnesium, chloride
Chloride	Total hardness, calcium, magnesium, sodium, potassium

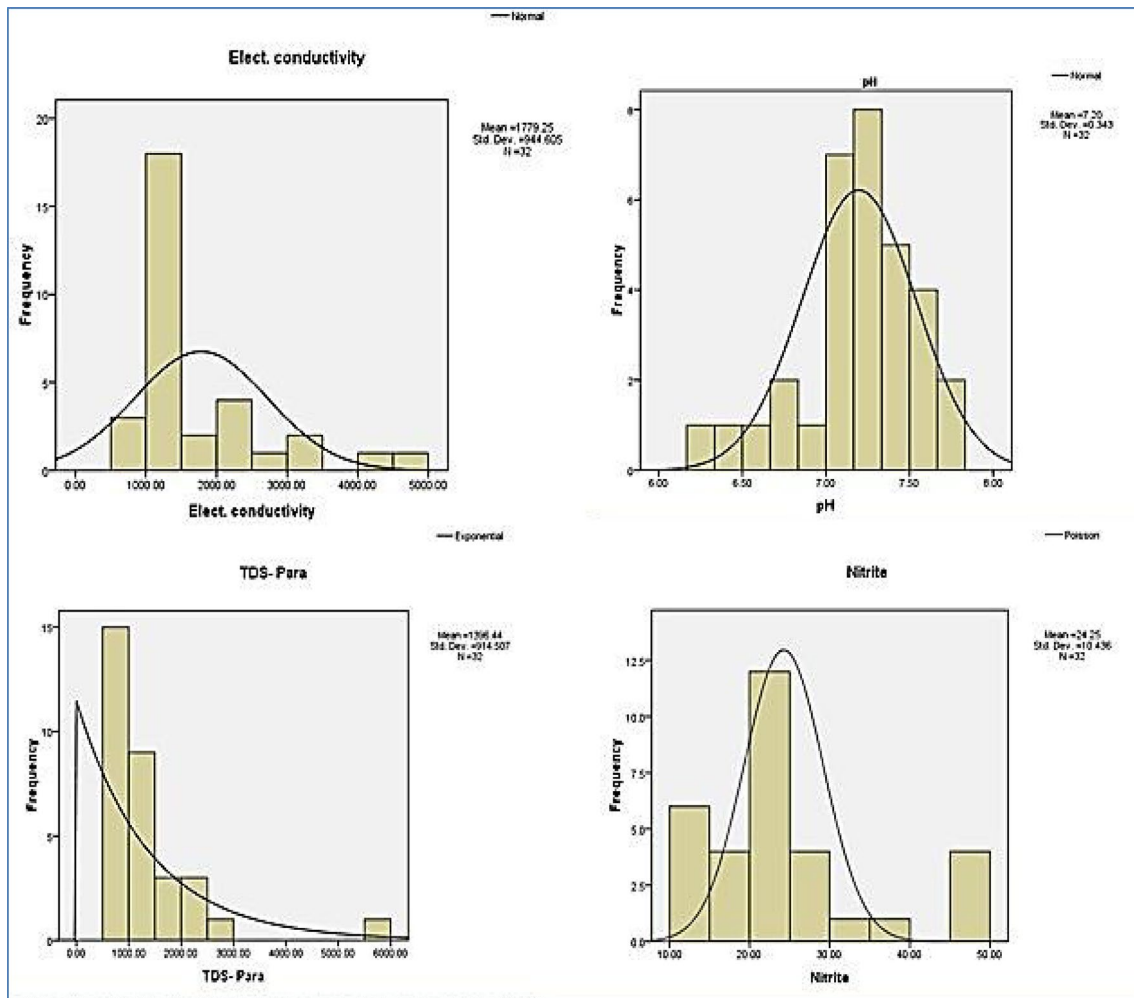


Fig. 11 Histogram and probability distributions of EC, PH, TDS and nitrite

Correlation

The correlation for all the tested values which gives the statistical relationship between the parameters has been found and represented in matrix form. The correlation matrix has been obtained for all the parameters chosen to be tested. From this, the strongly correlated parameters can be found on the basis of the correlation value. A value

above 0.6 is taken as strong correlation. Table 6 shows the correlation matrix of obtained data set.

