Research Article

Evaluation of seasonal and temporal variations of groundwater quality around Jawaharnagar municipal solid waste dumpsite of Hyderabad city, India

B. Soujanya Kamble[1] · Praveen Raj Saxena[2] · Rama Mohan Kurakalva[3] · K. Shankar[2]

Received: 19 June 2019 / Accepted: 5 February 2020 / Published online: 27 February 2020

Abstract

The present study aimed to assess the impact of municipal solid waste dumpsite on groundwater bodies at Hyderabad, India. Leachate and groundwater samples collected through pre- and post-monsoon analyzed the physicochemical, microbiological, biological and heavy metals. The analytical data were compared with Bureau of Indian Standards (BIS) drinking water quality standards. Water quality index (WQI), heavy metal pollution indices like heavy metal evaluation index (HEI) and degree of contamination (Cd) are calculated for groundwater samples. High total dissolve solids values in leachates revealed that they were highly contaminated with organic and inorganic salts. Biological oxygen demand values indicated that dumpsite was "old and stabilized" with decreasing biodegradability from time to time. According to WQI, about 75% of the water samples identified as "Poor" category that is not suitable for neither drinking nor domestic purposes as per BIS standards. Similarly, HEI and Cd results indicated that majority of the samples are labeled with low-metal pollution status. Spatial patterns obtained through geographic information systems using inverse distance weighted interpolation technique revealed that the concentrations of various parameters are high due to increased degradation of solid wastes during rainfall, especially during the post-monsoon. The study suggested that leachates have treated prior to disposal on land, and continuous monitoring of groundwater wells is required to minimize the pollution and potential health hazards.

Keywords Leachate · Municipal dumpsite · GIS · Groundwater · Heavy metal evaluation index (HEI) · Water quality index (WQI)

1 Introduction

India is the seventh largest country by area, the second most populous country with over 1.2 billion people and one of the mega diversity regions in the world. However, when it comes to MSW management, little is the way it is meant to be. With rapid industrialization and population growth, MSW has increased tremendously due to increased lifestyles and social status of the people. According to Ministry of Urban Affairs, Govt. of India estimates, India is generating approximately 100,000 metric tons of solid waste everyday of which 90% is disposed in the open place [1]. In spite of specifications of municipal solid wastes (management and handling rules) developed by MoEF & CC [2] for collection, segregation, storage, transportation, processing and disposal, lack of implementation

---

✉ K. Shankar, geoshankar1984@gmail.com; B. Soujanya Kamble, bsk.029@gmail.com; Praveen Raj Saxena, saxenapraveenraj@gmail.com; Rama Mohan Kurakalva, krenviron@ngri.res.in | [1]Department of Environmental Science, CVR College of Engineering, Mangalpalli, Ibrahimpatnam, India. [2]Department of Applied Geology, School of Applied Natural Sciences, Adama Science and Technology University, Adama, Ethiopia. [3]Hydrogeochemistry Group, CSIR-National Geophysical Research Institute (NGRI), Uppal Road, Hyderabad 500007, India.

SN Applied Sciences (2020) 2:498 | https://doi.org/10.1007/s42452-020-2199-0

is the main cause for the widespread of open waste disposal. Unconditional open dumping of the garbage in the absence of protective liners beneath causes leachate percolation into the aquifer system. It is a thick toxic soup which flows out of the decomposing solid wastes carrying harmful constituents like organic matter, heavy metals and xenobiotic organic compounds as a result of precipitation. Further, it seeps into the very next recipient soil and ultimately reaches the groundwater table disrupting the natural phenomena of hydrological cycle. Groundwater contamination due to MSW leachate poses a serious threat to the biotic communities as it is an important resource for drinking and agriculture purposes. Quality assessment and regular monitoring of groundwater wells around the dumpsites are also the need of an hour. Several scientific studies [3–13] are being carried out worldwide on MSW leachate pollution impact on water bodies. Spatial variation of groundwater quality depends on the geological formation through which it flows and on anthropogenic activities in the groundwater [14–31].

WQI is the superior environmental criterion and one of the most effective tools, which ultimately describes the water quality status for drinking purpose. The general WQI was developed [32] and improved by Deininger for the Scottish Development Department in [33]. WQI provides a single value that expresses overall water quality at a certain location. It converts the complex water quality data into information that is understandable and useable by the public and helps in developing environmental management strategies to control the groundwater pollution. In addition, water quality index (WQI) has been widely used to indicate a water quality class for drinking use [34]. Details on computation of WQI using relative weight and quality rating scale are presented in [20, 34–45].

Heavy metal pollution indices like heavy metal evaluation index (HEI) and degree of contamination (Cd) also hugely contribute in assessing the pollution status of the groundwater resources. Various researchers have successfully used HEI and Cd for interpretation of heavy metal pollution [46–62] and several others.

Geographic information system (GIS) combined with IDW interpolation technique is a powerful package in assessing and regular monitoring of the groundwater quality. It is less time-consuming and cost-effective process which transforms huge sets of data collection into spatial projections to observe the patterns and connections of pollutants. It also helps in identifying probable sources and origin of the contaminants. GIS-based study is the best idea to observe the evolution tendency of the water quality which keeps changing from time to time. This modern approach tremendously helps in precise monitoring and quick decision making process for environmental managers and decision makers.

In view of the above, the present investigations were undertaken at Jawaharnagar dumpsite with the following objectives (1) to assess the impact of leachates on groundwater quality (2) to study the seasonal variation of groundwater quality in two hydrological cycles and (3) to assess the extent of groundwater contamination using WQI and other heavy metal pollution indices with the aid of GIS.

2 Study area

Municipal solid waste dumpsite is situated in Jawaharnagar Village near Hyderabad city. It is just outside the limits of Greater Hyderabad Municipal Corporation (GHMC) and inside the HMDA (New limits of Hyderabad). The site is 35 km from Hyderabad city and 105 km away from the state highway connecting Hyderabad and Nagpur in west direction from boundary of project site. It is an open dumpsite which was established in the year 2002. The total area of Jawaharnagar village dumpsite is 350 acres from which the area occupied by the waste at present is 182 acres. It is located between 70° 30′ 01″ N to 17° 32′ 03″ N latitude and 78° 34′ 13″ E to 78° 37′ 47″ E longitude. The location map of the study area was prepared using Arc GIS 10.1 software developed by ESRI (Fig. 1).

Hyderabad is the capital city of Telangana state and is the sixth largest city in India. Currently, 5000 metric tons (MT) of municipal solid waste is generated in the city. This waste is collected by the municipal authorities with the help of tricycle carts and dumped into the three major collection points which are located in Yousufguda, Imlibun and Lower Tank bund. Eventually, waste collected from all the three collection points in the city are transported through trucks and dumped into the municipal dumpsite of Jawaharnagar without proper segregation and recycling process. The percentage composition of the municipal solid waste generated in Hyderabad city (Fig. 2) was reported elsewhere [63].

At the vicinity of the MSW dumpsite, it is observed that groundwater table is at 120 cm below ground level. The annual mean temperature is 26 °C. Summers are hot with maximum temperatures of 40 °C. Winter has temperatures varying from 14.7 to 28.6 °C. Heavy rain from the southwest monsoon falls between June and September, with annual rainfall of 812.5 mm.

3 Methodology

3.1 Sampling of leachate and groundwater

To examine the effect of leachate pollution on groundwater, leachate samples at two stations and twenty-three (23)

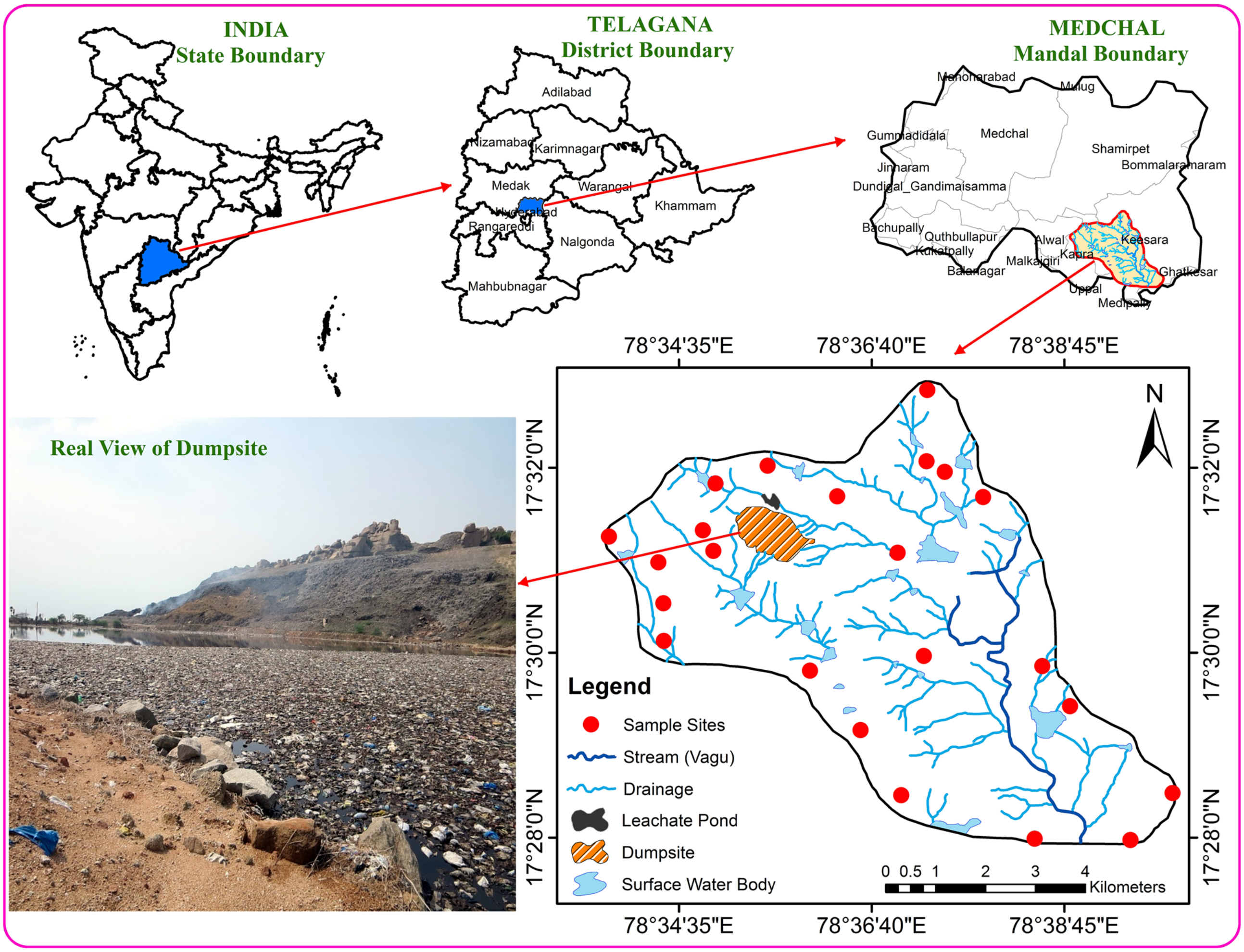

Fig. 1 Location map of the study area (i.e., Jawaharnagar dumpsite)

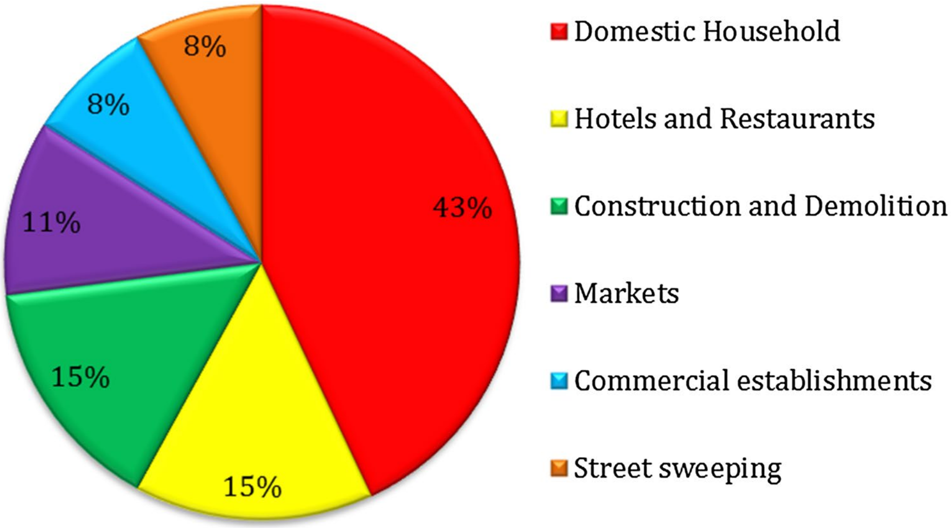

Fig. 2 Percentage composition of municipal solid waste in Hyderabad. *Source*: Raj et al. [63]

groundwater samples were collected around the dumpsite during pre- and post-monsoon in 2014 and 2015. Simple random sampling technique was employed covering an area of approximately 49 sq. km around the dumpsite to

