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Spatial Analysis of Groundwater Quality Around MSW Landfill Site

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ABSTRACT

Groundwater is the main source of water for domestic, industrial and agricultural consumption and its contamination has been recognized as one of the most severe issues in the recent times. The present study is focused on the monitoring of leachate contamination and groundwater quality around the uncontrolled MSW landfill sites located at Ramna village of Varanasi city, during pre and post-monsoon. On the basis of physico-chemical analysis of groundwater, it was found that EC, TDS, hardness, nitrate and Fe contents were higher than the standard value of drinking water quality in both pre and post-monsoon periods. Leachate pollution index (LPI) and water quality index (WQI) were used to quantify the contamination in leachate and groundwater respectively. Higher value of LPI (12.40) revealed the significant concentration of pollutants present in the landfill leachate. Water quality index (WQI) was calculated for water samples of different wells located near landfill sites and it was integrated with geographical information system (GIS) for spatial mapping to identify the status of water quality in the studied area. Groundwater modelling was done and path line and velocity vector of groundwater flow was generated. Relationship between LPI, WQI and flow path are used to predict the water contamination in groundwater due to percolation of leachate from open uncontrolled landfill site. Results were validated with field observations. The present study would be helpful for landfill strategy makers and the government authorities to safeguard the groundwater pollution risk from the landfill.

INTRODUCTION

In India, more than 90% of the municipal solid waste (MSW) is generated directly due to rapid industrialization and urbanization, and its dumping on land in an unsatisfactory manner poses threat to environment (Shanthi et al. 2013). Leachate from non-engineered landfill is one of the major sources of groundwater contamination in the vicinity of landfill site. About 960 million tonnes of solid waste is being generated annually in India. Approximately, 350 million tonnes are organic wastes, whereas 4.5 million tonnes are found to be hazardous in nature. It has been forecasted that around 19 billion tonnes of solid waste will be generated by 2025 (Pappu et al. 2007). Hence, it is a big challenge for developing countries like India for complete recycling, reusing and scientific land filling of solid wastes. Clean and hygienic water is a vital commodity for the well-being of human society. Unfortunately, the groundwater is severely being deteriorated by anthropogenic forces like municipal landfill which consists of toxic materials and acts as one of the major pollutant source (Remesan & Panda 2007). Therefore, it is emerging as a serious environmental threat to surface and sub-surface drinking water. The contaminated water is responsible for transmission of many waterborne diseases like cholera, diarrhoea, dysentery, hepatitis, typhoid and posing a threat to public health (WHO 2011). Polluted water loses its economic and aesthetic value. Therefore, monitoring and assessment of groundwater quality are important socio-economic necessity. WQI is an effective tool, based on a mathematical model, for assessing the overall water quality for drinking purpose, on the other hand LPI is used as a monitoring tool to assess the leachate pollution potential particularly at places where leachate leaching is at high risk of groundwater contamination (Manimekalai & Vijayalakshmi 2012). In groundwater study, many investigators applied IDW (inverse distance weighted) method for interpolation of unknown points in GIS environment because of its neighbourhood approach and spherical function to prepare the distribution map of the water pollutants (Chakraborty & Kumar 2016, Singh et al. 2016, Talalaj & Biedka 2016). Groundwater modelling also plays an important role in understanding the groundwater systems, estimation of aquifer properties and forecasting the future (Anderson et al. 2015).

At present the municipal solid waste management in Varanasi City is not satisfactory due to fast urbanization and lack of specialized waste management practices as per Municipal Solid Wastes Management and Handling Rules (2000) (MoEF 2000). The present study may be helpful for local authority in protection of groundwater pollution risk from the landfill and to active post-closure monitoring till the leachate production is stabilized and attained sustainability.

The objective of the present study is to (i) evaluate the LPI and WQI to quantify the contamination in leachate and groundwater respectively, (ii) to assess the seasonal variation in groundwater quality around the MSW landfill for drinking purpose and (iii) to identify a relationship between LPI, WQI and flow path to predict the water contamination in groundwater occurred due to percolation of leachate from open uncontrolled landfill site.

MATERIALS AND METHODS

Study area: Ramna MSW landfill area was selected for the present study, located between 25°14'38.3" N latitudes and 83°00'15" E longitudes in Varanasi City, Uttar Pradesh India. The area of this landfill site is approximately 53 acres and started to work in the year 2012. About 450 tonnes per day municipal solid waste is generated in Varanasi city (CPCB 2013). The large amount of MSW of the city is disposed off in low elevation areas near the Raman village, without taking any protection measures and equipped controls. The landfill area is located at approximately 2.64 kilometres in west of the river Ganga and mostly covered by agricultural fields around the landfill, which have a greater possibility of groundwater pollution due to leachate. The climate of the study area is humid sub-tropical with high temperatures (38.5 to 41.2 °C) during summer, intense rainfall (1100 mm) during monsoon and severe cold (8.4 to 15.0°C) during winter season. Geologically, the studied area is covered by alluvial deposits of the Pleistocene period to current times (Mohan et al. 2011). The area is exposed to flood during rainy season each year, which set down a carpet of silt, clay and loam. Study area generally contains quaternary alluvium soil formed by succession of clay, silty clay and sand deposits (Janardhana Raju et al. 2011).