Table 5 lists the strongly correlated parameters, which shows that the relation between each parameter has been strong (value above 0.6) from which it is evident that these contaminations in the groundwater are from the same leachate from the solid waste dump yard (Aderemi et al. 2007, 2011). From the values obtained from



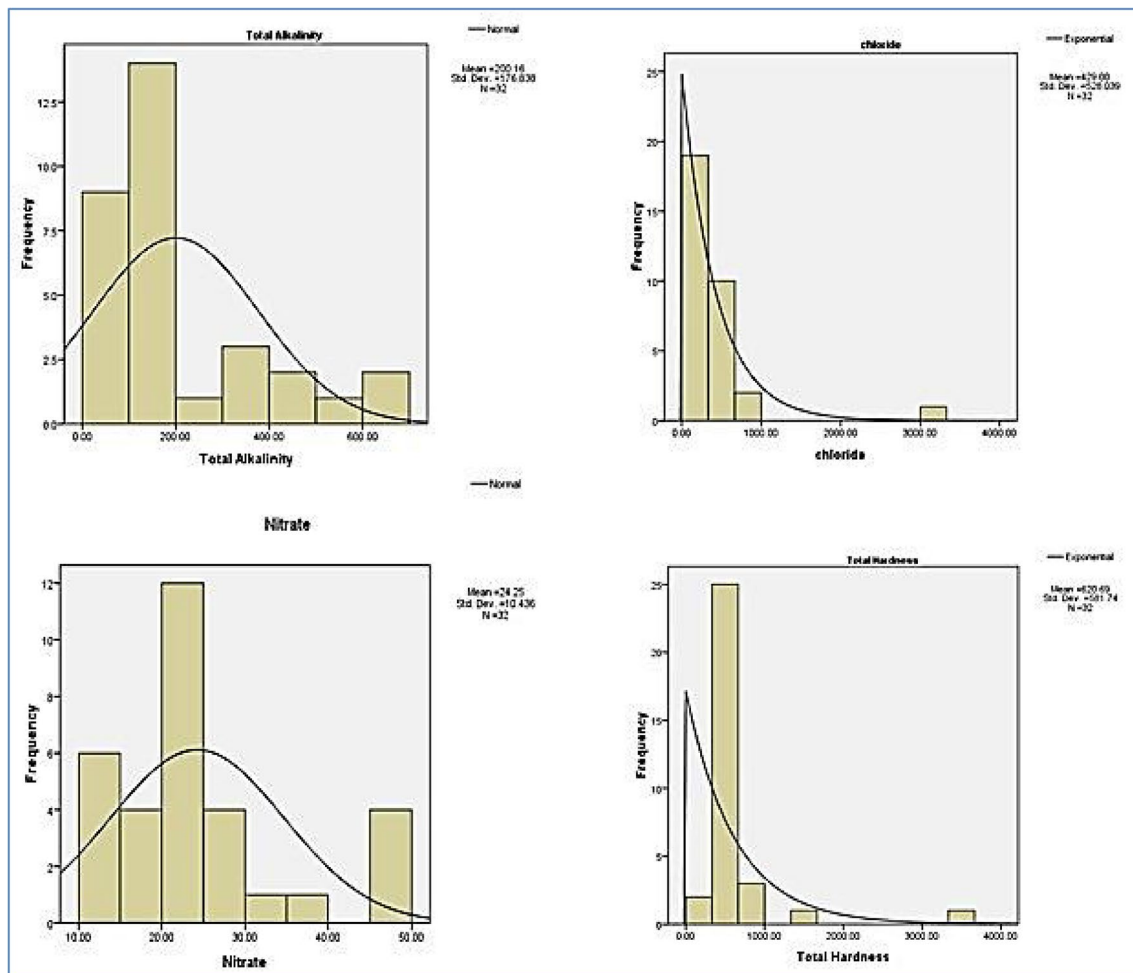


Fig. 12 Histogram and probability distribution of alkalinity, nitrate, hardness and chloride

the correlation matrix, the strongly correlated parameters have been found.

Histograms and probability distributions

Graphical representation (histogram) of theoretical and experimental distribution curves produces a particular result. Normal curve is a continuous function which is characterized by mean and standard deviation. Poisson curve is a

discrete function, and exponential curve is again a continuous function (Kobyas et al. 2012). The histograms of the EC, pH, TDS and nitrite are shown in Fig. 11. The histograms of alkalinity, nitrate, hardness and chloride are shown in Fig. 12. The histograms of potassium, calcium, sodium and magnesium are shown in Fig. 13. The histograms of BOD, COD, sulphate, fluoride are shown in Fig. 14. They are distributed as Poisson, normal and exponential distributions (Manoj et al. 2016; Krishnaraj et al. 2015). It has been