Table 1 Geographic coordinates of groundwater and leachates of the study area

S. no.	Sample site hamlet/village name	Sample ID	Latitude	Longitude	Sampling distance from dumpsite (km)
1	Dammaiguda	GW1	17.29.34.5	78.33.0.705	3
2	Yadgarpally	GW2	17.31.56.411	78.37.21.664	4
3	Godumkunta	GW3	17.29.28.432	78.38.43.162	5.7
4	Kundanpally	GW4	17.29.55.108	78.38.25.447	4.4
5	Karimguda	GW5	17.28.34.378	78.39.50.537	8.7
6	Malkaram	GW6	17.31.47.652	78.34.55.495	1.2
7	Y.S.R nagar	GW7	17.31.4.573	78.34.50.461	1.7
8	Indiramma Jinnaram	GW8	17.31.5.509	78.32.56.063	2.5
9	Cheriyal	GW9	17.31.40.039	78.37.46.538	4.2
10	Haridaspally	GW10	17.31.38.914	78.36.12.954	1.2
11	Ahmedguda	GW11	17.29.59.023	78.37.8.062	4.2
12	Nagaram	GW12	17.29.11.757	78.36.27.773	5
13	Gabbilalpet	GW13	17.31.17.408	78.34.44.687	1.4
14	Yadgarpally 2	GW14	17.32.1.653	78.37.10.386	4
15	Jawaharnagar	GW15	17.31.59.331	78.35.27.287	840 (in m)
16	Karimguda 2	GW16	17.28.9.435	78.39.32.925	8.7
17	Rampally	GW17	17.28.8.413	78.38.6.652	8.5
18	Charkpally	GW18	17.28.30.689	78.36.55.765	4.1
19	Wampugudem	GW19	17.30.6.671	78.34.20.407	5.3
20	Ambedkarnagar	GW20	17.30.31.96	78.34.21.753	6.2
21	Chennapur	GW21	17.30.56.098	78.34.16.948	3.1
22	Balajinagar	GW22	17.31.13.434	78.33.43.652	4.4
23	Timmaipally	GW23	17.32.50.585	78.37.10.307	6.1
24	Leachate 1	*L*1	17.31.59.330	78.35.27.280	120 (m)
25	Leachate 2	*L*2	17.31.59.329	78.35.27.279	121 (m)

observe the variations due to leachate pollution. The sampling locations were recorded using GPS (Table 1). All the samples were collected in 1-L pre-cleaned high-density polyethylene bottles (HDPE), transferred to the laboratory and were stored at 4 °C and analyzed within 2 days of sampling following APHA [64] methods. All the samples were analyzed for physicochemical parameters, viz. pH, EC, TDS, TA, TH, Ca^{2+}, Mg^{+2}, Na^+, K^+, CO_3^{-2}, HCO_3^-, NO_3^-, SO_4^{-2}, Cl^- and F^- and heavy metals, viz. cadmium (Cd), copper (Cu), lead (Pb), arsenic (As), chromium (Cr), iron (Fe), nickel (Ni) manganese (Mn) and zinc (Zn).

The pH and EC were measured in the field, immediately after the sampling using digital pH and conductivity meter (HANNA Inst). TDS was calculated using EC value using an empirical equation. TA, TH, Ca^{2+}, Mg^{2+} and Cl^- were estimated by titrimetry using standardized EDTA solution. Carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) were determined by titration with H_2SO_4. Sodium (Na^+) and potassium (K^+) were determined by flame photometry. Nitrates and fluoride determination was carried out using ion-selective electrodes (Orion). Sulfate (SO_4^{-2}) was measured by spectrophotometer (Spectronic 21). Heavy metals were analyzed using inductively coupled plasma optical emission spectrometry (ICP-OES, Perkin Elmer Optima 4300DV).

3.2 Water quality index (WQI)

In this study, for the calculation of water quality index (WQI), 11 parameters, namely pH, electrical conductivity, total dissolved solids, total hardness, calcium, magnesium, sodium, potassium, sulfates, nitrates and chlorides were chosen. Three major steps were carried out for computing WQI for groundwater samples as follows:

(1) Each of the chemical parameters were assigned a weighting factor (w_i) based on its importance and potential impact on overall water quality for drinking purpose. Highest weighting factor ($w_i = 5$) was assigned to the parameters (TDS, NO_3^- and Cl^-) which are known sources of dumpsite leachate contamination in groundwater, and a minimum weighting factor ($w_i = 2$) was assigned to the parameters (Ca^{2+}, Mg^{2+} and K^+) which have no significant effects on the water quality.

Table 2 Relative weights of various parameters to calculate water quality index (WQI)

Water quality parameters	BIS desirable limits (1998)[a]	Weighting factor (w_i)	Relative weight (W_i)
pH	8.5	3	0.0769
EC	200	3	0.0769
TDS	1000	5	0.1282
TH	300	3	0.0769
Ca^{2+}	75	3	0.0769
Mg^{2+}	30	3	0.0769
Na^{+}	100	3	0.0769
K^{+}	10	3	0.0769
SO_4^{2-}	200	3	0.0769
NO_3^{-}	45	5	0.1282
Cl^{-}	250	5	0.1282
		$\sum w_i = 39$	$\sum W_i = 1$

[a] Bureau of Indian Standards (BIS)

(2) The relative weight (W_i) was calculated using following Eq. 1 (Table 2).

$$W_i = \frac{w_i}{\sum_{n=1}^{n} w_i} \tag{1}$$

where W_i = relative weight, w_i = weighting factor of each parameter and n is no. of parameters.

(3) A quality rating scale (q_i) for each chemical parameter was calculated by dividing the analytical value of each groundwater sample parameter (C_i) with its respective [65] drinking water quality standard (S_i). The value obtained was further multiplied with 100 using following equation

$$q_i = \left(\frac{C_i}{S_i}\right)100 \tag{2}$$

(4) Further, sub-index (SI_i) for each chemical parameter was calculated by substituting the obtained values of relative weight (W_i) and quality rating scale (q_i) of each parameter in the following equation

$$SI = W_i q_i \tag{3}$$

(5) Finally, WQI was calculated by the summation of the sub-index values of all the chemical parameters using following equation

$$WQI = \sum_{i=1}^{n} SI_i \tag{4}$$

where n = no. of parameters.

3.3 Heavy metal evaluation index (HEI)

The HEI method estimates an overall water quality status with respect to heavy metals. The HEI is computed using the following equation:

$$HEI = \sum_{i=1}^{n} Hc_i / Hmac_i \tag{5}$$

where Hc is the monitored value of the ith parameter and Hmac is the maximum admissible concentration (MAC) of ith parameter.

3.4 Degree of contamination (Cd)

This method is used to evaluate the water quality by calculating the degree of contamination (Cd), and it was developed by [66]. The Cd is calculated by summation of the contamination factors (Cfi) of individual parameters that exceed their upper permissible value for every water sample. The parameters considered include As, Cd, Fe, Cu, Mn, Zn. Thus, Cd summarized the combined effect of these heavy metal parameters in groundwater which are harmful for human consumption. The Cd is computed from the following equations:

$$C_d = \sum_{i=1}^{n} C_{fi} \qquad C_{fi} = \frac{CA_i}{CN_i} - 1 \tag{6}$$

where C_{fi}, CA_i, CN_i represent the contamination factor, analytical value and upper permissible concentration of the ith component. The CN_i values were taken as maximum admissible concentration (MAC) value.

3.5 Inverse distance weighted (IDW) interpolation concept

Geostatistical analyst extension of ArcMap presents two groups of interpolation techniques such as deterministic and geostatistical. IDW is a deterministic method which predicts a value for any unmeasured location using the measured values surrounding the prediction location. The basic concept behind this prediction is that things that are closer to one another are alike than the things that are farther apart. More weights are given to the points closer to prediction location than the farther ones. Hence, it is named as inverse distance weighted.

$$W \infty 1/d^p$$

p is the optimal power which is determined by root-mean-square prediction error (RMSPE). RMSPE is determined using cross-validation. In cross-validation, the point which is measured is removed and compared to the value predicted for that location. This process continues for all the points present in a given space. This helps in quantifying the prediction error. Various powers are tried by geostatistical extension for IDW interpolation and plotted against RMSPE. The power $p=2$ is used as a default value to predict locations by geostatistical extension as it provides minimum RMSPE. In this study, a huge set of groundwater data has been introduced into geostatistical analyst environment. IDW method created spatial projections using Arc GIS 10.3 software developed by ESRI to observe the distribution patterns of various physicochemical parameters and pollution indices like WQI, HEI and Cd.

4 Results and discussion

4.1 Leachate characteristics

Leachates of Jawaharnagar dumpsite were analyzed for various physicochemical parameters including heavy metals, and the data were compared with Leachate land disposal standards MoEF & CC [2]. The significant seasonal and yearly variations in the concentrations of leachate constituents have been observed and were found beyond the prescribed permissible limits of MOEF & CC (Table 3). Leachates collected during post-monsoon season showed higher concentrations of pH, TDS, Cl^- and BOD5. It was also observed that the same parameters collected in the year 2015 had high concentrations compared to the year 2014 (Table 3). This could be attributed to the increased degradation and deterioration of solid wastes due to rainfall and time, respectively.

The leachates were observed amber in color with alkaline pH and fall within the standard limits. The increase in pH is mainly attributed to the decreased ionization of free volatile fatty acids, as a result of its conversion into methane and carbon-dioxide during methanogenic phase [67]. Total dissolved solids (TDS) of the leachate samples were found high compared to the standard limits. High TDS is mainly comprised of increased dissolved organic and inorganic salts. BOD5 values were found high in 2014 compared to 2015. This is due to anaerobic decomposition

Table 3 Jawaharnagar dumpsite leachates (of 2014 and 2015) compared to leachate land disposal standards MOEF [2]

Leachate parameters	Leachate 1				Leachate 2				Leachate land disposal standards MOEF [2]
	2014		2015		2014		2015		
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
pH	8.1	9.0	8.3	9.0	8.3	8.6	8	8.9	5.5–9.0
EC (µS/cm)	21,220	38,450	29,958	41,252	10,150	22,000	17,524	28,546	–
TDS	14,096	29,633	25,031	33,043	13,254	19,452	24,312	29,245	2100
TH	180	245	234	284	148	179	167	197	–
TA	195	278	253	322	158	179	174	230	–
Ca^{2+} (mg/L)	39	120	42	148	15	80	42	97	–
Mg^{2+} (mg/L)	6.5	15	10	17	3.5	12	6	15	–
Na^+ (mg/L)	2010	3225	2125	2547	1725	2585	1884	3210	–
K^+ (mg/L)	1870	1102	1141	1879	1432	953	1021	1721	–
$CO_3{}^{2-}$(mg/L)	79	195	91	214	45	69	57	76	–
$HCO_3{}^-$(mg/L)	652	811	714	921	455	532	471	612	–
$NO_3{}^-$ (mg/L)	876	1012	995	1100	615	944	752	1017	–
$SO_4{}^{2-}$ (mg/L)	141	150	150	164	114	125	146	155	–
Cl^- (mg/L)	6554	7247	12,266	45,319	3344	4655	11,003.6	34,876	600
F^- (mg/L)	0.2	0.3	0.2	0.7	0.2	0.3	0.2	0.7	–
BOD5	996	991	490	436	520	518	323	318	100
COD	10,204	10,200	7147	7122	5388	5379	3413	3400	–
T. coli (100 ml)	≥ 1609	≥ 1609	≥ 1609	≥ 1609	≥ 1609	≥ 1609	≥ 1609	≥ 1609	–
F. coli (100 ml)	Present	Present	Present	Present	Present	Present	Present	Present	–
E. coli (100 ml)	Present	Present	Present	Present	Present	Present	Present	Present	–

Table 4 Jawaharnagar dumpsite leachates heavy metals compared to leachate land disposal standards MOEF [2]

Heavy metals (μg/L)	Leachate 1	Leachate 2	Leachate land disposal standards, MOEF [2]
Al	569.9	490.4	–
As	66.3	35.5	0.2
Cd	1.16	0.98	–
Co	27.32	17.1	–
Fe	6550	5458	–
Cu	53.8	46.14	–
Mn	6272	5142	–
Ni	67.3	10.22	–
Pb	BDL	BDL	–
Zn	12.3	10.44	–

of methanogenic phase where in the absence of oxygen, humic and fulvic acid compounds dominate over organic matter. Thus, the biodegradability decreases with time and age of the dumpsite [68]. Chlorides (Cl^-) were also found high in the leachate samples when compared with standard limits. Chloride is one of the major constituents to determine the leachate contamination in groundwater. The main sources of chlorides in MSW leachate are food scraps and animal wastes. The presence of various metals in the leachates indicated the disposal of variety of wastes at the dumpsite. Heavy metals like arsenic (As), concentration was found above the standard limits. Dumping of arsenic containing wastes like cosmetics and personal care products (CPCP) might be responsible for the increased concentration of arsenic in groundwater. However, iron (Fe) was found predominant in the leachates (Table 4).