Methodology

Groundwater sampling and testing: Groundwater samples were collected in properly washed and cleaned plastic bottles during pre and post-monsoon seasons in the year 2016 from 7 wells and 9 hand-pumps located around Ramna village area. The depth of the sampling wells varies from 7 to 13 metre in pre and post-monsoon periods. Differential global positioning system (DGPS) was used to identify the sampling location. The distance between landfill site and the sampling wells ranges from 480 to 1500 meter. Leachate sample was collected in clean plastic bottles made airtight by capping it. All the water samples and leachate samples were analysed for important physico-chemical parameters according to internationally recognized procedures and standard methods (APHA 1999).

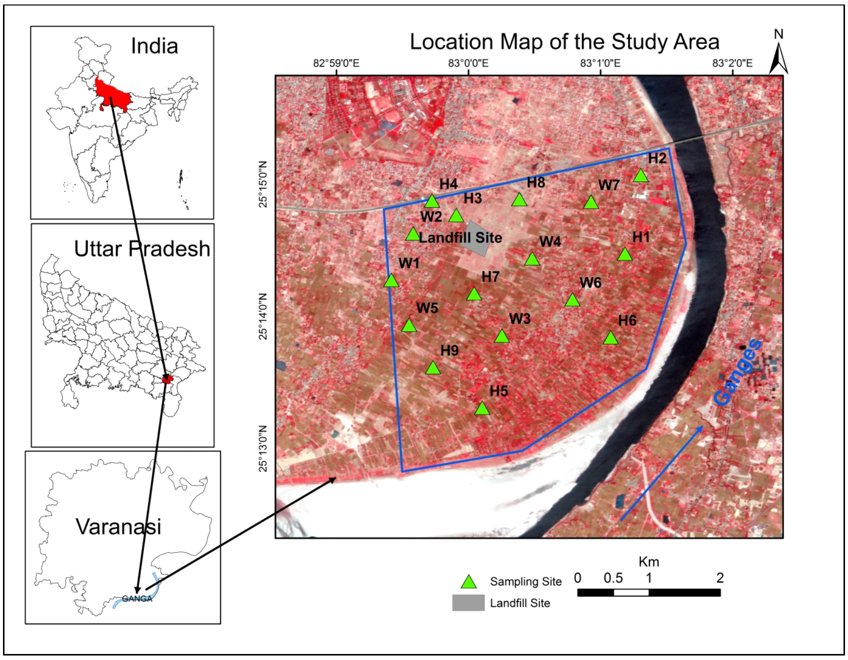

Fig. 1: Map of the studied area showing sampling locations and landfill site.

Temperature, pH, electrical conductivity (EC), total dissolved solid (TDS) and dissolved oxygen (DO) of the samples were determined by multi-parameter detector instrument at the sampling site. Alkalinity, total hardness and chloride contents in the samples were determined by titrimetric analysis in the laboratory. Heavy metal (Fe, Cr, Zn, Cd, Pb, Ni, As and Cu) contents were determined by flame AAS 4141 instrument (Electronic Corporation of India Ltd). Estimation of heavy metals for the leachate sample was carried out by digesting 50 mL sample in 10 mL of concentrated HNO_3 at 80°C until the solution becomes transparent (APHA 2012). Na, K and Ca were determined by a flame photometer. NO_3^- was determined by the colorimetric method with the help of a spectrophotometer. Fluoride was determined by using an ion-selective electrode meter.

Calculation of LPI: In order to assess the leachate pollution potential of Ramna landfills sites, leachate pollution index (LPI) was calculated by using the following equation which is based on Rand Corporation Delphi technique.

$$\text{LPI} = \sum_{i=1}^{m} w_i p_i \,/\, \sum w_i \qquad \text{...(1)}$$

Where, w_i is the weight factor for the i^{th} pollutant variable, p_i is the sub-index score of the i^{th} pollutant variable and m is the number of known concentration of leachate contaminant variables. The sub-index scores were calculated from averaged sub-index curves reported by Kumar & Alappat (2005). The cumulative pollution rating ($w_i\, p_i$) was calculated by multiplying the weight factor with the sub index value. Sum of cumulative pollution rating of all variables gives LPI of the landfill sites.