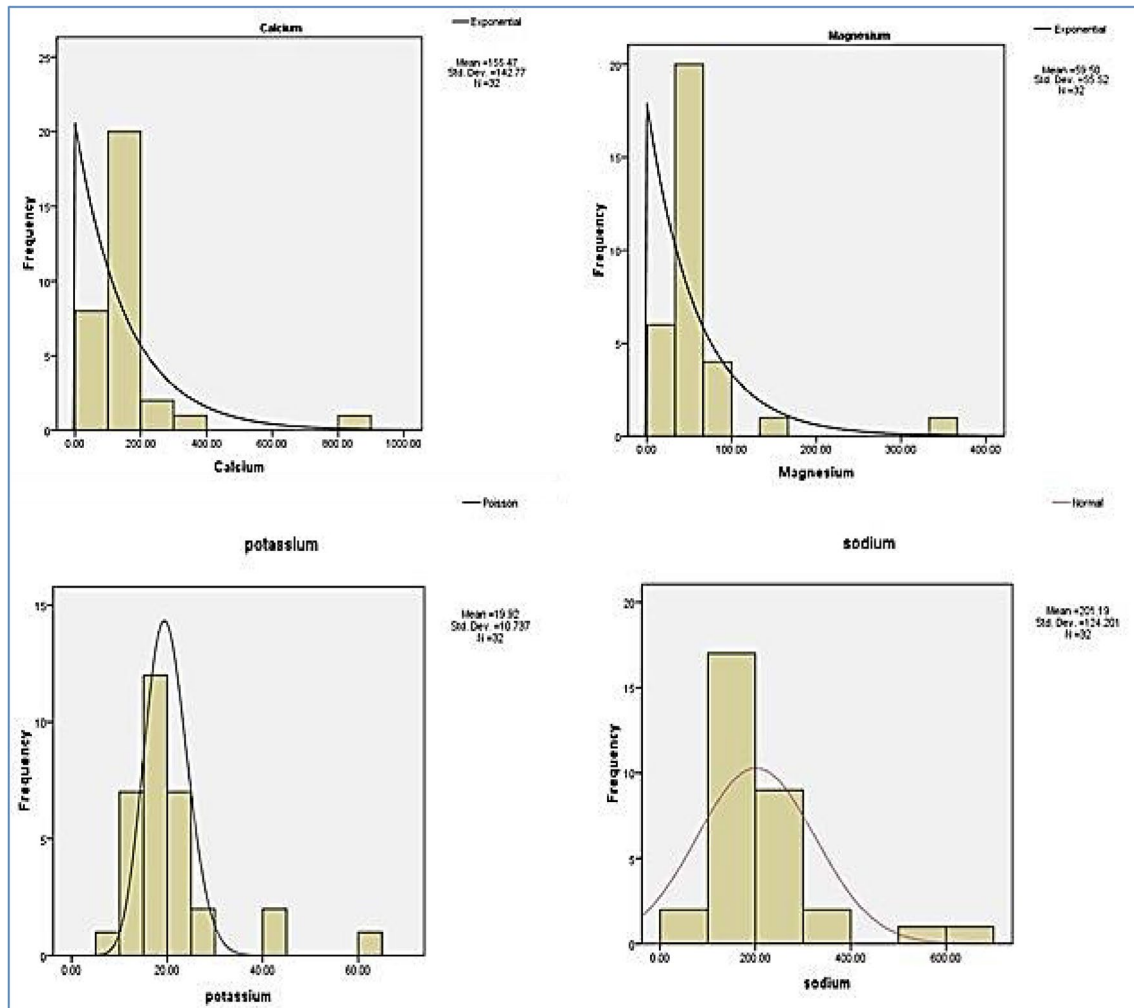


Fig. 13 Histogram and probability distribution of potassium, calcium, sodium and magnesium

inferred that the trend of distribution will retain irrespective of the number of samples. Any number of samples in the same belt of the study area will give the similar type of probability distribution.

The variable X can take on the values of the parameters tested. In this histogram (Fig. 11), X is a random variable which is the outcome of statistical experiment. Descriptive statistics is a method for summarizing the data. For these bell-shaped distributions, the mean values are 68% for one

standard deviation, 95% for two standard deviations and 99.7% for three standard deviations were found.

A Poisson distribution is the statistical tool gives the status of experiment has the properties are successes or failures. From Fig. 12, the number of successes (μ) that occurs in a particular region is known. And the probability, the possibility or existence of success has the same trend and proportional to the size of the specified region, but is very small and considered as negligible.