4.2 Groundwater pollution monitoring

The groundwater samples ($n=23$) collected and analyzed for various parameters in both pre- and post-monsoon seasons for two consecutive years, i.e., 2014 and 2015 to observe the seasonal and temporal variations and were compared with WHO drinking water quality standards [69] to determine the suitability for human consumption (Tables 5 and 6). All the groundwater samples were colorless and odorless except for GW10 (Haridaspally) which is located at 1.2 km from the dumpsite. The pH of all the groundwater samples was found within the permissible range of WHO standards. EC values of all the groundwater samples were found within the WHO limits except for few samples located near the dumpsite. High conductivity is mainly due to the presence of high concentration of dissolved inorganic ions in the groundwater due to the leachate contamination [25].

The parameters like TDS, TH, Na^+, NO_3^- and Cl^- were found exceeding the permissible limits of WHO standards. Municipal dumpsite leachates are the major indeed sources of high TDS, Cl^- and NO_3^- in groundwater. High TDS observed might be possibly due to the presence of dissolved organic and inorganic salts of the leachates in groundwater. High concentrations of chlorides are added to the groundwater from the municipal wastes, which clearly indicate the impact of landfill leachate [6, 70]. Other sources include farm drainage and sewage effluents [6]. High chlorination of groundwater possibly leachate derived produces trihalomethanes (THM). These chlorine byproducts trigger the production of free radicals in the body causing cell damage and are highly carcinogenic [71]. High nitrates observed in groundwater are mainly due to the leachate contamination. According to [72], major sources of nitrates include domestic sewage, runoff from agricultural fields and leachate from landfill sites.

Spatial distribution maps of TDS, Cl^- and NO_3^- were prepared using IDW method in Arc GIS 10.3 software to observe the seasonal and temporal variations in groundwater [20, 73] due to leachate contamination (Figs. 3, 4 and 5). From the figures, the observations were made as follows:

(1) The concentrations of three parameters (TDS, Cl^- and NO_3^-) were high during post-monsoon season in both years.
(2) The TDS, Cl^- and NO_3^- concentrations in groundwater increased in 2015 compared to 2014.
(3) As the distance increased from the dumpsite, the extent of contamination has decreased.

During rainfall, the deterioration and degradation of solid wastes are high which results in increased leaching and percolation of solid waste constituents into groundwater environment. Thereby, groundwater quality is deteriorating with time which is evident from the impact of leachates.

Table 5 Physicochemical analysis of groundwater collected around Jawaharnagar dumpsite during pre- and post-monsoon in 2014 and its comparison with WHO standards [69]

Sl. no.	pH		EC		TDS		TH		Ca^{2+}		Mg^{2+}		Na^{+}		K^{+}		CO_3^{2-}	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pree	Post	Pre	Post
GW1	7.1	7.8	1400	1500	896	960	370	470	74	89	45	60	31	42	3	4	16	24
GW2	7.4	7.8	191	700	122	448	168	175	20	41	5.3	16	28	45	2	4	12	18
GW3	7.4	7.6	1300	1403	832	898	285	300	68	80	9.7	35	84	101	2	5	12	26
GW4	7.5	7.6	1400	1602	957	1025	185	300	45	86	18	20.6	95	149	2	4	15	25
GW5	7.1	7.3	980	1502	627	961	320	325	78	90	24	31	74	126	2	5	19	28
GW6	7.3	7.6	600	772	494	512	185	200	45	78	12	18	42	77	1	6	6	34
GW7	7.2	7.5	1000	1254	640	803	341	370	82	102	11	33	41	57	1	3	5	21
GW8	7.2	7.5	1495	1610	768	1030	260	548	114	132	36	53	84	128	1	2	12	30
GW9	7.21	7.3	1494	1500	640	956	300	325	72	78	29	42	93	107	4	5	15	28
GW10	7.3	7.6	1060	3154	1060	2018	315	610	73	220	14.5	36	97	142	2	4	9	21
GW11	7.2	7.5	2104	2200	1347	1408	380	492	320	332	13	21	142	226	2	3	6	16
GW12	7.1	7.4	1115	1200	714	768	207	290	32	50	20	31	98	134	3	5	6	9
GW13	7.2	7.3	720	800	461	512	265	268	62	65	26	28	48	61	5	5	8	9
GW14	7.3	7.6	210	711	120	440	200	202	21	41	5	17	27	46	2	4	13	20
GW15	7.2	7.6	1100	1221	460	474	234	250	83	105	12	32	42	57	1	2	6	22
GW16	7.2	7.3	982	1000	625	1021	319	326	78	91	25	33	75	124	2	4	20	35
GW17	7.2	7.4	1285	1301	1014	1133	187	200	47	60	12.1	19	83	164	2	3	19	24
GW18	7.1	7.3	1248	1257	452	631	165	178	36	43	14	28	52	67	1	3	14	22
GW19	7.2	7.4	1247	1320	435	611	169	177	42	54	21	30	45	51	2	2	12	21
GW20	7.2	7.2	1324	1421	512	695	174	182	34	42	24	33	39	44	2	3	9	25
GW21	7.3	7.4	1120	1226	455	524	159	168	44	58	22	34	33	53	1	2	11	23
GW22	7.1	7.3	1210	1342	412	533	168	184	39	47	21	44	52	60	2	5	18	25
GW23	7.2	7.4	1262	1346	152	245	155	174	41	56	30	42	29	38	2	4	12	20
Minimum	7.1	7.2	191	700	120	245	155	168	20	41	5	16	27	38	1	2	5	9
Maximum	7.5	7.8	2104	3154	1347	2018	380	610	320	332	45	60	142	226	5	6	20	35
Mean	7.2	7.5	1123.8	1362.7	617.2	809.0	239.6	291.9	67.5	88.7	19.5	32.0	62.3	91.3	2.0	3.8	12	22.9
WHO [69]	6.5–8.5		1500		500		500		75		50		200		12		NA	

Sl. no.	HCO^{3-}		SO_4^{2-}		Cl^{-}		F^{-}		NO^{3-}		TA	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
GW1	98	350	132	174	337	352	0.5	0.8	74	164	100	293
GW2	128	153	80	95	36	43	0.6	1.2	12	38	125	205
GW3	85.4	378	135	154	260	315	1.4	1.6	39	58	95	330
GW4	100	158	120	158	320	347	1.1	1.3	73	91	102	239
GW5	79	360	110	133	290	340	0.4	0.9	56	67	75	350
GW6	104	256	74	141	74	141	1.2	1	12	26	95	251
GW7	140	214	132	246	132	246	0.8	1	125	190	125	250
GW8	390	415	125	173	337	479	0.9	1	15	22	340	390
GW9	284	293	120	146	121	213	0.8	1.4	62	156	256	364
GW10	280	299	143	152	957	1138	0.9	1	32	44	245	280
GW11	120	171	123	152	820	851	0.4	0.6	64	75	130	150
GW12	142	156	120	132	156	220	0.4	1.2	75	76	126	143
GW13	98	112	82	96	145	251	1.3	1.5	165	170	165	170
GW14	127	153	81	90	35	43	0.6	1.2	12	39	125	205
GW15	142	210	125	200	125	240	0.7	1	70	84	120	245
GW16	200	378	112	130	287	344	0.4	0.9	56	66	77	345
GW17	80	354	156	191	333	341	0.2	1	57	81	181	394
GW18	82	125	75	84	40	51	0.5	0.6	41	54	95	124

Table 5 (continued)

Sl. no.	HCO^{3-}		SO_4^{2-}		Cl^-		F^-		NO^{3-}		TA	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
GW19	74	132	64	70	36	45	0.4	0.5	39	50	121	136
GW20	81	154	71	87	33	41	0.5	0.6	45	56	112	144
GW21	78	122	73	92	45	57	0.4	0.6	47	55	135	157
GW22	85	136	70	81	36	47	0.2	0.4	33	47	128	155
GW23	76	140	77	82	42	50	0.2	0.3	37	53	131	142
Minimum	74	112	64	70	33	41	0.2	0.3	12	22	75	124
Maximum	390	450	156	246	957	1138	1.4	1.6	165	190	340	394
Mean	133.6	226.9	104.3	133.0	217.3	269.3	0.6	0.9	54	76.6	139.3	237.5
WHO [69]	NA		250		250		1.5		45		500	

Table 6 Physicochemical analysis of groundwater collected around Jawaharnagar dumpsite during pre- and post-monsoon in 2015 and its comparison with WHO standards [69]

Sl. no.	pH		EC		TDS		TH		Ca^{2+}		Mg^{2+}		Na^+		K^+		CO_3^{2-}	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
GW1	7.3	7.7	1467	1584	942	997	382	487	80	91	54	78	43	56	5	7	23	32
GW2	7.3	7.8	489	768	350	475	110	172	25	46	17	25	35	57	4	8	15	24
GW3	7.5	7.7	1298	1399	859	912	260	310	72	85	12	40	95	124	3	9	20	31
GW4	7.4	7.7	1534	1643	981	1287	210	321	54	88	23	35	112	168	4	6	21	61
GW5	7.3	7.7	1345	1560	687	995	250	334	81	95	30	44	87	145	3	7	12	40
GW6	7.3	7.8	630	824	490	538	210	257	53	84	15	24	51	82	2	5	10	55
GW7	7.4	7.6	1200	1301	697	829	325	388	42	6	15	39	52	69	2	5	17	28
GW8	7.4	7.7	1387	1685	810	1234	278	584	125	147	43	61	98	139	3	6	18	37
GW9	7.1	7.4	1282	1500	784	980	241	269	29	78	38	46	102	112	6	10	28	51
GW10	7.4	7.8	1341	3214	1217	2107	242	758	16	41	23	54	108	165	3	5	15	27
GW11	7.1	7.4	2245	2284	1385	1478	410	545	140	152	14	26	154	253	3	7	14	27
GW12	7.2	7.4	1285	1546	754	802	230	324	28	61	31	40	121	147	3	6	10	17
GW13	7.1	7.2	621	785	497	562	279	355	71	78	32	36	56	74	5	7	14	28
GW14	7.3	7.8	489	768	352	475	110	172	26	47	18	26	35	57	4	8	16	24
GW15	7.4	7.5	1201	1300	697	829	324	388	43	87	16	40	53	70	2	5	17	27
GW16	7.3	7.7	1344	1560	687	995	250	334	81	95	31	44	89	105	3	7	13	28
GW17	7.4	7.6	1623	1812	1200	1285	203	250	51	67	15	27	95	177	4	6	35	53
GW18	7.2	7.5	478	678	352	487	115	175	24	45	16	23	41	52	2	4	22	30
GW19	7.1	7.4	470	689	412	521	230	280	30	46	24	36	36	58	3	4	16	25
GW20	7.3	7.6	512	720	382	475	212	241	52	71	20	38	34	56	3	5	22	41
GW21	7.2	7.5	479	723	374	481	221	253	35	51	30	41	39	50	2	5	15	32
GW22	7.1	7.5	475	721	385	492	290	321	42	52	24	36	44	53	3	6	20	30
GW23	7.2	7.3	480	689	368	474	248	312	44	54	26	36	42	55	3	5	17	35
Minimum	7.1	7.2	470	678	350	474	110	172	16	6	12	23	34	50	2	4	10	17
Maximum	7.5	7.8	2245	3214	1385	2107	410	758	140	152	54	78	154	253	6	10	35	61
Mean	7.3	7.6	1029.3	1293.6	681	857	244.8	340.4	54.1	72.5	24.7	38.9	74.5	101	3.3	6.2	17.8	34
WHO [69]	6.5–8.5		1500		500		500		75		50		200		12		NA	

