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Application of Principal Component Analysis and Correlation for Assessing Groundwater Contamination in and around Municipal Solid Waste Landfill of Ghazipur, Delhi

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ABSTRACT

The present study has been executed to assess the groundwater quality and to investigate the possible sources of contamination in the adjoining areas of Ghazipur landfill site, Delhi. The groundwater samples were collected during pre and post monsoon seasons and various physico-chemical and heavy metals concentration were also analyzed. The results show that the samples which were taken adjacent to landfill site had a higher concentration of total dissolved solids (2383 mg/l), chloride (991mg/l), total hardness (659 mg/l), ammonical nitrogen (2.3mg/l), sodium (350 mg/l), calcium (534 mg/l) and sulphate (631 mg/l). Most of the heavy metals concentration in groundwater samples was found within the prescribed limit except Cu and Pb. The principal component analysis (PCA) extracted 3 factors which collectively explained 80.1% of the variation in data during post-monsoon whereas 75.4% of the variation in pre-monsoon season. The obtained results clearly show that K^+, Mg^{2+}, Na^+, SO_4^{2-}, and NO_3^- ions significantly contribute towards the high temporal pollution load to groundwater quality. Factor analysis also suggested that the continuous percolation of these contaminants from the nearby landfill could be the possible sources of contamination into groundwater aquifer system. The concentration of heavy metals in leachate have followed the order as- Fe>Zn>Cu>Pb>Ni>Cr>Cd. The overall result indicates that the landfill leachate is significantly affecting the nearby groundwater quality through continuous leaching over a long period of time. As the groundwater is used by some local residents for domestic purposes, immediate action and alternative effort should be made to supply clean water.

INTRODUCTION

Groundwater is one of the most important natural resources for India, as it the largest user in the world. But due to overexploitation and some anthropogenic source, groundwater quality has been depleting continuously. One of the most hazardous sources of groundwater contamination is unlined municipal solid waste landfill. Landfills are the most common and easiest method of waste disposal in developing countries. They receive solid waste from different sources like domestic, commercial, agricultural and industrial establishments. Therefore, type of waste disposed off in the landfill is most heterogeneous in nature. Generally, landfills were developed in the area where land was easily available but in an unscientific manner, i.e., without considering the local geology, hydrogeology and its surrounding environment. As, these unscientifically developed landfills are hydrologically connected to ground and surface water, it poses a long-term risk of contamination of the surrounding water bodies. A number of researchers have studied the impact of landfill leachate on surrounding groundwater and found leachate as the major source of contamination and health risk as well (Fatta et al., 1999; Mor et al., 2006; Ostman et al., 2006). Landfill leachate moves in horizontal as well as vertically downward direction, through soil strata and finally reaches the subsurface saturated zone and contaminate the groundwater. Leachate plumes can spread mainly by the process of dispersion and advection (Prommer et al., 2006). Therefore, it is necessary to understand the groundwater flow pattern and to know the mechanism of transport of pollutants through groundwater.

The main aim of this study was to investigate the hydro geochemical processes and impact of landfill leachate on groundwater adjacent to the oldest landfill site (Ghazipur) of Delhi. The study will help to understand and identify the anthropogenic influences, as well as the natural (rock-water interaction) process, occurring underneath. Additionally, it is also affected by pollutants leached from the landfills (Srivastava and Ramanathan, 2008). Various studies have found that groundwater quality is chemically altered by means of internal mixing of different groundwater along the sub-surface flow path and also due to its interaction with aquifer minerals (Rushton, 2004; Kumar et al., 2006). Hence, the direction of groundwater movement can be understood by the spatial distribution of chemical contaminants. The numbers of studies were conducted on groundwater and surface water contamination due to landfill and reported high contamination (Kontos et al., 2005; Mor et al., 2006). The different landfills of National Capital, Delhi has been significantly generating a large amount of leachate annually, which is affecting groundwater quality (CPCB, 2001). The younger alluvium of the study area leads to more leaching and possibly deteriorates the nearby groundwater quality. Therefore, more attention is required for understanding of the groundwater flow pattern and transport of pollutants as it is the major source for domestic and drinking purpose in most of the cities in India.