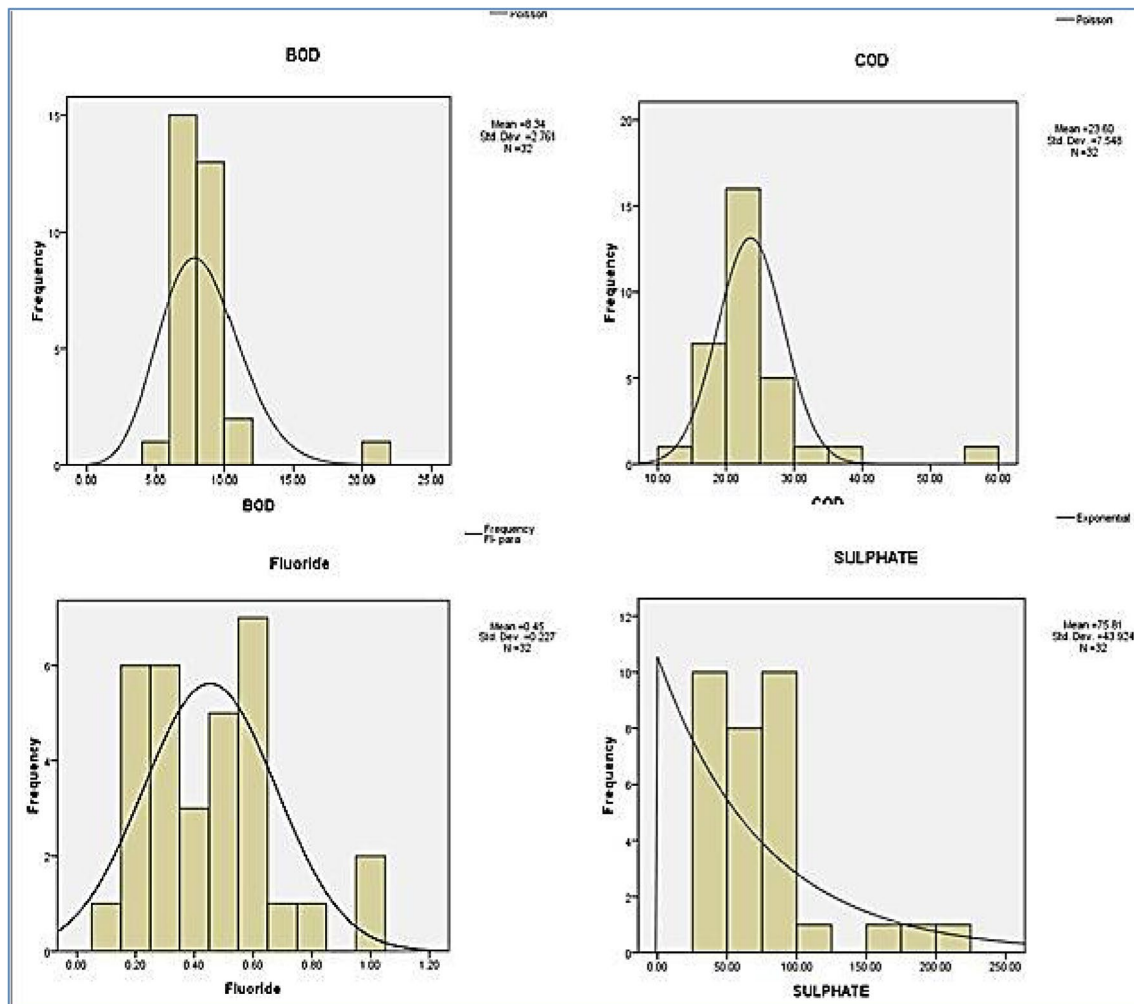


Fig. 14 Histogram and probability distribution of BOD, COD, fluoride and sulphate

Figure 13 shows the mean and standard deviation occurred as normally distributed bell-shaped curve. It shows the symmetrical density curve which is determined through standard deviation. The normal distribution is zero, because the 'x' lies away from the mean. And so it is not suitable method for distribution analysis, and robust statistical inference methods were adopted.

Obtain the unknown future data through known data, the predications of this method are called plug-in distribution model, and the value estimated through rate parameter ' λ ' is shown in Fig. 14.