Calculation of WQI: Water quality index was determined by using weight arithmetic method which is helpful to identify the status of the water resource (Chakraborty & Kumar 2016). ArcGIS 10.1 is used for spatial estimation of the WQI in the present studied area through IDW method. For the WQI calculation, firstly, a weight (w_i) was assigned to each parameter on the basis of their significance to the complete groundwater quality. The highest weight was given to parameter that causes a serious health effect when its value increases above the certain critical concentration limits (Varol & Davraz 2015). The weight factor (Wi) of the parameter is determined by dividing the individual weight of each parameter by sum of all parameter weight ($Wi = w_i / \sum_{i=1}^{n} wi$).

In Table 3, W represents the relative weight while w_i denotes the weight of each parameter, n is the total number of the parameters. Finally, water quality index (WQI) was calculated by the following formula:

$$\text{WQI} = \sum_{i=1}^{n} SIi \times W_i \qquad \text{...(2)}$$

Where, SI_i is sub-index value of i^{th} parameter and which is calculated by sub-index curve developed by Ramesh et al. (2010), by giving rating value between 0 and 100 based on its desirable and acceptable limits prescribed by Bureau of Indian Standards (BIS 2012) and World Health Organization guideline (Gordon et al. 2008). As per the water quality index values, the water quality is classified into six classes (Ramesh et al. 2010).

Groundwater modelling: Visual Modflow software was used to know the groundwater flow direction and simulation. The combination of Darcy's law and continuity equation explain the flow of groundwater in non-homogenous anisotropic aquifer system.

***Groundwater flow direction equation*:**

$$\frac{\partial}{\partial x}\left(Kxx\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(Kyy\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial z}\left(Kzz\frac{\partial h}{\partial x}\right) + W = Ss\frac{\partial h}{\partial t} \qquad \text{...(3)}$$

Where, *Kxx*, *Kyy* and *Kzz* are hydraulic conductivity along the *x*, *y* and *z* coordinate axes, *h* indicates the potentiometric head, *W* is a volumetric flux per unit volume indicates sources and sinks of the water, *Ss* is the specific storage of the porous material and *t* is the time. Thirty seven wells were selected for observation and the water was measured for analysis of groundwater flow systems around the study area.

As concerned boundary condition for groundwater flow modelling, constant head value of 77.5 m, 76.5 m, 77 m, 78 m and 77 m was assigned at south-west side, north-west side, north side, south-east side and north-east side respectively. River is also considered as boundary condition with constant values of riverstage i.e., 64 m and 66 m for pre and post monsoon period respectively. The model is run to know the groundwater flow direction and velocity rate for 365 days time period.

RESULTS AND DISCUSSION

Evaluation of leachate pollution index (LPI): Leachate pollution index (LPI) of landfill was estimated with the help of weight factor, pollution concentration and sub-index

Table 1: Classification of drinking water quality index.

Category	Range of WQI Score	Remark
Excellent	≥ 97.5 to 100	Best Quality
Good	≥ 92.5 to <97.5	Good Quality
Fair	≥ 85.0 to <92.5	Acceptable Quality
Marginal	≥ 75.0 to <85.0	Threatened Quality
Poor	≥ 60.0 to <75.0	Poor Quality
Very Poor	<60.0	Worst Quality

Table 2: Input data for groundwater flow modelling regarding soil and lithology (Mohan et al. 2011).

Layers	Lithology	Kx, Ky	Kz	S_s	S_y	Total porosity	Effective porosity
Horizon	Clayey Sand	9E-06	9E-07	0.0011	0.06	0.42	0.21

Table 3: Leachate pollution index (LPI) of Ramna MSW landfill site.

S.No.	Parameters	Weight factor (w_i)	Pollutant conc. (All values are in mg/L except pH)	Sub-index value (p_i)	Cumulative pollution rating($w_i p_i$)
1	COD	0.062	8279.00	70	4.320
2	BOD_5	0.061	27.80	5	0.305
3	pH	0.055	8.82	5	0.275
4	TDS	0.050	2322.50	5	0.275
5	Chloride	0.049	1221.00	7.5	0.367
6	Cr	0.064	1.77	5.5	0.352
7	Pb	0.063	0.00	5	0.315
8	Zn	0.056	0.00	5	0.280
9	Ni	0.052	0.18	5	0.260
10	Cu	0.050	0.33	5	0.250
11	Fe	0.045	5.40	5	0.225
12	As	0.061	0.00	5	0.305
		$\sum w_i = 0.607$		$\sum_{i=1}^{m} w_i p_i = 7.529$	

value of twelve important leachate pollution index parameters as given in Table 3. LPI of Ramna landfill site was found high, that is 12.40.

$$\text{LPI} = \sum_{i=1}^{m} w_i p_i \,/ \sum w_i$$

$$= 7.529/0.607$$

$$= 12.40$$

The higher value of LPI (12.40) of landfill indicates that the contaminants observed in the leachate are high in concentration with poor environmental conditions. LPI value higher than 7.50 specifies that leachate is the main source of pollution and has adverse effect on surrounding environment (Esakku et al. 2007). High LPI for this landfill site represents a hazardous nature and it can be responsible to some level to the water, air and land pollution. Therefore, a suitable treatment methodology and continuous monitoring are required to control the LPI for this landfill site.