STUDY AREA

The Ghazipur landfill site is one of the oldest landfill sites of the densely populated and urbanized city of Delhi, which is saturated since 2004. It is located in east Delhi at the latitude of 28°37'22.4" N and 77°19'25.7" E with a stretch of 70 acres of land. About 80% of the landfill i.e. around 55 acres of area is occupied with 60 lakh cubic meter of waste by volume. The existing average height of waste pile is about 50 m whereas at some points it reaches up to 60 m (maximum) with an average side slope of 60°-70°. An integrated solid waste management facility and power plant are located on the western side of the landfill. Domestic wastes, construction and demolition waste collected from Shahdara (North and West) zone, Sadar Paharganj zone, City zone, NDMC area, and Cantonment Board area of Delhi are

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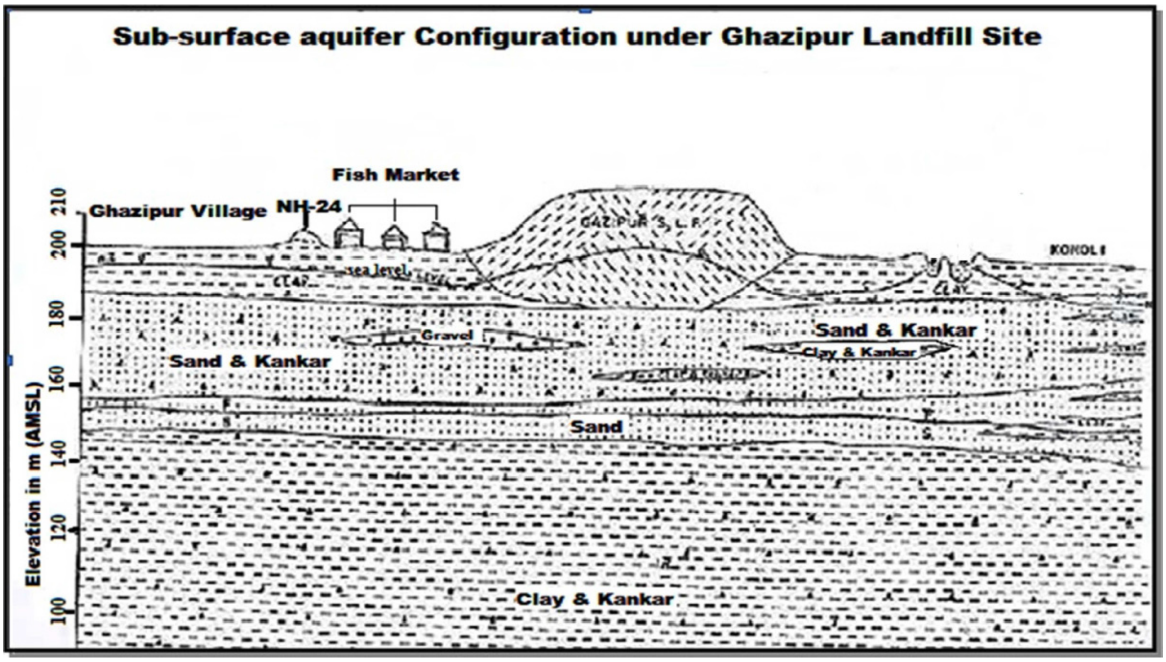

Fig.1. Schematic of geological cross-section of Ghazipur landfill site (CGWB & BARC, 2004)

dumped at this site regularly. Additionally, wastes are also dumped from the nearby dairy farm, poultry market, slaughter market, fish market, and hospital's non-infectious waste as it is very close to the study area.