Table 6 (continued)

Sl. no.	HCO^{3-}		SO_4^{2-}		Cl^-		F^-		NO^{3-}		TA	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
GW1	40.3	384	135	240	340.3	440	0.5	0.6	172	190	120	315
GW2	135	174	110.4	115	49.6	202	0.9	1.9	49	94	144	231
GW3	95	412	173	198	262.2	355	1.6	1.7	42	56	114	355
GW4	124	168	111	145	319	355	0.7	1.2	81	95	134	266
GW5	88	195	112	145	287	351	0.6	1	100	143	97	384
GW6	125	310	110	134	78	121	1.1	1.5	20	28	112	284
GW7	167	235	150	195	127.6	202	0.7	0.9	142	187	147	297
GW8	421	433	164	250	340	364	1	1	35	56	365	415
GW9	292	331	114	168	128	294	1.3	1.6	120	162	294	375
GW10	294	347	138	160	910	1111.3	0.6	1	36	54	284	347
GW11	135	184	132	190	817	859	0.5	0.6	132	155	145	187
GW12	161	178	117	129.6	223	230.4	1.1	1.3	73	77	145	164
GW13	121	142	106	112	134.7	266	1.3	1.6	166	170	114	137
GW14	135	174	110	115	50	200	0.9	1.9	49	94	114	231
GW15	165	238	150	195	128	202	0.7	0.9	140	188	145	294
GW16	89	190	112	145	300	351	0.6	1	100	142	97	385
GW17	254	412	160	208	320	355	0.5	0.6	104	167	203	412
GW18	120	152	130	235	300	350	0.4	0.5	52	90	121	300
GW19	89	165	102	114	90	125	0.5	0.7	50	92	142	212
GW20	85	112	112	132	97	142	0.6	0.7	82	90	102	245
GW21	52	100	113	135	75	156	0.4	0.6	51	93	120	240
GW22	112	158	100	124	78	136	0.5	0.6	50	90	98	180
GW23	82	145	110	120	92	212	0.4	0.7	48	91	92	125
Minimum	40.3	100	100	112	49.6	121	0.4	0.5	20	28	92	125
Maximum	421	433	173	250	910	1111.2	1.6	1.9	172	190	365	415
Mean	147	232.1	124.8	161.1	241.1	320.9	0.8	1.0	82.3	113.2	150	277.4
WHO [69]	NA		250		250		1.5		45		500	

4.3 Water quality index (WQI)

Water quality index (WQI) was calculated for groundwater samples (*n* = 23) collected during pre- and post-monsoon seasons of year 2014 and 2015 and were presented (Table 7). The percentages of groundwater samples falling in different water quality status were shown (Table 8). It indicated that majority (60%) of the groundwater samples were falling in the "Poor" water class range (100–200). Water samples show a good pre- and post-monsoon water quality of 39% and 26% in 2014; 39% and 30% in 2015. GWQI spatial distribution maps were created using IDW interpolation method to observe the water quality patterns in connection with leachate pollutants. From the figures, it is clear that as the distance increased from the dumpsite the groundwater was not influenced by the leachates. On the other hand, the groundwater wells in the vicinity of the dumpsite (approx. 2 km) were highly contaminated (Fig. 6). This study demonstrates that the use of GIS and WQI methods could provide useful information for water quality assessment.

4.4 Heavy metal pollution indices

It was observed from the literature [74] that only 0.02% of heavy metals leaches out from the total heavy metals