Statistical analysis of physico-chemical characteristic of groundwater quality: Statistical measures of physical and chemical parameters including minimum concentration, maximum concentration, mean concentration and standard deviation of pre and post-monsoon data are given in Table 4. Temperature of the water samples (n=16) of the studied area was found to vary from 30.1°C to 32.5°C with an average value of 31.6°C in pre-monsoon and from 20.4°C to 22.9°C with an average value of 21.6°C in post-monsoon. However, pH of the groundwater samples fluctuated from 5.6 to 7.4 with an average value of 6.5 in pre-monsoon and from 7.0 to 7.7 with an average of 7.3 in post-monsoon, which may be due to the dissolved carbonates mainly in the HCO_3^- form (Adams et al. 2001). The dissolved oxygen varied from 3.5 to 7.8 in pre-monsoon and from 4.3 to 7.9 in post-monsoon. The total dissolved solids (TDS) ranged from 331 to 1140 (mg/L) with a mean value of 652 mg/L in pre-monsoon, and from 358 to 1245 (mg/L) with a mean value of 651 in post-monsoon. Mean value of TDS was found to be higher than WHO and BIS standard (500 mg/L) of water quality in both pre and post-monsoon periods. High EC and TDS may be due to leaching of ions into the groundwater released from waste of the landfill to the sampling sites. Total hardness of water sample was found to vary from 230 to 604 (mg/L) in pre-monsoon, and from 236-470 (mg/L) in post-monsoon, the mean value of hardness was found above the drinking water standard limit (300 mg/L). The maximum concentration of hardness may be due to carbonate weathering in the study area. Alkalinity ranged from 230 to 630 (mg/L) in pre-monsoon and 265 to 410 (mg/L) in post-monsoon. The mean value of alkalinity was observed below the WHO guideline (500 mg/L), while above the Indian acceptable limit in both pre and post-monsoon. Chloride ranged between 39-205 (mg/L) in pre-monsoon and from 35.50-144 mg/L in

Table 4: Descriptive statistics of physico-chemical analysis of groundwater samples (16) in pre and post-monsoon periods.

	Pre-monsoon (2016)				Post-monsoon (2016)						
Parameters	Min.	Max.	Mean	Std. Deviation	Min.	Max.	Mean	Std. Deviation	Undesirable effect	Drinking water guideline (WHO 2011)	Drinking water acceptable limit (BIS-2012)
Temp.	30.1	32.5	31.55	0.67	20.4	22.9	21.56	0.62		-	-
pH	5.6	7.4	6.5	1.6	7	7.7	7.32	0.21	Taste	6.5-9.2	6.5-8.5
DO	3.5	7.8	6.33	1.08	4.3	7.9	6.75	1.03		-	-
EC	0.56	1.67	0.96	0.34	0.54	1.87	0.97	0.42		0.3	-
TDS	331	1140	652	241	358	1245	651	280	Gastro intestinal irritation	500	500
Hardness	230	604	381	149	236	470	353	72.71	Scale formation	300	200
Alkalinity	230	630	377	118	265	410	343	45.15		500	200
Chloride	39	205	91.19	58.17	35.5	144	79.67	33.62	Salty taste	250	250
Na^+	6	137	113.56	7.83	8	171	171.6	65.31	Salinity	200	-
Ca^{2+}	10.6	77.4	30.55	17.97	34	63.4	50.16	10.29	Scale formation	150	75
K^+	0.3	41.6	4.72	9.91	3	20	10.37	4.75		-	-
Nitrate	16	252	67.81	65.38	10	171	52.48	65.38	Blue baby syndrome	50	45
Fluoride	0.1	1.1	0.51	0.27	0.1	0.7	0.24	0.17	Fluorosis	1.5	1
Fe	0.01	3.66	0.93	0.27	0.08	2.31	0.97	0.68	Bad taste	0.3	0.3
COD	21	360	96.5	84.64	15	271	94.5	84.64		-	-
As	ND	ND	ND	ND	ND	ND	ND	ND		0.01	0.05
Cr	ND	ND	ND	ND	ND	ND	ND	ND		0.005	0.05
Zn	ND	ND	ND	ND	ND	ND	ND	ND		-	5
Cu	ND	ND	ND	ND	ND	ND	ND	ND		-	0.05
Cd	ND	ND	ND	ND	ND	ND	ND	ND		0.003	0.003
Ni	ND	ND	ND	ND	ND	ND	ND	ND		-	0.02