The Delhi with an elevation ranging from 198 to 220 m above MSL (Mean Sea Level) mainly lies in Indo-Gangetic alluvial plains. Lithologically, the area is transacted by a quartzite ridge extended from the north-east (Aravalli Hills) to south-east part (CGWB and CPCB 2000). Both sides of the ridge have a different nature of alluvial formations overlying the quartzitic bedrock. The geology of the study area is underlain by younger alluvium. Based on lithology and geophysical logs constructed by CPCB, fine to medium sand mixed with coarse hard kankar underlain up to the depth of 50 m bgl (below ground level) and quaternary alluvium of about 134 m thick below which weathered and fractured quartzite is present. Therefore it may be inferred as a single aquifer system of 50m depth only however minor clay silt horizon are also present at some places within the sand horizon. Clay is dominantly present in sediments below this depth. There are three aquifers which can be seen at the depth of 0.00 to 12.00 m, 15.00 to 30.00 m and 41.00 to 47.00 m bgl are separated by

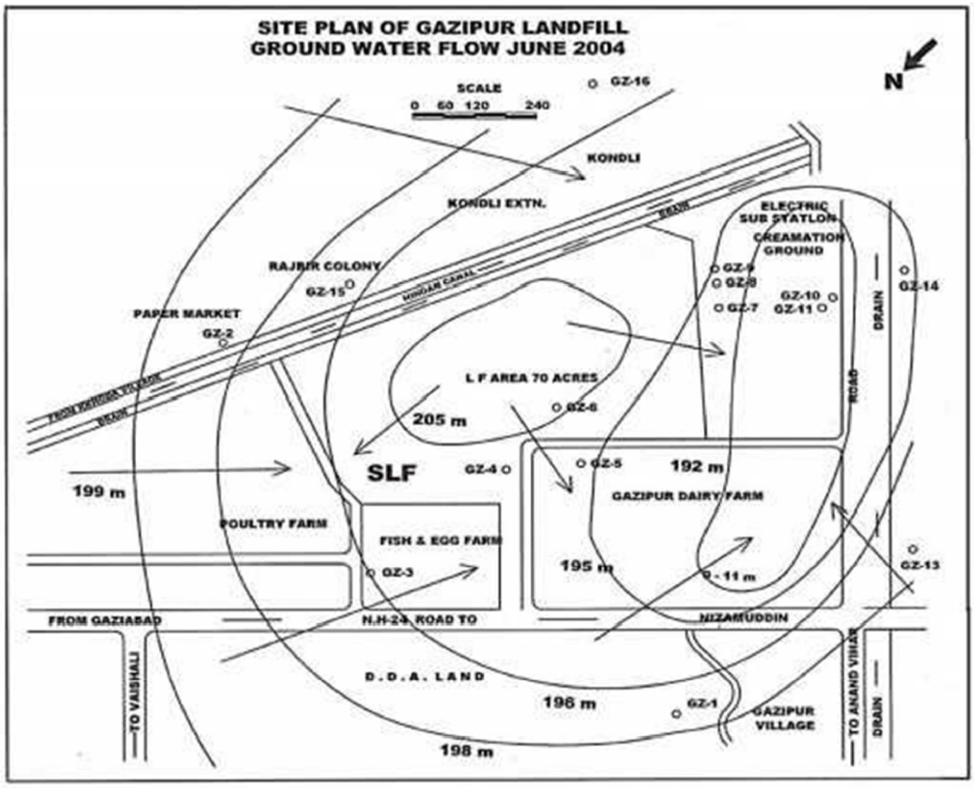

Fig.2. Water table contours showing regional and local groundwater flow (CGWB & BARC, 2004)

silt mixed with minor clay and kankar in this area are due to the existence of clay silt horizon. During the construction of shallow piezometers (CPCB 2000), solid waste materials were found to the depth of 6 m. The sub-surface cross-section of landfill site has been shown in Fig.1.