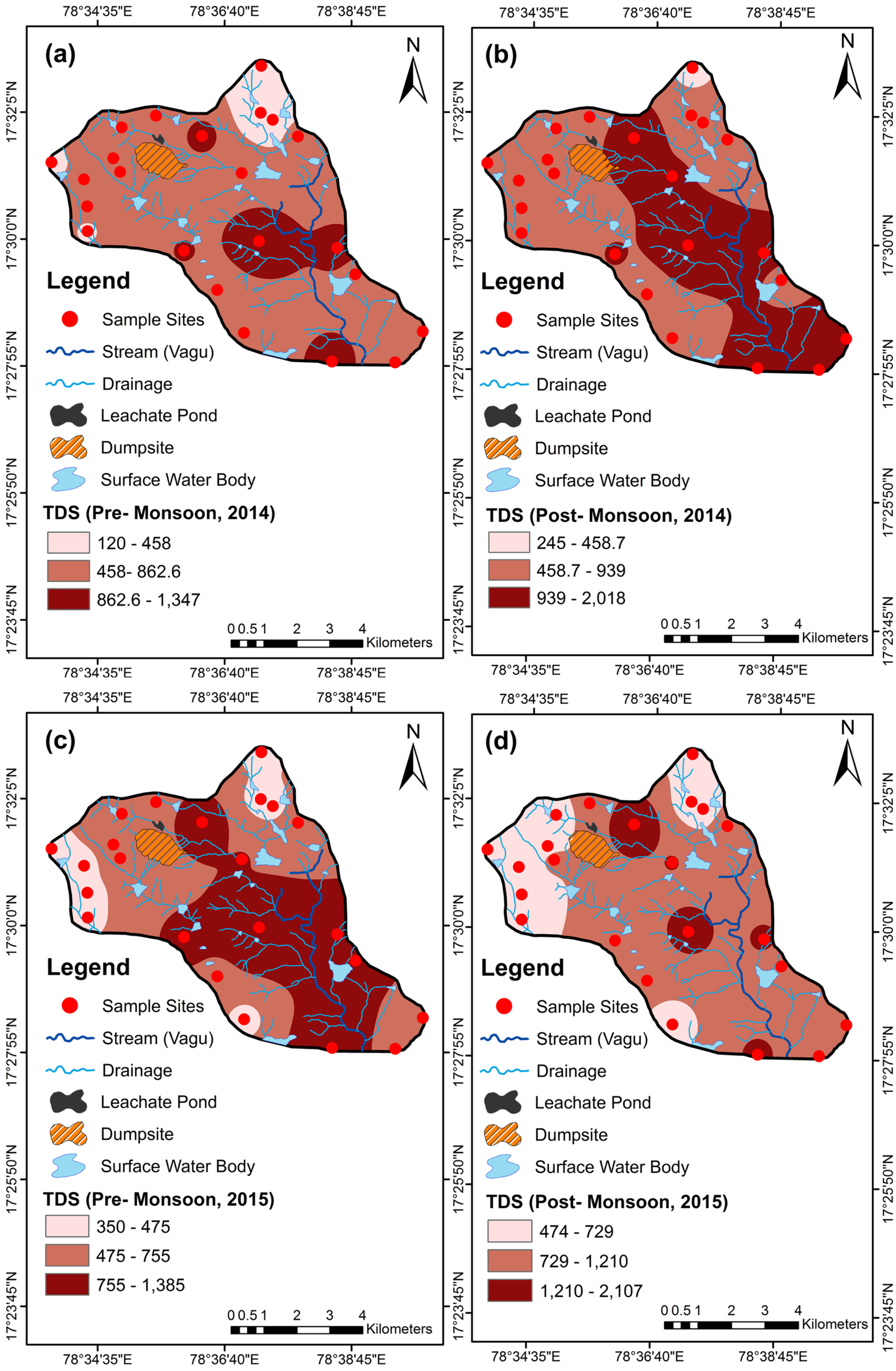

Fig. 3 Spatial distribution map of total dissolved solids (TDS) in groundwater

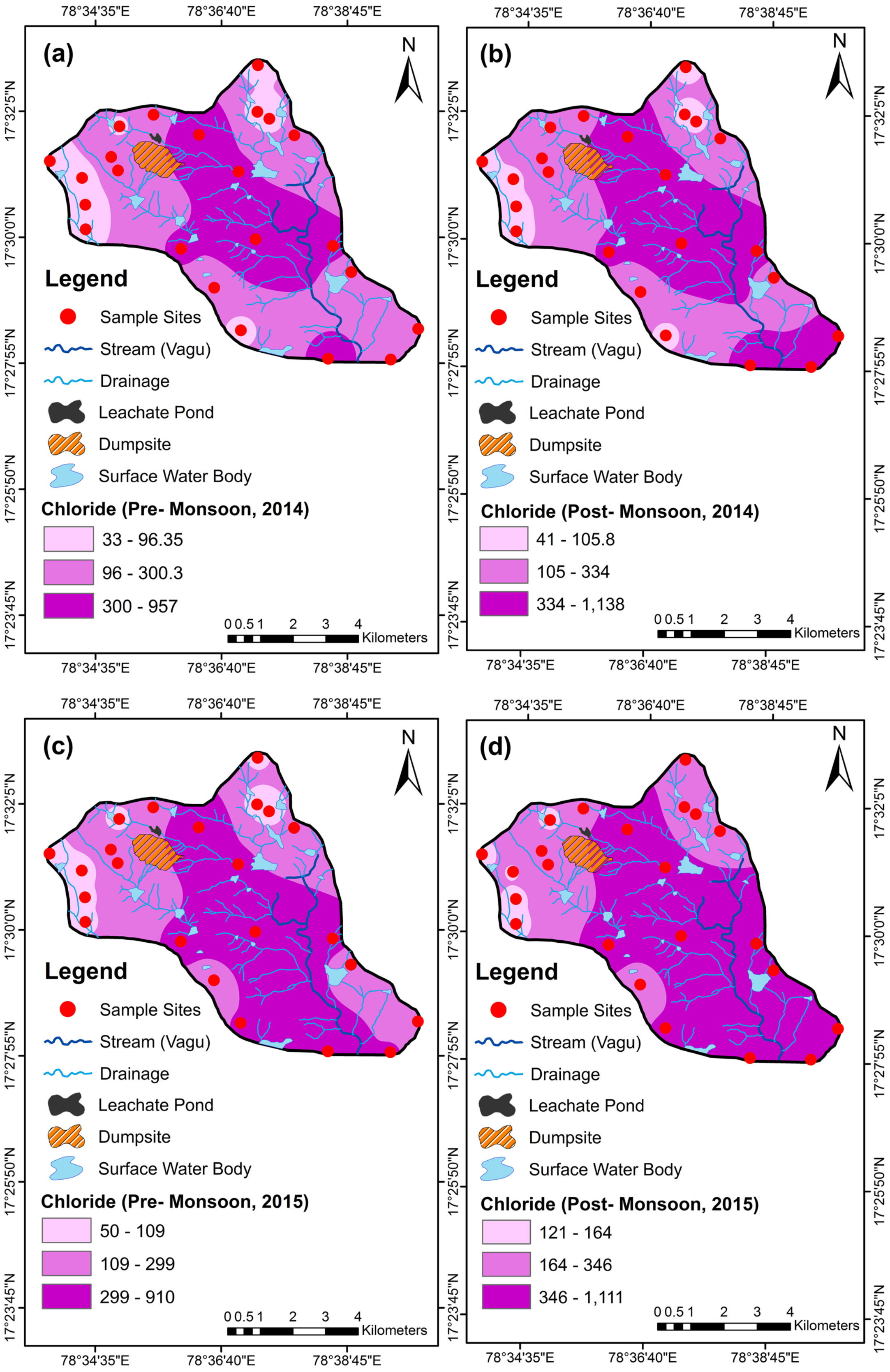

Fig. 4 Spatial distribution map of chlorides (Cl⁻) in groundwater

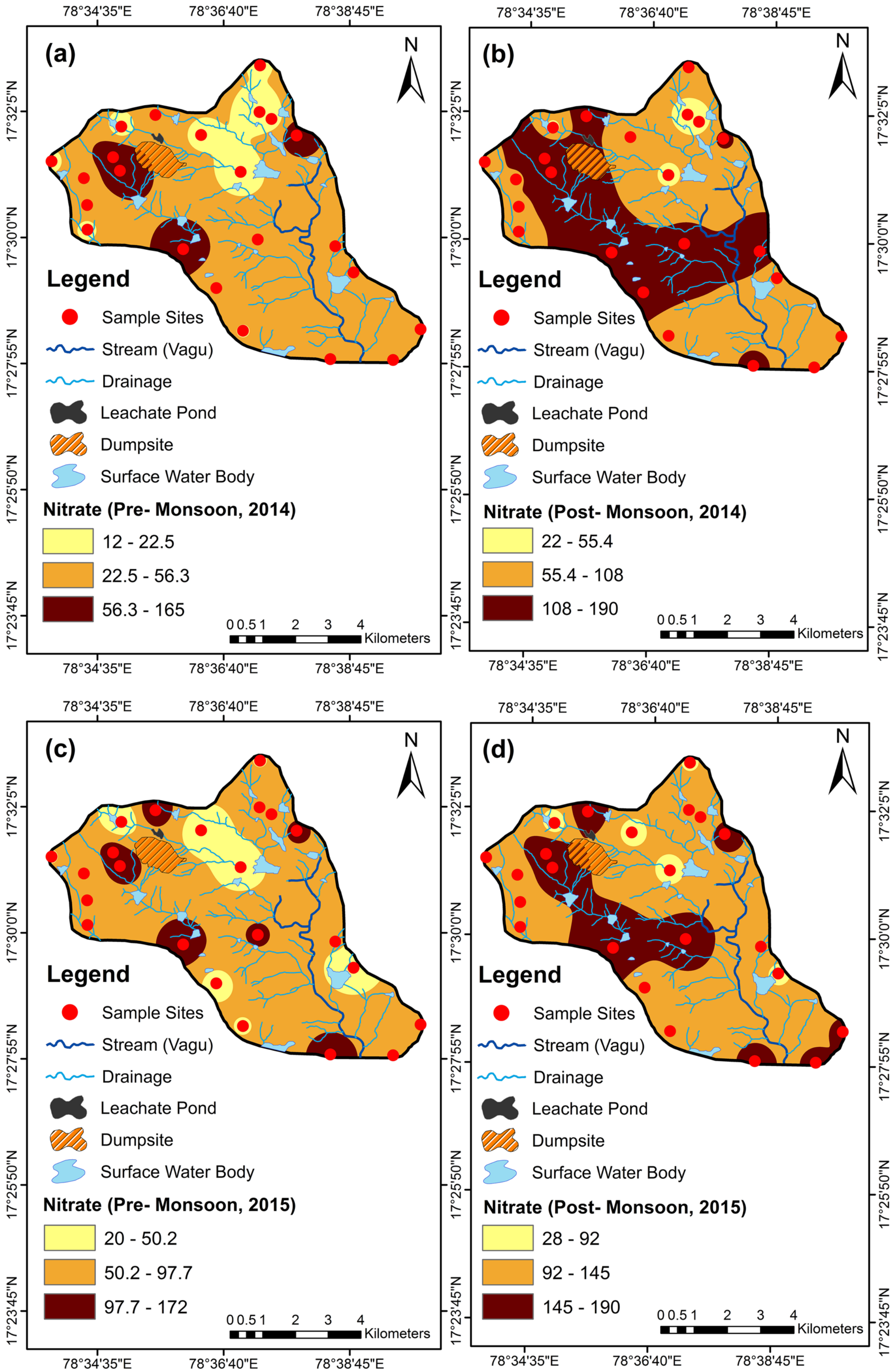

Fig. 5 Spatial distribution map of nitrates (NO_3^-) in groundwater

Table 7 Water quality index (WQI) values of groundwater samples collected in 2014 and 2015

S. no.	Water quality index (WQI) values			
	2014		2015	
	Pre	Post	Pre	Post
GW1	110.2	166	156.9	184.9
GW2	47.6	49	66.5	116.5
GW3	107.1	127	113.4	132.5
GW4	121.6	139	117	153.7
GW5	86.7	118	110.9	160.1
GW6	69	64	70.1	82
GW7	119.4	169	130.5	168.4
GW8	120	119	102.4	146.4
GW9	93.4	162	132	174.8
GW10	113	187	130.2	202.4
GW11	142.9	161	177.2	206.6
GW12	107.7	102	109.4	121.3
GW13	136	145	139	155
GW14	48	49	67	117
GW15	120.3	168	112	168
GW16	86	118.2	136.2	160
GW17	102.1	138	112	180
GW18	94.2	93	96	98
GW19	88.4	94	98	100
GW20	77.9	82	89	92
GW21	85	91	95	96
GW22	78	87	87	94
GW23	48.3	48	52	55

Table 8 Classification of pre-monsoon and post-monsoon groundwater quality based on WQI value (2014 and 2015)

WQI value	Water quality	2014		2015	
		% of GW samples	% of GW samples	% of GW samples	% of GW samples
		Pre	Post	Pre	Post
< 50	Excellent	13%	13%	Nil	Nil
50–100	Good	39%	26%	39%	30%
100–200	Poor	47%	60%	60%	60%
200–300	Very poor	Nil	Nil	Nil	8%
> 300	Unsuitable	Nil	Nil	Nil	Nil

deposited at landfill at the period of 30 years, so low concentrations of heavy metals are seen in methanogenic leachate. Therefore, all the groundwater samples were also analyzed for heavy metals like arsenic (As), cadmium (Cd), iron (Fe), copper (Cu), manganese (Mn), nickel (Ni), zinc (Zn) only for 1 year, i.e., 2015 during pre-monsoon to understand their leachability in the study area.

Heavy metal pollution indices such as HEI and Cd were computed and presented (Table 9). According to HEI heavy metal index method, 82% of the samples fall in low-pollution class, 8% of the samples fall in medium pollution class and remaining 8% fall in high-pollution class. According to degree of contamination (Cd) factor, 91% of the groundwater samples fall in low-pollution class and 8% of the samples fall in high-pollution class (Table 10). The spatial distribution pattern of HEI and Cd of all the groundwater samples indicated that heavy metals were highly concentrated in the groundwater samples located in the vicinity than away from the dumpsite (Figs. 7 and 8).

Pearson's correlation was carried out between individual heavy metal parameters and pollution indices in order to identify the main contributing heavy metals to pollution indices (Table 11). It suggested that Fe and Mn were the significant contributing parameters as Cd and HEI strongly correlated with Fe ($r=0.881$) and Mn ($r=0.945$). Fe and Mn positively correlated ($r=0.706$) with each other indicating the similar source of leachate contaminating the groundwater. Further, Cd and HEI correlation is significant ($r=0.998$) where the results show similar trends with high concentrations of Fe and Mn.

The cumulative concentration of heavy metals (As + Cd + Fe + Cu + Mn + Zn) load versus pH in the leachates and in the groundwater was plotted (Fig. 9) [75, 76]. Majority of the samples (56%) were classified as near neutral-low metal. 24% of the samples were classified as near neutral-high metal. However, groundwater samples (3%) located less than 2 km distance from the dumpsite show neutral pH-extreme metal content similar to what was observed in leachates. This is further confirming that leachates are infiltrating into the groundwater system of the study area.

The distribution of the heavy metals in groundwater was observed as follows: Fe (509.2 ppb) > Mn

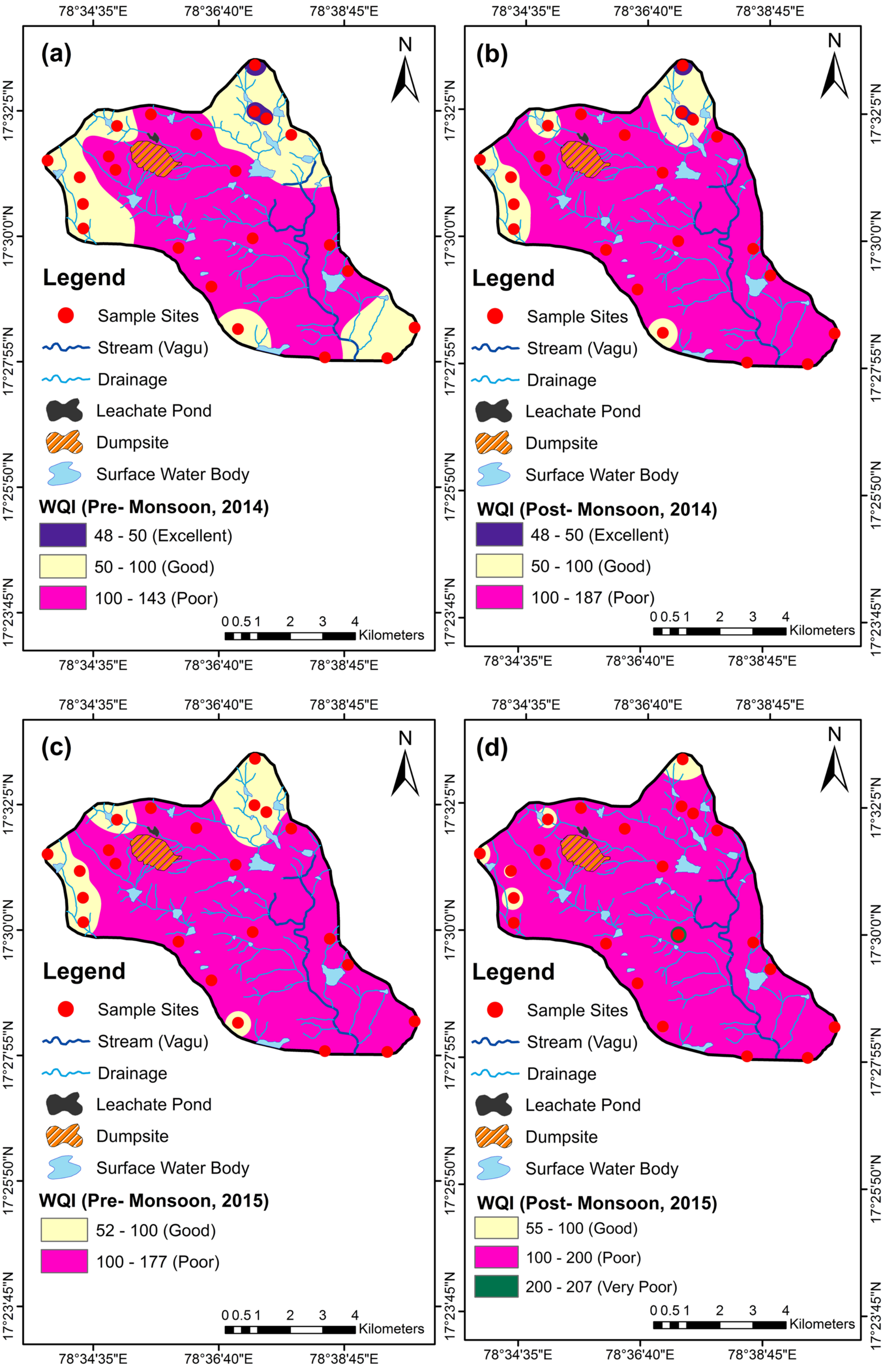

Fig. 6 Spatial distribution map of water quality index (WQI) of groundwater

Table 9 Heavy metals, HEI and Cd values of groundwater samples collected around the dumpsite