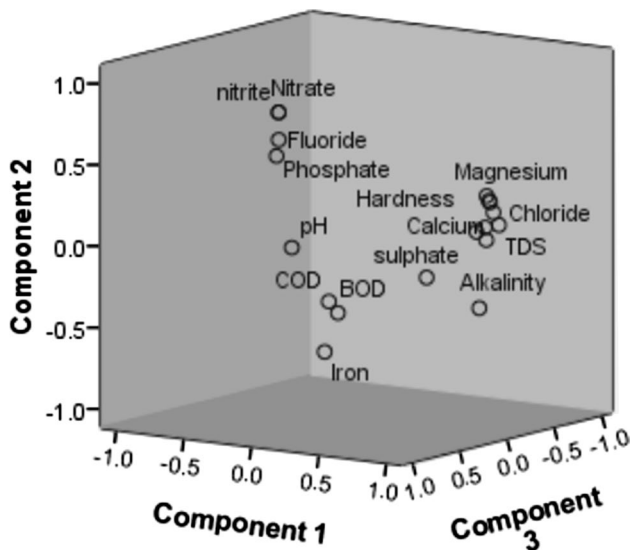
Principal component analysis (PCA): it is the process used to convert a set of correlated variables into uncorrelated variables, and they are given in Table 6

Table 6 shows the principal and rotated component matrix. The mathematical approach used in PCA is called eigenanalysis through eigenvalues and eigenvectors of rows or column of the component matrix.

From Table 6, the rotated component matrix which is the component matrix converged to its fifth iteration. A component value close to 0.8 is taken for interpretation. Thus,

Table 6 Principal component matrix and rotated component matrix

S. No	Parameters	Principal component matrix			Rotated component matrix		
		1	2	3	1	2	3
1	F1	-0.317	0.628	0.369	-0.081	0.790	0.019
2	TDS	0.974	0.163	-0.114	0.968	-0.217	0.072
3	pH	-0.625	-0.150	-0.208	-0.614	-0.022	-0.281
4	Alkaline	0.700	-0.400	-0.298	0.514	-0.687	0.052
5	Hardness	0.911	0.297	-0.109	0.961	-0.082	0.011
6	Calcium	0.910	0.310	-0.099	0.964	-0.068	0.015
7	Magnesium	0.892	0.336	-0.101	0.958	-0.040	-0.001
8	Chloride	0.934	0.237	-0.113	0.959	-0.142	0.036
9	Electrical conductivity	0.925	0.075	-0.050	0.883	-0.248	0.151
10	Sodium	0.937	0.158	-0.021	0.923	-0.170	0.148
11	Potassium	0.904	0.133	0.023	0.880	-0.161	0.189
12	Nitrite	-0.338	0.790	0.342	-0.035	0.921	-0.71
13	Sulphate	0.729	-0.124	0.301	0.596	-0.202	0.492
14	BOD	0.438	-0.294	0.823	0.218	-0.026	0.953
15	COD	0.394	-0.224	0.856	0.202	0.062	0.945
17	Phosphate	-0.545	0.461	0.068	-0.328	0.589	-0.244
18	Nitrate	-0.338	0.790	0.342	-0.035	0.921	-0.071
19	Iron	0.158	-0.600	0.562	-0.135	-0.309	0.765

**Fig. 15** Component plot

with regard to that, hardness, calcium, magnesium, chloride, EC, sodium and potassium have values above 0.8 in the first component. This infers that the source of these contaminations is same which can possibly from leachate of the solid waste dump yard (Manoj and Pravin 2015). Similarly, nitrite and nitrate have component value above 0.9 in the second component which shows that it has the same source for which fertilizer can be a reason. In the third component, BOD and COD have considerable values which can be from an improper industrial effluent disposal (Manoj et al. 2016).

Figure 15 shows the component plot which exhibits all the three components and its corresponding values, which gives the clear idea about the sources of contamination. The plot is a 3D plot of the rotated component matrix which shows the stand of the component value of each parameter in the system.

Conclusion

From the work done, it is confirmed that the groundwater quality is affected by the leachate from the studied dump yard. The generation of contamination is due to the increase in pollution which is the key parameter being identified. Construction of engineered landfill and geosynthetic clay liners (GCL) can decrease the rate of seepage of leachate into the soil to reach the water table. There are a few contaminations apart from the leachate source. From the principal component analysis, it is inferred that two other sources of contaminations are also present. It shows that nitrite and nitrate are obtained from the same source which can be fertilizers used around the location of the study area. BOD and COD are from a similar source which can be from an improper industrial effluent disposal.

Acknowledgements The authors gratefully acknowledge the Management and Authorities, SRM University, Tamil Nadu, India, for providing the necessary facility to complete this work in a successive manner.

Compliance with ethical standards

Conflict of interest The authors have no conflict of interest.

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