The regional groundwater flow direction near the study area is towards southeast i.e. towards river Yamuna (CPCB 2004). However, the local groundwater flow pattern is entirely different from the regional flow pattern. As the waste filling has increased rapidly, groundwater mount is built up within the landfill which finally led to changes in the local flow pattern of groundwater (CPCB 2004). The higher utilization of groundwater in the area of Ghazipur dairy farm and DDA flats, lies north to landfill, is the main reason of groundwater flows towards the north. It may also be due to the trough development in these areas. Figure 2 illustrate the water table contour showing local and regional ground water flow direction.

MATERIAL AND METHODS

Groundwater and Leachate Sampling, Parameters and Analysis

To understand the extent of groundwater pollution and the reason behind the spatial variation near the landfill site, twenty groundwater samples were collected within 2 km radius (2016 to 2018) (Fig.3). The details of groundwater sampling points are presented in Table 1. The leachate samples were collected randomly from three different points (as surface runoff) at the foot of landfill site, as there was no appropriate collection system available. The physical and chemical composition of MSW dumped at Ghazipur landfill site is depicted in Table 2 &3. As the leachate originates due to rains, which subsequently influences the ground water, sampling was carried out during the pre and post monsoon seasons.

Total 15 physico-chemical parameters of groundwater and 16 parameters of leachate were analyzed according to the standard method of American Public Health Association (APHA, 1998). For heavy metals analysis, 100 ml samples were collected separately and preserved with pure nitric acid (analytical grade) and filtered using filter paper Whatman No. 42. The heavy metals like Pb, Cu, Cr, Cd, Ni and Zn were estimated through Atomic absorption spectrophotometer (Agilent 280 FS AA). All the analysis was done in triplicates and average values were stated. The descriptive statistics of physico-chemical parameters of leachate is shown in Table 4.

Table 1. Detail of groundwater sampling points near Ghazipur landfill site

Groundwater Sampling Points	Distance from landfill site (km)	Depth (in m)	Coordinates	
			Latitude	Longitude
GW 1*	0.35	12	28°37'31.68"	77°19'18.85"
GW 2	2.13	45	28°37'12.09"	77°18'11.84"
GW 3	1.40	30	28°36'55.46"	77°18'48.78"
GW 4	0.28	24	28°37'13.79"	77°19'46.09"
GW 5	0.69	36	28°37'13.21"	77°20'04.81"
GW 6	1.31	36	28°37'13.17"	77°20'31.04"
GW 7	1.25	36	28°37'39.10"	77°20'31.90"
GW 8	1.68	36	28°37'54.32"	77°20'42.56"
GW 9	2.03	33	28°38'38.34"	77°20'30.50"
GW 10	1.92	33	28°38'36.10"	77°19'28.77"
GW 11	2.09	33	28°38'08.69"	77°18'31.50"
GW 12	0.66	30	28°37'00.48"	77°19'22.88"
GW 13	1.11	24	28°36'45.77"	77°19'50.47"
GW14	1.98	30	28°36'18.49"	77°19'58.00"
GW 15	0.95	33	28°36'50.92"	77°19'50.32"
GW 16	0.76	36	28°37'02.34"	77°19'13.39"
GW 17	1.08	36	28°37'10.54"	77°18'53.25"
GW 18	0.23	40	28°37'23.24"	77°19'21.19"
GW 19	0.09	36	28°37'20.60"	77°19'27.14"
GW 20*	0.07	12	28°37'35.10"	77°19'35.30"

RESULT AND DISCUSSION

Leachate Composition

The 16 water quality parameters and six heavy metals were analyzed for landfill leachate of Ghazipur during pre and post monsoon season for two consecutive years (2016-2018) (Table 3).