S. no.	As*	Cd*	Fe*	Cu*	Mn*	Zn*	HEI*	Cd*	Metal load
GW1	35.9	0.73	bdl	4.7	29	bdl	1.54	2.45	0.07
GW2	bdl	0.78	bdl	3.1	bdl	bdl	0.26	1.73	0.0038
GW3	bdl	0.3	bdl	5.8	bdl	bdl	0.106	1.89	0.0061
GW4	9.3	0.66	bdl	16.6	bdl	83.9	0.438	2.59	0.1104
GW5	bdl	bdl	bdl	1.2	26.3	bdl	0.527	1.46	0.0275
GW6	bdl	1.16	bdl	2.39	bdl	93.6	0.401	2.58	0.097
GW7	26.6	0.72	2245	6.12	36.5	705.5	17.28	16.95	3.24
GW8	bdl	0.8	bdl	11.62	466.8	bdl	9.6	10	0.479
GW9	bdl	0.148	bdl	bdl	bdl	bdl	0.149	0.95	0.00014
GW10	bdl	bdl	3952	2.6	2353	bdl	66.8	66.8	6.3
GW11	bdl	0.74	bdl	1.89	bdl	bdl	0.38	2.6	0.0093
GW12	bdl	1.06	bdl	2.85	21	134.1	0.48	2.8	0.159
GW13	bdl	0.68	3234	9.15	61.7	1217	17.88	17.8	4.52
GW14	bdl	0.78	bdl	3.1	bdl	bdl	0.26	1.73	0.0038
GW15	bdl	bdl	2234	2	2121	bdl	42.44	42.41	2.12
GW16	bdl	bdl	bdl	1.2	26.3	bdl	0.527	1.46	0.027
GW17	bdl	bdl	bdl	bdl	bdl	bdl	0	0	0
GW18	bdl	bdl	36	1.2	bdl	bdl	0.18	0.17	0.0372
GW19	bdl	bdl	11	2	bdl	bdl	0.169	2.74	0.018
GW20	bdl	0.4	bdl	2.1	bdl	bdl	0.135	1.85	0.0025
GW21	bdl	bdl	bdl	1.1	bdl	bdl	1.1	0.99	0.0011
GW22	bdl	bdl	bdl	1	bdl	bdl	1	0.9	0.001
GW23	bdl	bdl	bdl	0.98	bdl	bdl	0.98	0.999	0.00098
Mean	6.9	0.44	948.8	7.3	662.2	90.27			
WHO [69]	10	3	50	2000	500	3000			
MAC	50	3	200	1000	50	5000			

*All parameters are expressed in μg/L

Table 10 Classification of groundwater samples based on HEI and Cd indices

S. no.	Index method	Class	Extent of pollution	% of GW samples (pre 2015)
1	HEI	< 27	Low	82
		27–54	Medium	8
		> 54	High	8
2	Cd	< 18	Low	91
		18–36	Medium	–
		> 36	High	8

(223.5 ppb) > Zn (97.1) > Cr (10.1 ppb) > Cu (3.5 ppb) > As (3.1 ppb) > Cd (0.38 ppb). Iron (Fe) was found predominant heavy metal in groundwater (Table 9). It might be due to the dumping of the iron scraps.

Arsenic (As) was in below detectable limits (bdl) for all the samples except for GW1 and GW7 which exceeded the permissible limits of WHO standards. The spatial distribution pattern of Arsenic indicated that the leachate bearing arsenic wastes was accumulated at GW7 (1.7 km) and GW1 (3 km) borewells from the dumpsite (Fig. 10). The distribution of cadmium in groundwater samples was found

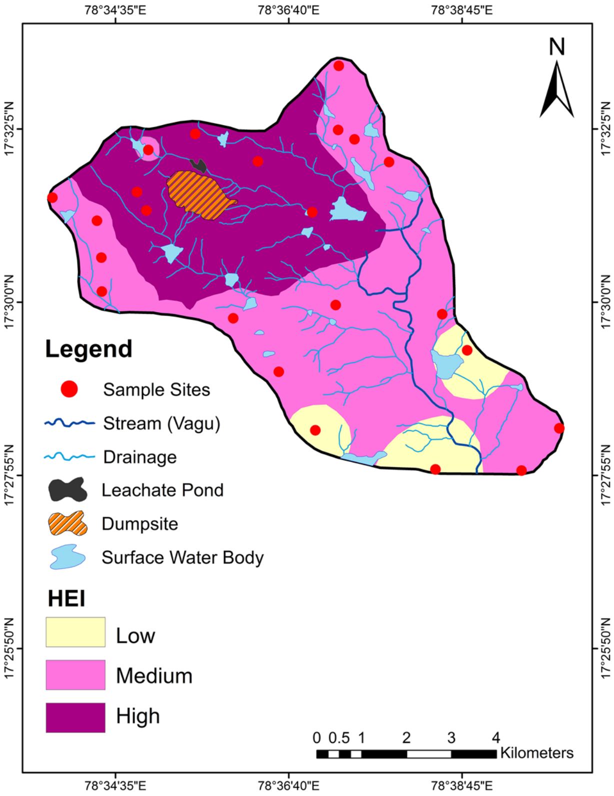

Fig. 7 Spatial distribution map of heavy metal evaluation index (HEI) groundwater

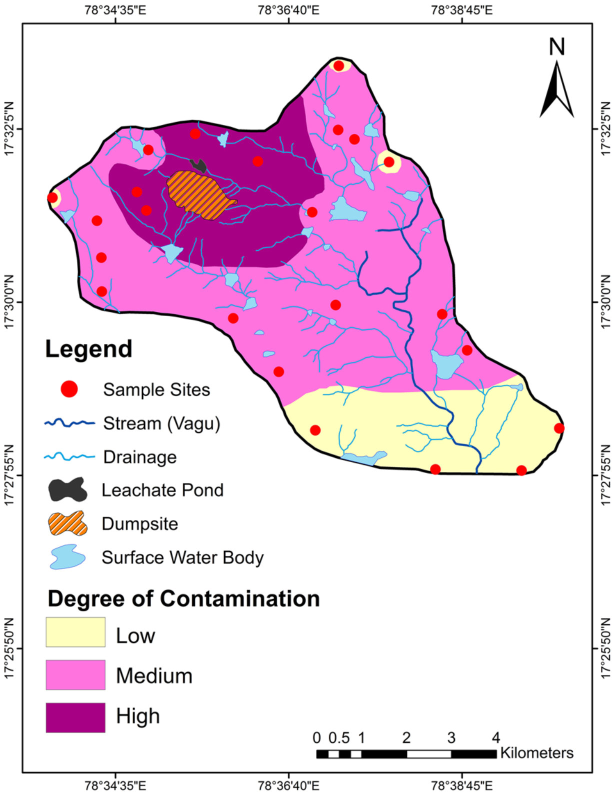

Fig. 8 Spatial distribution map of degree of contamination (Cd) in groundwater

Table 11 Correlations between heavy metal concentration and index values

Variables	As	Cd	Fe	Cu	Mn	Zn	HEI	Cd
As	1	0.287	0.098	0.281	−0.108	0.218	0.003	−0.003
Cd	0.287	1	−0.072	0.468	−0.265	0.303	−0.192	−0.168
Fe	0.098	−0.072	1	0.155	0.706	0.596	0.889	0.881
Cu	0.281	0.468	0.155	1	−0.029	0.374	0.056	0.065
Mn	−0.108	−0.265	0.706	−0.029	1	−0.098	0.942	0.945
Zn	0.218	0.303	0.596	0.374	−0.098	1	0.179	0.166
HEI	0.003	−0.192	0.889	0.056	0.942	0.179	1	0.998
Cd	−0.003	−0.168	0.881	0.065	0.945	0.166	0.998	1

within the permissible limits of WHO, as given in [67]. Iron (Fe) was found in below detectable limits (bdl) except for GW7 (1.7 km), GW10 (1.2 km), GW13 (1.4 km) and GW15 (1.3 km) showing higher concentrations due to their locations closest to the dumpsite which can be observed from the spatial distribution map of Fe in groundwater (Fig. 11). Copper (Cu) distribution in all groundwater samples was within the permissible limits of WHO, as given

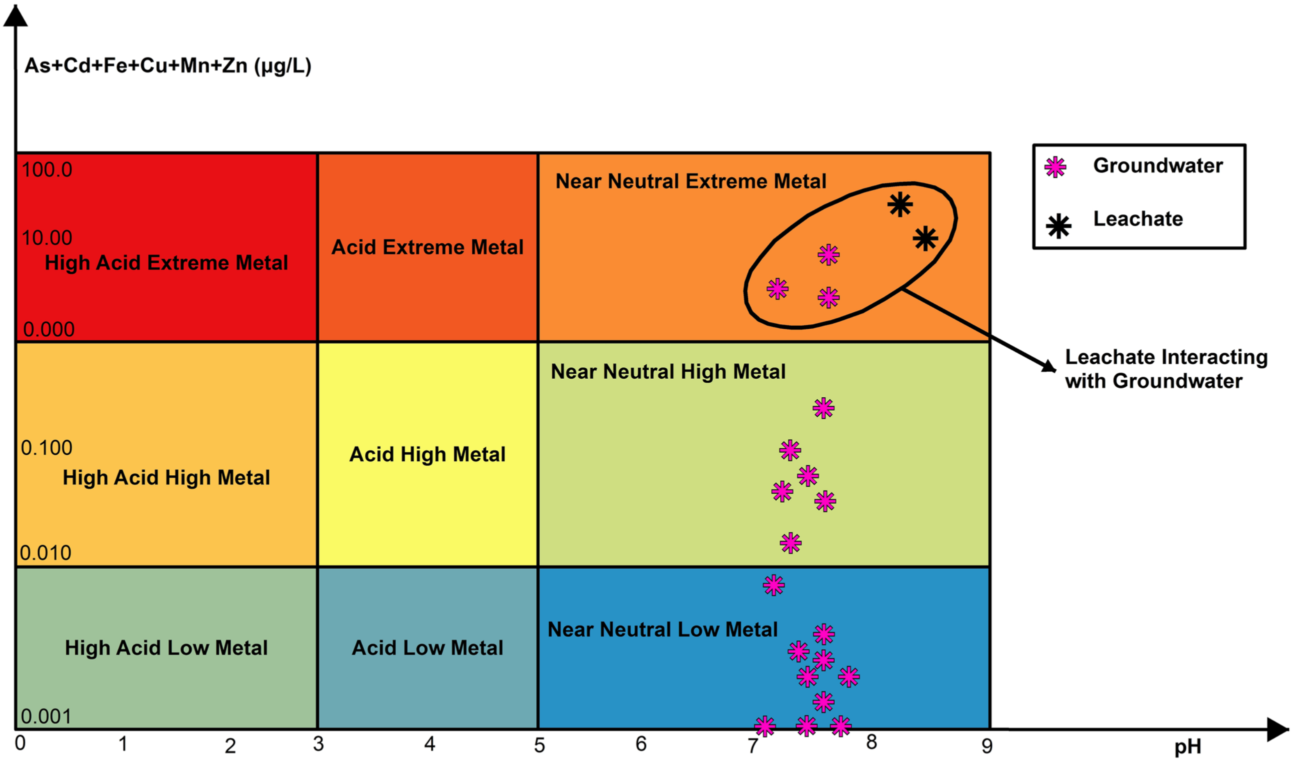

Fig. 9 Calculation of groundwater samples based on Ficklin Plot of metal load Vs pH