All the values are in mg/L except temperature (°C), EC (mS/cm) and pH; ND: Not detectable

post-monsoon which was below the limit of WHO guideline and acceptable limit of BIS. Na^+, Ca^{2+} and K^+ varied from 6 to 37 (mg/L), 10.60 to 70.40 (mg/L), and 0.30 to 41.60 respectively in pre-monsoon, while they varied from 8 to 171 (mg/L), 34.00 to 63.40 (mg/L) and 3 to 20 mg/L respectively, in post-monsoon. Nitrate value was observed to be from 16 to 142.6 (mg/L) with the mean value of 68.81 mg/L in pre-monsoon and 10 to 171 mg/L with the average value of 52.48 in post-monsoon. It may be due to the domestic sewage, or agriculture runoff near to the sampling location. Fluoride varied from 0.1 to 1.1(mg/L) in pre-monsoon and from 0.1 to 0.7 (mg/L) in post-monsoon. Low concentration of fluoride indicates controlled lithogenic impact of fluoride ion in groundwater samples. The COD varied from 21 mg/L to 350 mg/L with a mean value of 96.50 mg/L in pre-monsoon, while from 15 mg/L to 275 mg/L with a mean value of 94.5 mg/L in post-monsoon. The observed mean value of iron was found to be above the acceptable limit (0.3mg/L) in both pre (0.93 mg/L) and post-monsoon (0.97 mg/L) samples. Higher consumption of these ions with water may lead to a liver disease known as haemosiderosis (Rajappa et al. 2010). Arsenic was not detected in any water sample in pre and post-monsoon. TDS, hardness and nitrate concentrations were found to be much higher than the WHO guideline and Indian acceptable limit of groundwater quality for drinking purpose. Anthropogenic activities like direct discharge of domestic effluents, agricultural impact and landfill leaching are major causes of such type of seasonal variation in groundwater quality in the studied area.

Assessment of groundwater quality using WQI: The results of all 16 groundwater samples were used for WQI evaluation. Further, the World Health Organization guideline (Gordon et al. 2008) and Bureau of Indian Standards (BIS 2012) standards were used for WQI calculations as given in Table 5.

WQI of groundwater was calculated for all the samples in both pre and post-monsoon and given in Table 6.

The calculated WQI values range from 89.42 to 99.37 in

Table 5: Relative weights of water quality parameters.

Water quality parameters	WHO Standards (2008) (mg/L)	BIS Standards (2012) (mg/L)	Weight (w)	Relative Weight ($W_i = w_i/\Sigma w_i$)
pH	6.5-8.5	7.5	0.0260	0.040
EC	-	1.5	0.287	0.040
Total hardness	-	200	0.0260	0.036
Total alkalinity	-	200	0.0260	0.036
Chloride	250	250	0.0289	0.040
Na^+	200	0	0.0289	0.040
Ca^{2+}	300	75	0.0260	0.036
Nitrate	-	45	0.0578	0.080
Fluoride	-	1	0.052	0.072
Fe	-	0.3	0.347	0.048
Cr	0.05	0.05	0.751	0.104
Zn	3	5	0.052	0.072
Cu	2	0.05	0.052	0.072
Cd	0.003	0.003	0.0751	0.104
Pb	0.01	0.01	0.0751	0.104
Ni	0.02	0.02	0.520	0.072
			$\sum wi = 0.7192$	$\sum Wi = 1$

All the values are in mg/L except pH.

Table 6: Types of the water in pre and post-monsoon in the studied area.

Samples	Pre-monsoon WQI= $\sum_{i=1}^{n} SIi \text{x} W_i$	Pre-monsoon Water type	Post-monsoon WQI = $\sum_{i=1}^{n} SIi \text{x} W_i$	Post-monsoon Water type
W1	99.37	Excellent	97.79	Excellent
W2	89.42	Fair	96.90	Good
W3	97.78	Excellent	90.07	Fair
W4	97.81	Excellent	93.14	Excellent
W5	95.01	Good	97.63	Excellent
W6	97.73	Excellent	95.48	Good
W7	95.93	Good	99.62	Excellent
H1	98.05	Excellent	98.35	Excellent
H2	96.77	Good	99.40	Excellent
H3	95.96	Good	89.25	Fair
H4	96.74	Good	88.96	Fair
H5	94.84	Good	96.11	Good
H6	97.09	Good	95.52	Good
H7	98.44	Excellent	90.55	Fair
H8	99.33	Excellent	91.63	Fair
H9	97.99	Excellent	90.98	Fair