The slightly alkaline nature of leachate was observed with a pH value of 7.8-8.9. The high pH of leachate indicates the low metal

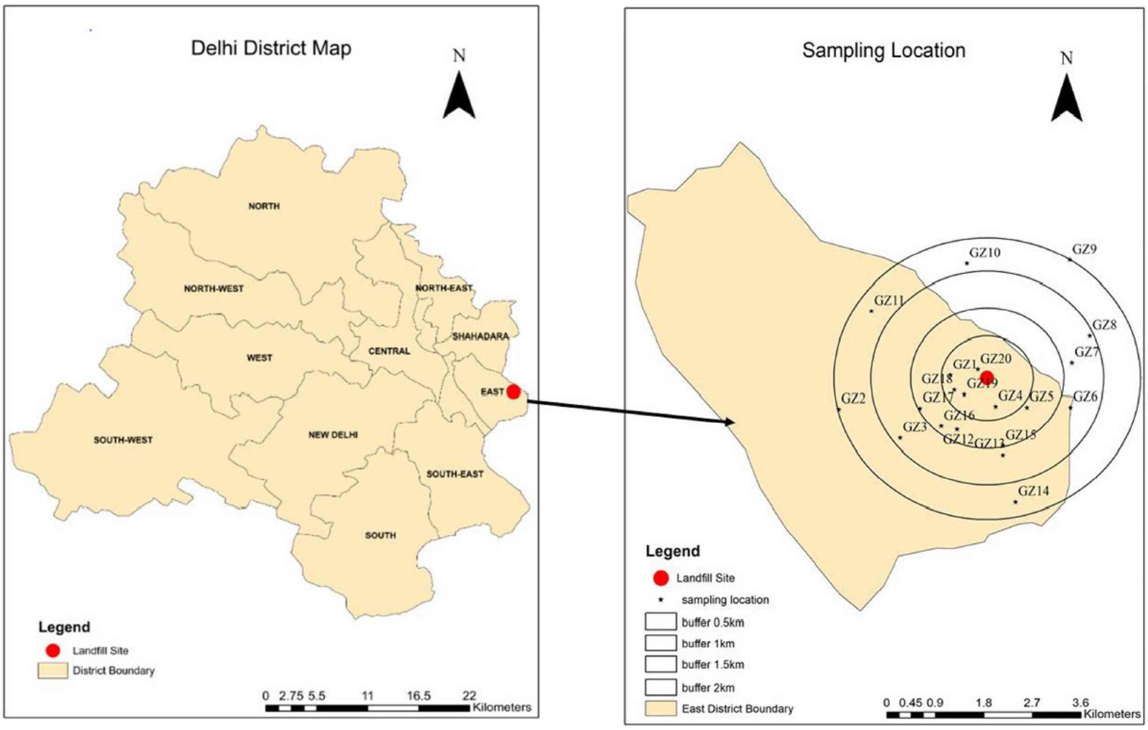

Fig.3. Delhi district map showing the Ghazipur landfill site and the Groundwater sampling points.

Table 2. Physical composition of MSW at Ghazipur landfill (% on a basis of wet weight)