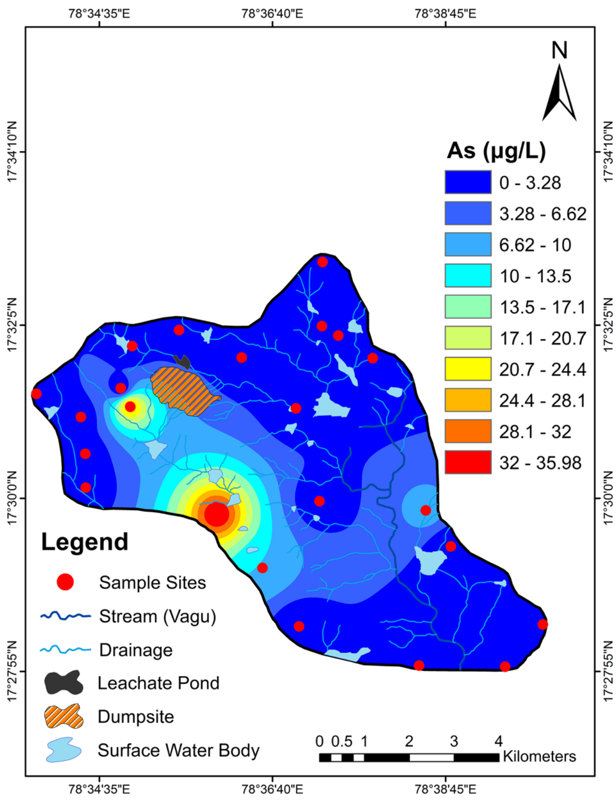

Fig. 10 Spatial distribution map of arsenic (As) in groundwater

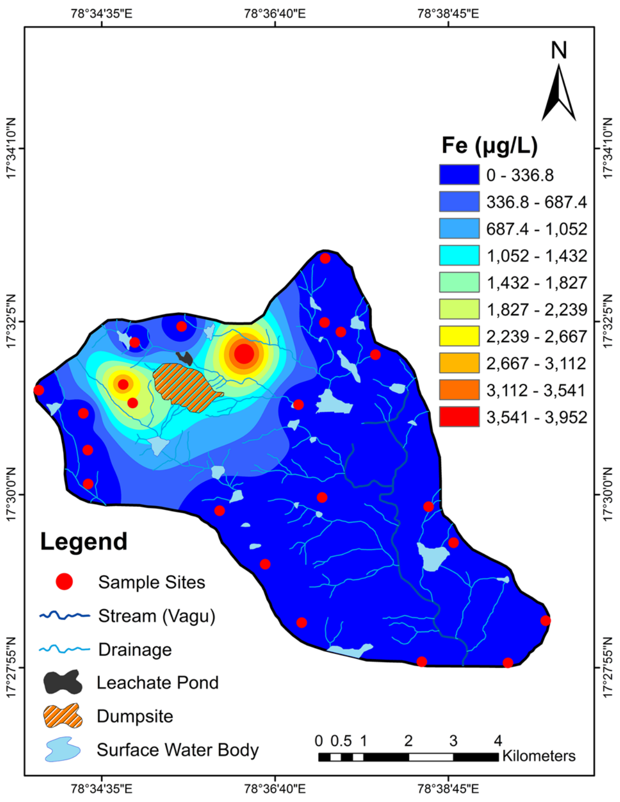

Fig. 11 Spatial distribution map of iron (Fe) in groundwater

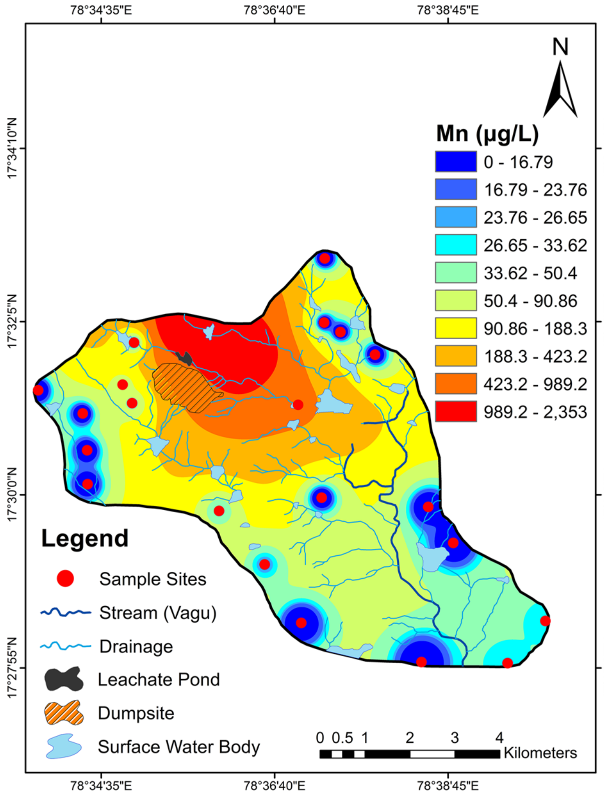

Fig. 12 Spatial distribution map of manganese (Mn) in groundwater

in [67]. The distribution of manganese (Mn) was found to be within the permissible limits of WHO, as given in [67]. Exceptionally, GW10 (1.2 km) and GW15 (1.3 km) wells located in the vicinity of the dumpsite showed high concentrations of manganese (Mn) which can be observed from its spatial map (Fig. 12). It is mainly due to the leachate impact on groundwater. Nickel (Ni) was found to be within the permissible limits of WHO, as given in [67] in all the groundwater samples. However, Pb and Ni which are toxic and even in low concentrations were found to be in below detectable limits (bdl) in groundwater.

5 Conclusion

Groundwater is the main source of drinking and irrigation in Hyderabad City's municipal solid waste dumpsite around Jawaharnagar. The present study, therefore, focused on assessing the impact of municipal solid waste (MSW) dumpsites on seasonal and temporal variations in groundwater quality. In order to confirm groundwater quality, WHO standards were compared with major ions and heavy metal concentrations, and various graphical methods and indices were used for groundwater quality assessment that concludes: High TDS concentrations of dissolved organic and inorganic constituents were found above the permissible levels of leachate land disposal standards. Decreased biodegradability and alkaline pH in leachate samples indicated the old age of the dumpsite belonging to methanogenic phase. The distribution of heavy metals in groundwater was found as follows: Fe > Mn > Zn > Cr > Cu > As > Cd. Iron (Fe) was found to be predominantly heavy metal in groundwater. It could have been due to the dumping of iron scrap. The spatial distribution pattern of HEI and Cd of all the groundwater samples indicated that heavy metals were highly concentrated in the groundwater samples located in the vicinity than away from the dumpsite. Heavy metal pollution indices indicated that different types of wastes are being dumped without segregation process. Post-monsoon values of various parameters increased to the fact that during rainfall, leachate percolation into the surrounding environment is high due to the increased degradation of solid wastes dumped. The spatial maps of critical parameters like TDS, Cl$^-$, and NO$_3^-$ indicated leachate contamination in groundwater wells approx. 2 km from the dumpsite. WQI was computed using relative weight and quality rating scale. It shows that majority (60%) of groundwater samples have poor water quality. This study indicates the leachates generated from the dumpsite should be properly treated prior to the land disposal to reduce the contamination. Regulatory authorities should create public awareness on solid waste management hierarchy that leads to control of the extent of groundwater pollution.

Acknowledgements The author (B. Soujanya Kamble) is extremely thankful to University Grants Commission—Rajiv Gandhi National Fellowship (UGC—RGNF) for awarding the fellowship to carry out this study and CSIR-National Geophysical Research Institute, Hyderabad for carrying out heavy metal analysis. The author conveys her gratitude to Dr. Ramana Kumar (Laboratory Incharge), Dept. of Applied Geochemistry, for immensely assisting in field and laboratory works.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. MoUD (2000) Manual on municipal solid waste management, the expert committee constituted by Ministry of Urban Development, Government of India
2. MoEF & CC (2015) Municipal solid wastes (management and handling rules). Ministry of Environment, Forest and Climate Change, Government of India, New Delhi
3. Adamcova D, Vaverkova M, Barton S, Havlicek Z, Brouskova E (2016) Soil contamination in landfills: a case study of landfill in

Czech Republic. Solid Earth 7:239–247. https://doi.org/10.5194/se-7-239-2016

4. Boateng TK, Opoku F, Akoto O (2019) Heavy metal contamination assessment of groundwater quality: a case study of Oti landfill site, Kumasi. Appl Water Sci 9:1–15. https://doi.org/10.1007/s13201-019-0915-y
5. Jhamnani B, Singh SK (2009) Ground water contamination due to Bhalaswa landfill site in New Delhi. Int J Civil Environ Eng 1:121–125
6. Kamble BS, Saxena PR (2016) Environmental impact of municipal dumpsite leachate on groundwater quality in Jawaharnagar, Rangareddy, Telangana, India. Appl Water Sci. https://doi.org/10.1007/s13201-016-0480-6
7. Kurakalva RM, Aradhib KK, Mallela KY, Venkatayogi S (2016) Assessment of groundwater quality in and around the Jawaharnagar municipal solid waste dumping site at Greater Hyderabad, Southern India. Proc Environ Sci 35:328–336. https://doi.org/10.1016/j.proenv.2016.07.013
8. Longe EO, Balogun MR (2010) Ground water quality assessment near a municipal landfill, Lagos, Nigeria. Res J Appl Sci Eng Technol 2:39–44
9. Przydatek G, Kanownik W (2019) Impact of small municipal solid waste landfill on groundwater quality. Environ Monit Assess 191:169. https://doi.org/10.1007/s10661-019-7279-5
10. Mishra S, Tiwari D, Ohri A, Agnihotri AK (2018) Assessment of groundwater quality using WQI and GIS near the Karsara municipal landfill site, Varanasi, India. Arab J Geosci 11:252. https://doi.org/10.1007/s12517-018-3604-5
11. Sabahi EA, Abdul Rahim, Wan Zuhairi WY, Al Nozaily Fadhl, Fares Alshaebi (2009) The characteristics of leachate and ground water pollution at municipal waste solid landfill of Ibb city, Yemen. Am J Environ Sci 5:256–266. https://doi.org/10.3844/ajessp.2009.256.266
12. Alslaibi TM, Mogheir YK, Afifi S (2011) Assessment of groundwater quality due to municipal solid waste landfills leachate. J Environ Sci Technol 4:419–436. https://doi.org/10.3923/jest.2011.419.436
13. Vasanthi P, Kaliappan S, Srinivasaraghavan R (2008) Impact of poor solid waste management on ground water. Environ Monit Assess 143:227–238. https://doi.org/10.1007/s10661-007-9971-0
14. Aravindan S, Shankar K (2011) Trace element concentration mapping in groundwater of Paravanar River Sub-Basin, Cuddalore District, Tamilnadu using Geospatial Technique. J Appl Geochem: 54–67
15. Aravindan S, Shankar K (2011) Ground water quality maps of Paravanar river sub basin, Cuddalore District, Tamil Nadu, India. J Indian Soc Remote Sens 39(4):565. https://doi.org/10.1007/s12524-011-0152-9
16. Aravindan S, Shankar K (2011) Groundwater quality in Paravanar river sub-basin, Cuddalore District, Tamilnadu, India, Gondwana. Geol Mag 26(2):139–146
17. Aravindan S, Shankar K, Mini SS (2011) Integrated geohydrological studies in the sedimentary part of Gadilam river basin, Cuddalore District, Tamil Nadu. Asian J Earth Sci 4:183–192. https://doi.org/10.3923/ajes.2011.183.192
18. Kavitha MT, Divahar R, Meenambal T, Shankar K, VijaySingh R, Haile Tamirat Dessalegn, Gadafa Chimdi (2019) Dataset on the assessment of water quality of surface water in Kalingarayan Canal for heavy metal pollution, Tamil Nadu. Data Brief 22:878–884. https://doi.org/10.1016/j.dib.2019.01.010
19. Kavitha MT, Shankar K, Divahar R, Meenambal T, Saravanan R (2019) Impact of industrial wastewater disposal on surface water bodies in Kalingarayan canal, Erode district, Tamil Nadu, India. Arch Agric Environ Sci 4(4):379–387. https://doi.org/10.26832/24566632.2019.040403
20. Kawo NS, Shankar K (2018) Groundwater quality assessment using water quality index and GIS technique in Modjo River Basin, Central Ethiopia. J Afr Earth Sci 147:300–311. https://doi.org/10.1016/j.jafrearsci.2018.06.034
21. Kumar PS, Balamurugan P (2018) Evaluation of groundwater quality for irrigation purpose in Attur Taluk, Salem, Tamilnadu, India. Water Energy Int 61(4):59–64
22. Li P, Wu J, Qian H, Zhang Y, Yang N, Jing L, Yu P (2016) Hydrogeochemical characterization of groundwater in and around a wastewater irrigated forest in the southeastern edge of the Tengger Desert, Northwest China. Expo Health 8(3):331–348. https://doi.org/10.1007/s12403-016-0193-y
23. Mahlknecht J, Merchán D, Rosner M, Meixner A, Ledesma-Ruiz R (2017) Assessing seawater intrusion in an arid coastal aquifer under high anthropogenic influence using major constituents, Sr and B isotopes in groundwater. Sci Total Environ 587:282–295. https://doi.org/10.1016/j.scitotenv.2017.02.137
24. Shankar K, Aravindan S, Rajendran S (2010) GIS based groundwater quality mapping in Paravanar River Sub-Basin, Tamil Nadu, India. Int J Geomat Geosci 1(3):282–296
25. Shankar K, Aravindan S, Rajendran S (2011) Spatial distribution of groundwater quality in Paravanar river sub basin, Cuddalore district, Tamil Nadu. Int J Geomat Geosci 1(4):914–931
26. Shankar K, Aravindan S, Rajendran S (2011) Hydrochemical profile for assessing the groundwater quality of Paravanar river subbasin, Cuddalore district, Tamil Nadu, India. Curr World Environ 6(1):45–52. https://doi.org/10.12944/CWE.6.1.05
27. Shankar K, Aravindan S, Rajendran S (2011) Hydrogeochemistry of the Paravanar river sub-basin, Cuddalore District, Tamilnadu, India. E-J Chem 8(2):835–845. https://doi.org/10.1155/2011/107261
28. Shankar K, Aravindan S, Rajendran S (2011) Assessment of ground water quality in Paravanar river sub-basin, Cuddalore district, Tamil Nadu, India. Adv Appl Sci Res 2(5):92–103
29. Subramani T, Elango L, Damodarasamy SR (2005) Groundwater quality and its suitability for drinking and agricultural use in Chithar river basin, Tamil Nadu, India. Environ Geol 47:1099–1110. https://doi.org/10.1007/s00254-005-1243-0
30. Venkateswaran S, Karuppannan S, Shankar K (2012) Groundwater Quality in Pambar sub-basin, Tamil Nadu, India using GIS. Int J Recent Sci Res 3(10):782–787
31. Wu J, Wang L, Wang S, Tian R, Xue C, Feng W, Li Y (2017) Spatiotemporal variation of groundwater quality in an arid area experiencing long-term paper wastewater irrigation, northwest China. Environ Earth Sci 76(13):460. https://doi.org/10.1007/s12665-017-6787-2
32. Brown RM, Mc Clelland NI, Deininger RA, Tozer RG (1970) A water quality index: do we dare? Water Sew Works 117:339–343
33. SDD, Scottish Development Department (1975) Towards cleaner water. HMSO, Report of a River Pollution Survey of Scotland, Edinburgh
34. Rabeiy RE (2017) Assessment and modeling of groundwater quality using WQI and GIS in Upper Egypt area. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-017-8617-1
35. Babiker IS, Mohamed MAA, Hiyama T (2006) Assessing groundwater quality using GIS. Water Resour Manag 214:699–715. https://doi.org/10.1007/s11269-006-9059-6
36. Boateng TK, Opoku F, Acquaah SO, Akoto O (2016) Groundwater quality assessment using statistical approach and water quality index in Ejisu-Juaben Municipality, Ghana. Environ Earth Sci 75:489. https://doi.org/10.1007/s12665-015-5105-0
37. Gebrehiwot AB, Tadesse N, Jigar E (2011) Application of water quality index to assess suitability of groundwater quality for drinking purposes in Hantebet watershed, Tigray, Northern Ethiopia. ISABB J Food Agric Sci 1:22–30