W-Well, H-Hand pump

the pre-monsoon and from 88.25 to 99.62 in the post-monsoon. During pre-monsoon eight water samples (W_1, W_3, W_4, W_6, H_1, H_7, H_8 and H_9) are classified as excellent water and seven samples (W_5, W_7, H_2, H_3, H_4, H_5 and H_6) are classified as good water, while only one sample (W_2) comes under fair water quality. In post-monsoon, five water samples (W_1, W_4, W_7, H_1, H_2) come under excellent water quality, four samples (W_2, W_6, H_5, H_6) under good water quality and six samples (W_3, H_3, H_4, H_7, H_8, H_9) under fair water quality. Results of WQI showed that in pre-monsoon 50% of groundwater samples are excellent that encountered desirable level, 43.75% are good and 6.25% are fair water quality for drinking purpose. During post-monsoon, the quality of water is significantly changed, that is 37.5% are excellent, 25% are good and 37.5% are fair. It may be due to rise in groundwater table in post-monsoon, therefore; water may be contaminated easily in comparison to deep groundwater table in pre-monsoon.

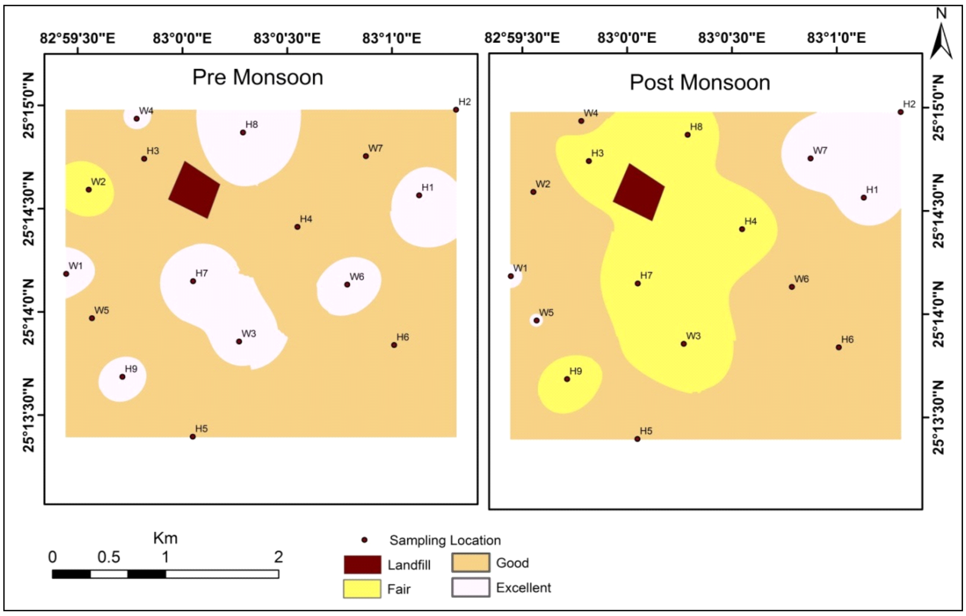

Fig. 2: Map of WQI showing water quality status.

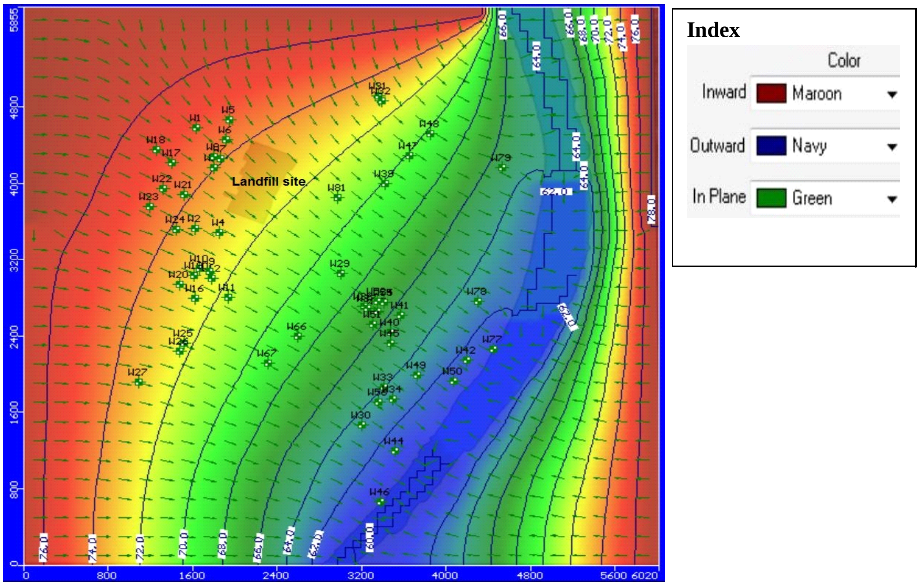

Fig. 3: Map showing groundwater flow direction in pre-monsoon.