Borehole No.	Depth (m)	Plastic[1]	Paper[2]	Cloth	Metal[3]	Stone[4]	Compostable[5]
1	0 to 3	8.7	14.1	21.4	0	8.5	47.3
1	3 to 6	7.6	14.5	13.6	6	0	53.9
1	6 to 9	0	5.2	7.5	0	8.2	79.1
2	0 to 3	35.1	5.8	32.2	0	0	16.9
3	0 to 3	5.2	2.1	17.7	2.9	0	72.1
3	3 to 6	0	0	9	0	15.4	76.6
3	6 to 9	0	0	20.1	0	0	79.9
4	0 to 3	6.4	6.4	11.1	4.2	0	71.9
4	3 to 6	5.2	0	16.4	13.2	6.6	58.2
4	6 to 9	0	0	20.7	4.6	0	74.7
5	0 to 3	29.7	12	34.8	1.9	0.9	20.7
5	3 to 6	38.4	5.8	14.7	17.9	0	23.2
5	6 to 9	0	0	32.7	0	0	67.3
6	0 to 3	7	11.5	27.5	1.8	1.5	50.7
6	3 to 6	0	0	14.9	0	4.7	79.4
6	6 to 9	0	0	43	0	1	56
7	0 to 3	5	3.8	35.6	1.9	0	53.7
7	3 to 6	2.6	2.6	10.1	0	9.7	75
7	6 to 9	0	0	17.8	0	5.5	76.7
7	9 to 12	0	0	36.4	0	2.7	60.9
8	0 to 3	12.2	3.2	19.2	0	0.6	64.8
8	3 to 6	0	0	46.7	0	1.1	52.2
8	6 to 9	0	0	44.8	6.8	0	48.4
9	0 to 3	20.5	8.1	24.8	2.9	0.4	43.3
9	3 to 6	5	1.1	20	0	15.4	58.5
Average	0 to 3	14.3±11.3	7.4±4.3	24.9±8.4	1.7±1.5	1.3±2.7	49±20
	3 to 6	7.4±12.9	3.0±5.1	18.2±12	4.6±7.2	6.6±6.4	59.6±18.3
	6 to 9	0±0	0.7±2	26.7±13.9	1.6±2.9	2.1±3.4	68.9±12.3
ΣAverage		7.3±7.2	3.7±3.4	23.3±4.5	2.7±1.7	3.3±2.9	59.2±9.9

(Source: Mor et al., 2006); [1]Plastic bags, plastic bottles, packaging material. [2]Paper, wrapper, cardboard, packaging paper. [3]Cables, foils, ferrous and non- ferrous material. [4]Stones, bricks, construction material. [5]Vegetables, food, garden waste, wood.

solubility because metal ions are precipitated as insoluble hydroxide (Kanmani and Gandhimathi, 2013). The high value of electrical conductivity (EC) (32340-42115 µS/cm) and total dissolved solid (TDS) (23221-29123 mg/l) indicates the presence of dissolved inorganic matter and high loads of mineral salts and ion concentration. The high concentration of chloride (Cl^-) (850-1877 mg/l) was found in both the year. The high concentration of various anions and cations like Na^+, K^+, NO_3^-, F^- and PO_4^{3-} were also observed. The observed high concentration of nitrate (NO_3^-) (328- 533 mg/l) could be due to the dumping of nearby slaughter house, dairy farm and poultry market waste in the landfill site. The high value of ammonia nitrogen was possibly due to deamination of amino acid in the decomposition process of organic compound present in the landfill (Crawford and Smith, 2016; Tatsi and Zouboulis, 2002). It also gives the foul smell to leachate. The high value of biological oxygen demand (BOD) (9250-13150 mg/l) and chemical oxygen demand (COD) has been continuously observed during the investigating period indicates high organic content and high microbial activity to decompose the leachate.

The high concentration of iron (Fe^{2+}) in the leachate sample is possibly due to regular dumping of iron and iron-containing alloys in the landfill. Over a period of time, oxidation of ferrous to ferric and ferric hydroxide colloids and complexes, formation with fulvic or humic substance give the dark brown colour to the leachate (Chu et al., 1994). The dumping of lead- based batteries, lead-based pipes, and paints at the landfill site are the major source of lead in the leachate samples (Kale et al., 2010; Moturi et al., 2004). The used batteries and fluorescent lamps were also dumped at the landfill which finally leads to a high value of zinc in leachate (Moturi et al., 2004). Other metals like Cu, Ni, Cr, and Cd was also observed in high concentration in leachate. It also indicates that the variety of regular waste like cans, other food containers, wire hangers, house fixtures (pipes, keys, lighting, doorknobs etc.) was regularly dumped at dump site (Moturi et al., 2004; Mor et al., 2006). Other researchers have also found these compounds and metals in landfill leachate (Ogundiran and Afolabi, 2008).