38. Jhariya DC, Kumar T, Dewangan R, Pal Dharm, Dewangan PK (2017) Assessment of groundwater quality index for drinking purpose in the Durg district, Chhattisgarh using geographical information system (GIS) and multi-criteria decision analysis (MCDA) techniques. J Geol Soc India 89:453. https://doi.org/10.1007/s12594-017-0628-5
39. Kalaivanan K, Gurugnanam B, Pourghasemi HR, Suresh M, Kumaravel S (2017) Spatial assessment of groundwater quality using water quality index and hydrochemical indices in the Kodavanar sub-basin. Sustain Water Resour Manag, Tamil Nadu. https://doi.org/10.1007/s40899-017-0148-x
40. Lad S, Mukherjee S, Umrikar B (2019) Suitability of groundwater for drinking purposes by physico-chemical parameters and water quality index from Haveli region India. Hydrosp Anal 2(2):83–90. https://doi.org/10.21523/gcj3.18020201
41. Priya R, Elango L (2018) Evaluation of geogenic and anthropogenic impacts on spatio-temporal variation in quality of surface water and groundwater along Cauvery River, India. Environ Earth Sci 77:2. https://doi.org/10.1007/s12665-017-7176-6
42. Selvam S, Manimaran G, Sivasubramanian P, Balasubramanian N, Seshunarayana T (2013) GIS-based evaluation of water quality index of groundwater resources around Tuticorin coastal city, south India. Environ Earth Sci 716:2847–2867. https://doi.org/10.1007/s12665-013-2662-y
43. Shankar K, Kawo NS (2019) Groundwater quality assessment using geospatial techniques and WQI in North East of Adama Town, Oromia region, Ethiopia. Hydrosp Anal 3(1):22–36. https://doi.org/10.21523/gcj3.19030103
44. Singh P, Khan I (2011) Ground water quality assessment of Dhankawadi ward of Pune by using GIS. Int J Geomat Geosci 2:688–703
45. Wagh VM, Mukate SV, Panaskar DB, Muley AA, Sahu UL (2019) Study of groundwater hydrochemistry and drinking suitability through water quality index (WQI) modelling in Kadava river basin. SN Appl Sci, India. https://doi.org/10.1007/s42452-019-1268-8
46. Edet AE, Offiong OE (2002) Evaluation of water quality pollution indices for heavy metal contamination monitoring. A study case from Akpabuyo–Odukpani area, lower cross river basin (southeastern Nigeria). Geo J 57:295304. https://doi.org/10.1023/b:gejo.0000007250.92458.de
47. Kumar PS, Delson PD, Babu PT (2012) Appraisal of heavy metals in groundwater in Chennai city using a HPI model. Bull Environ Contam Toxicol 89(4):793–798. https://doi.org/10.1007/s00128-012-0794-5
48. Koda E, Miszkowska A, Sieczka A, Osinski P (2018) Heavy metals contamination within restored landfill site. J Environ Geotech. https://doi.org/10.1680/jenge.18.00031
49. Pawar NJ, Pawar JB (2016) Intra-annual variability in the heavy metal geochemistry of ground waters from the Deccan basaltic aquifers of India. Environ Earth Sci 75(8):654. https://doi.org/10.1007/s12665-016-5450-7
50. Prasanna MV, Praveena SM, Chidambaram S, Nagarajan R, Elayaraja A (2012) Evaluation of water quality pollution indices for heavy metal concentration monitoring: a case study from Curtin Lake, Miri City, East Malaysia. Environ Earth Sci 67:1987. https://doi.org/10.1007/s12665-012-1639-6
51. Herojeet Rajkumar, Madhuri S, Rishi Kishore Naval (2015) Integrated Approach of heavy metal pollution indices and complexity quantification using chemometric models in the Sirsa basin, Nalagarh valley, Himachal Pradesh, India. Chin J Geochem 34(4):620–633. https://doi.org/10.1007/s11631-015-0075-1
52. Selvam S, Venkatramanan S, Singaraja C (2015) A GIS-based assessment of water quality pollution indices for heavy metal contamination in Tuticorin Corporation, Tamilnadu, India. Arab J Geosci 8(12):10611–10623. https://doi.org/10.1007/s12517-015-1968-3
53. Singaraja C, Chidambaram S, Srinivasamoorthy K, Anandhan P, Selvam S (2015) A study on assessment of credible sources of heavy metal pollution vulnerability in groundwater of Thoothukudi districts, Tamilnadu, India. Water Qual Expo Health. https://doi.org/10.1007/s12403-015-0162-x
54. Singh R, Venkatesh AS, Syed TH, Reddy AGS, Kumar M, Kurakalva RM (2017) Assessment of potentially toxic trace elements contamination in groundwater resources of the coal mining area of the Korba Coalfield, Central India. Environ Earth Sci 76(16):566. https://doi.org/10.1007/s12665-017-6899-8
55. Tiwari AK, Singh PK, Mahato MK (2014) GIS-based evaluation of water quality index of groundwater resources in West Bokaro Coalfield, India. Curr World Environ 9(3):843–850. https://doi.org/10.12944/CWE.9.3.35
56. Tiwari AK, De Maio M, Singh PK, Mahato MK (2015) Evaluation of surface water quality by using GIS and a heavy metal pollution index (HPI) model in a coal mining area, India. Bull Environ Contam Toxicol 95:304–310. https://doi.org/10.1007/s00128-015-1558-9
57. Tiwari AK, Singh PK, Singh AK, De Maio M (2016) Estimation of heavy metal contamination in groundwater and development of a heavy metal pollution index by using GIS technique. Bull Environ Contam Toxicol 96:508–515. https://doi.org/10.1007/s00128-016-1750-6
58. Varghese J, Jaya DS (2014) Metal pollution of groundwater in the vicinity of Valiathura sewage farm in Kerala, South India. Bull Environ Contam Toxicol 93(6):694–698. https://doi.org/10.1007/s00128-014-1410-7
59. Venkatramanan S, Chung SY, Kim TH, Prasanna MV, Hamm SY (2015) Assessment and distribution of metals contamination in groundwater: a case study of Busan City, Korea. Water Qual Expo Health 7:219–225. https://doi.org/10.1007/s12403-014-0142-6
60. Vetrimurugan E, Brindha K, Elango L, Ndwandwe OM (2016) Human exposure risk to heavy metals through groundwater used for drinking in an intensively irrigated river delta. Appl Water Sci 6:1–14. https://doi.org/10.1007/s13201-016-0472-6
61. Wagh VM, Panaskar DB, Mukate SV, Gaikwad SK, Muley AA, Varade AM (2018) Health risk assessment of heavy metal contamination in groundwater of Kadava River Basin, Nashik, India. Model Earth Syst Environ 4(3):969–980. https://doi.org/10.1007/s40808-018-0496-z
62. Yankey RK, Fianko JR, Osae S, Ahialey EK, Duncan AE, Essuman DK, Bentum JK (2013) Evaluation of heavy metal pollution index of groundwater in the Tarkwa minning area, Ghana. Elixir Pollut 54:12663–12667
63. Raj GG, Joseph P, Harsha BLS, Ravi VK, Sarath CY (2015) Solid Waste management scenario in India, Issues in MSW and case study of Jawaharnagar, Hyderabad and Bengaluru Planning Colloquium. http://www.slideshare.net/kamsaniravivarma/msw-in-india. Accessed 19 Jan 2015
64. APHA (1998) American public health association, standard method for examination of water and waste water, 17th edn. APHA, Washington, DC
65. BIS (1988) Drinking water specification. Bureau of Indian Standards, New Delhi, p 10500
66. Backman B, Bodis D, Lahemo P, Rapant S, Tarvainen (1997) Application of groundwater contamination index in Finland and Slovakia. Environ Geol 36(1–2):55–64. https://doi.org/10.1007/s002540050320
67. Qiao S, Tian T, Qi B, Zhou J (2015) Methanogenesis from wastewater stimulated by addition of elemental manganese. Sci Rep 5:12732. https://doi.org/10.1038/srep12732
68. Peter K, Morton AB, Alix PR, Anders B, Ledin A, Thomas HC (2002) Present and long-term composition of MSW landfill leachate: a

review. Crit Rev Environ Sci Technol 32(4):297–336. https://doi.org/10.1080/10643380290813462

69. WHO (2011) Guidelines for drinking water quality, 4th edn. WHO, Geneva, p 27
70. Ganiyu SA, Badmus BS, Olurin OT, Ojekunle ZO (2018) Evaluation of seasonal variation of water quality using multivariate statistical analysis and irrigation parameter indices in Ajakanga area, Ibadan, Niger. Appl Water Sci 8:35. https://doi.org/10.1007/s13201-018-0677-y
71. Phaniendra A, Jestadi DB, Periyasamy L (2015) Free radicals: properties, sources, targets, and their implication in various diseases. Indian J Clin Biochem 30:11–26. https://doi.org/10.1007/s12291-014-0446-0
72. Jalali M (2005) Nitrate leaching from agricultural land in Hamadan western Iran. Agric Ecosyst Environ 110:210–218. https://doi.org/10.1016/j.agee.2005.04.011
73. Aravindan S, Shankar K, Ganesh BP, Rajan KD (2010) Hydrogeochemical mapping of in the hard rock area of Gadilam River basin, using GIS technique, Tamil Nadu. Indian J Appl Geochem 12(2):209–216
74. Aziz HA, Yussff MS, Adlan MN, Adnan NH, Alias S (2004) Physicochemical removal of iron from semi-aerobic leachate by limestone filter. Waste Manag 24:353–358. https://doi.org/10.1016/j.wasman.2003.10.006
75. Caboi R, Cidu R, Fanfani L, Lattanzi P, Zuddas P (1999) Environmental mineralogy and geochemistry of the Pb–Zn abandoned Montevecchio-Ingurtosu mining district, Sardinia, Italy. Chronique de la recherche miniére 534:21–28
76. Ficklin WH, Plumlee GS, Smith KS, McHugh JB (1992) Geochemical classi fication of mine drainage and natural drainages in mineralized areas. In: Kharaka YK, Maest AS (eds) Proceedings of the 7th water rock interaction congress, WRI-7, Park City, Utah, USA. Balkema AA, Rotterdam, pp 381–384