Spatial mapping of WQI: WQI map (Fig. 2) delineates two classes of water quality in pre-monsoon, and three classes in post-monsoon. The WQI map shows that most of the studied area around the landfill comes under the good water quality in pre-monsoon and it changes in fair water quality in post-monsoon period which is very close to the landfill site. The significant change in water quality around the landfill in post-monsoon may be due to increase in water level of wells that easily fascinate the leachate pollutants to contaminate the groundwater. In the map a significant change from good to fair water quality is observed near to the landfill. Isolated patches of excellent water quality in the map are observed around the landfill site in pre monsoon, but in post monsoon it was observed in north-west of the study area and east region of the study area. WQI map clearly shows that as the depth and distance of the wells increases from the landfill site, simultaneously groundwater quality also improves (Reddy &Nandini 2011).

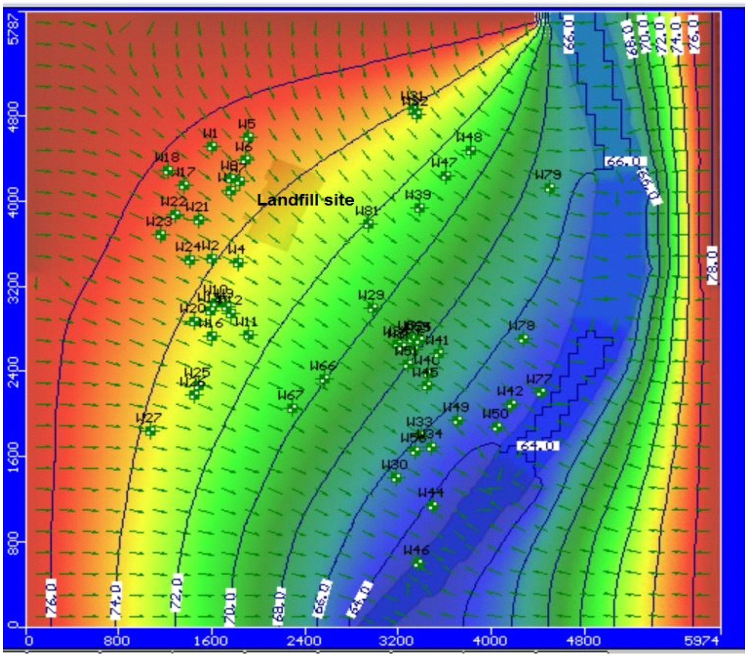

Fig. 4: Map showing groundwater flow direction in post-monsoon.

Evaluation of groundwater flow direction: The path lines of the groundwater flow is shown by groundwater flowing map (Fig. 3 & Fig. 4) of the simulated model which indicates that the groundwater is flowing from higher heads to lower heads (towards Ganga river) in both pre and post-monsoon. The water table in the study area ranges from 57.76 m to 71.72 m in pre-monsoon while in post monsoon it ranges from 59.54 m to 75.82 m. The maximum velocity of groundwater flow is calculated to be 1.5E-06 m/s and 2.1E-06 m/s in pre and post-monsoon respectively. The studied area having two distinct flow patterns, one is from east plain area to west riverside and other is from west plain to east riverside following the topographical elevation. Therefore, increase in hydraulic head during the post monsoon may be responsible for downward and outward flow of leachate pollutants from the landfill and it may be the cause of groundwater contamination towards river side. The result of the spatial mapping of WQI reveals that most of the study area is fair in post-monsoon, and groundwater flow modelling of the study also shows the direction of groundwater flow towards the fair water quality. Therefore, this finding may play an important role in protecting the fair water quality to become threatened water.

CONCLUSION

Evaluation of WQI revealed that 50% of groundwater samples are excellent that encountered desirable level, while 43.75% are good and 6.25 % are fair water quality for drinking purpose. During post-monsoon the quality of water significantly changes i.e., 37.5 % water samples are excellent, 25% are good and 37.5 % are fair water quality for drinking purpose. The WQI map shows that the maximum area comes under good water quality in pre-monsoon and fair water quality in post-monsoon which is acceptable for domestic purpose. Spatial distribution of water quality index indicated that the wells with fair water quality were located very close to the landfill site. However, by analysis of groundwater characteristics, it was concluded that EC, TDS, hardness, nitrate and Fe were found above the standard limit of drinking water quality in both pre and post-monsoon period, which is not safe for drinking purpose. On the basis of model analysis, it is concluded that the groundwater flow around the landfill site is significantly influenced by the head sand direction of groundwater flow is towards river with velocity 1.5E-06 m/s and 2.1E-06 m/s in pre and post-monsoon respectively. This study would be helpful for landfill strategy makers and the government authorities to safeguard groundwater pollution risk from the landfill.