Seasonal variation in Groundwater Quality

The seasonal variation of groundwater quality in the vicinity of Ghazipur landfill is depicted by box plots in Fig. 4.

The hydrogen ion concentration (pH) of all the groundwater samples remained neutral which lies from 6.82 to 7.68 (±0.2) in pre monsoon and 6.71 to 7.6 (±0.24) in post monsoon season. A few samples (GW 1, 4, 18, 19 and 20) were observed with remarkably high EC during both the season as they were very close to landfill site as well as collected from a shallow depth, therefore, more prone to leachate contamination (CGWB, 2015). It indicates that landfill leachate has a great impact on groundwater quality. The TDS of water indicates the nature of water quality. It is higher in pre monsoon season (603 – 2365 ± 410.64 mg/l) than the post monsoon season (589-2382.60 ± 400 mg/l) due to continuous percolation of pollutants through landfill into groundwater system (Fatta et al., 1999).

The alkalinity of water attributed to the occurrence of carbonates, bicarbonates and hydroxyl ions in a free state. The total alkalinity (TA) as $CaCO_3$ was observed higher in pre monsoon (185 – 588 ± 101.19 mg/l) and lower in post monsoon (166 -598 ± 115.42 mg/l) season. The alkaline water has an unpleasant taste and might be toxic for human health if it also consist high value of pH, TDS, and hardness. Total Hardness (TH) is usually expressed as the total concentration of

Table 3. Chemical composition of MSW at Ghazipur landfill (% on a basis of wet weight) (Source: Mor et al., 2006)

Bore hole No.	Depth (m)	pH	Moisture content*	Volatile Solid*	Organic matter*	N*	C*	H*	P*	K*
1	0 to3	7.8	23.9	27.2	23.6	0.84	6.1	0.9	0.8	0.7
1	3 to 6	8.2	30.3	31.6	27	0.79	7.6	0.96	0.7	0.5
1	6 to 9	8.2	21.4	27	22.6	0.99	8.98	1.17	0.6	1
2	0 to 3	7.9	27.2	31.6	26.7	0.74	6.02	0.84	0.7	1
3	0 to 3	8.6	10.7	26.3	21.8	0.96	9.67	1.15	0.6	1.2
3	3 to 6	8.4	51.2	26.9	22.1	0.97	9.32	1.22	0.5	1.2
3	6 to 9	7.6	38.9	25.3	21.8	0.75	5.74	0.79	0.6	1.5
4	0 to 3	7.8	40.5	31.1	26.4	0.78	5.89	0.87	0.8	1
4	3 to 6	8.1	45.6	29.6	26.7	0.94	8.91	1.25	0.7	1
4	6 to 9	8.1	53.2	30.1	27.1	1.20	9.37	1.35	0.7	0.7
5	0 to 3	7.9	31.9	29.1	23.4	0.89	9.30	1.25	0.6	1
5	3 to 6	8.6	42.6	27.1	23	0.83	8.36	1.04	0.8	0.5
5	6 to 9	8.4	40.2	25.6	21.5	0.94	8.52	1.14	0.7	0.5
6	0 to 3	8.2	37.1	30.8	25.9	1.05	8.85	1.25	0.6	1.2
6	3 to 6	7.8	60.9	24.6	20.8	0.95	9.58	1.35	0.6	1
6	6 to 9	8.1	52.6	26.9	21.1	0.84.	6.92	0.98	0.6	0.7
7	0 to 3	8	27.2	24.6	20.8	1.11	10.63	1.55	0.5	0.7
7	3 to 6	8.2	43.6	24.9	21	1.16	10.46	1.53	0.6	0.7
7	6 to 9	8.4	54.5	31.6	27.9	0.99	7.38	1.11	0.6	1
7	9 to 12	7.9	57.7	26.6	23.5	1.08	8.79	1.36	0.6	1
8	0 to 3	8.1	30.2	24.9	20.5	0.97	8.39	1.32	0.4	1
8	3 to 6	8.6	53.5	31.2	26.8	0.95	9.90	1.38	0.5	1.2
8	6 to 9	8.4	54.3	28.9	23.1	1.02	10.8	1.40	0.5	1
9	0 to 3	8.4	30.2	30.2	26.9	0.92	8.05	0.96	0.7	1.2
9	3 to 6	8.2	43.8	31.4	28.2	0.78	5.00	0.83	0.6	1
Avg.	0 to 3	8.1±0.3	28.8±8.5	28.4±2.7	24±2.6	0.92±0.1	8.11±1.7	1.13±0.2	0.63±0.13	1.0±0.19
	3 to 6	8.3±0.3	46.4±9	28.4±2.9	24.5±3	0.92±0.12	8.66±1.7	1.2±0.23	0.62±0.1	0.89±0.29
	6 to 9	8.2±0.3	45±12.4	27.9±2.4	23.6±2.8	0.99±0.15	8.26±1.7	1.14±0.21	0.6±0.07	0.91±0.32
ΣAvg.		8.2±0.3	40.1±12.9	28.2±2.5	24±2.6	0.94±0.13	8.35±1.6	1.16±0.22	0.62±0.1	0.94±0.25