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REFERENCES

Adams, S., Titus, R., Pietersen, K., Tredoux, G. and Harris, C. 2001. Hydrochemical characteristics of aquifers near Sutherland in the Western Karoo, South Africa. J. Hydrol., 241: 91-103.

Anderson, M., Woessner, W.W. and Hunt, R. 2015. Applied Groundwater Modeling, Second Edition: Simulation of Flow and Advective Transport. doi:10.1016/B978-0-08-091638-5.00001-8.

APHA-WEF-AWWA 1999. Standard Methods for the Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington DC.

APHA-AWWA-WEF 2012. Standard Methods for the Examination of Water and Wastewater. Stand. Methods, pp. 541. doi: ISBN 9780875532356.

BIS 2012. Indian Standard Drinking water - Specification. Available at: http://cgwb.gov.in/Documents/WQ-Standards.pdf.

Chakraborty, S. and Kumar, R.N. 2016. Assessment of groundwater quality at a MSW landfill site using standard and AHP based water quality index: a case study from Ranchi, Jharkhand, India. Environ. Monit. Assess., 188: 188-335.

CPCB 2013. Status Report on Municipal Solid Waste Management. CPCB, pp. 1-13.

Esakku, S., Karthikeyan, O.P., Joseph, K., Nagendran, R., Palanivelu, K., Pathirana, K.P.M.N., Karunarathna, A.K. and Basnayake, B.F.A. 2007. Seasonal variations in leachate characteristics from municipal solid waste dumpsites in India and Srilanka. Proc. Int. Conf. Sustain. Solid Waste Manag., pp. 341-347.

Gordon, B., Callan, P. and Vickers, C. 2008. WHO Guidelines for Drinking Water Quality. WHO Chronicle, 38(3), p. 564.

Janardhana Raju, N., Shukla, U.K. and Ram, P. 2011. Hydrogeo-chemistry for the assessment of groundwater quality in Varanasi: a fast-urbanizing center in Uttar Pradesh, India. Environ. Monit. Assess., 173: 279-300.

Kumar, D. and Alappat, B.J. 2005. Analysis of leachate pollution index and formulation of sub-leachate pollution indices. Waste Manag. Res., 23: 230-239.

Manimekalai, M.B. and Vijayalakshmi, P. 2012. Analysis of leachate contamination potential of a municipal landfill using leachate pollution index. J. Environ. Sci. Toxicol. Food Technol., 2: 16-39.

MoEF 2000. Municipal Solid Waste (Management & Handling) Rules, 2000). Gazette, Accecssed 12 august 2017.

Mohan, K., Ivastava, A. and Rai, P.K. 2011. Ground water in the city of Varanasi, India: Present status and prospects. Quaest. Geogr., 30: 47-60.

Pappu, A., Saxena, M. and Asolekar, S.R. 2007. Solid wastes generation in India and their recycling potential in building materials. Build. Environ., 42: 2311-2320.

Rajappa, B., Manjappa, S. and Puttaiah, E. 2010. Monitoring of heavy metal concentration in groundwater of Hakinaka Taluk, India. Contemp. Eng. Sci., 3: 183-190.

Ramesh, S., Sukumaran, N., Murugesan, A.G. and Rajan, M.P. 2010. An innovative approach of drinking water quality index- a case study from Southern Tamil Nadu, India. Ecol. Indic., 10: 857-868.

Reddy, P.S. and Nandini, N. 2011. Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. Nat. Environ. Pollut. Technol., 10: 415-418.

Remesan, R. and Panda, R.K. 2007. Groundwater quality mapping using GIS: A study from India's Kapgari Watershed. Environ. Qual. Manag., 16: 41-60.

Shanthi, P., Sundari, P.M. and Meenambal, T. 2013. Evaluating the physico-chemical characteristics of municipal solid waste in Coimbatore City, Tamilnadu. Nat. Environ. Pollut. Technol., 12: 69-74.

Singh, S., Raju, N.J., Gossel, W. and Wycisk, P. 2016. Assessment of pollution potential of leachate from the municipal solid waste disposal site and its impact on groundwater quality, Varanasi environs, India. Arab. J. Geosci., 9: 1-12.

Talalaj, I.A. and Biedka, P. 2016. Use of the landfill water pollution index (LWPI) for groundwater quality assessment near the landfill sites. Environ. Sci. Pollut. Res., 23: 24601-24613.

Varol, S. and Davraz, A. 2015. Evaluation of the groundwater quality with WQI and multivariate analysis: a case study of the Tefenni plain (Burdur/Turkey). Env. Earth Sci., 73: 1725-1744.

WHO 2011. Technical Guidance on Water-related Disease Surveillance Technical Guidance on Water. Accecssed on 10 August 2017.