Ca^{2+} and Mg^{2+} cations. The concentration of Mg^{2+} ions ranged from 18.53-121± 27.37 mg/l in pre monsoon and 9.85-104 ± 24.06 mg/l in post monsoon season. For the health point of view, Mg^{2+} salts are beneficial as well as diuretic depending upon the intake amount. Total hardness as $CaCO_3$ was observed lower during post monsoon sampling (244 - 616 ± 87.6 mg/l) than the pre monsoon season (270 – 659 ± 99.32 mg/l). It may be due to the dilution of contaminant (carbonate and bicarbonate) into groundwater, after a monsoon. According to groundwater classification on the basis of total hardness, all groundwater samples falls in the category of very hard type (>180mg/l) (Durfor and Becker, 1964) in the study area. It may increase the threat of calcification of arteries, concretions of urinary and various diseases related to kidney, stomach or bladder (Sharma et al. 2017). The concentration of calcium ions ranged from 87.82-534 ± 116.16 mg/l in pre monsoon whereas it is 69.94-498 ± 107.38 mg/l in post monsoon season. The dissolution of concrete material used in street and footpath construction may be considered as the source of Ca^{2+} ion. The spatial distribution of Ca^{2+} concentration indicates the highest concentration in GZ 4 (sampling site) which lies in the dairy farm area and also near to landfill site while it decreases with the distance. Therefore, it indicates the leachate percolation from the landfill site. The high concentration of calcium was also observed in leachate as well (CPCB, 2001). The high concentration of chloride (Cl^-) is considered as the pollution indicator and tracer from groundwater contamination (Loizidou and Kapetanios, 1993). Its high concentration was found in pre monsoon (145 – 991 ± 236.6 mg/l) and (133 – 784 ± 194.33 mg/l) in post monsoon season. The maximum samples near to landfill site (GW1, 4, 18, 19 and 20) have exceeded the WHO standard limits (250 mg/l) of chloride (Mor et al., 2006). The anthropogenic contamination of chloride may be due to domestic effluent, livestock waste, inorganic fertilizers, animal feeds, paper and plastic waste and effluents of septic tank coming to the landfill site (Mor et al., 2006).

The presence of nitrogen nutrients like ammonium and nitrate may be due to some anthropogenic sources like domestic sewage, livestock or human wastes, agricultural runoff and leachate from unlined

Table 4. Descriptive statistics of Physico-chemical parameters of leachate sample during pre and post-monsoon season

Parameters*	Pre Monsoon			Post Monsoon		
	Min	Max	Avg.	Min	Max	Avg.
Ph	8.75	8.9	8.825	7.87	8.43	8.15
TDS	25632	29123	27377.5	23221	27268	25244.5
EC	38840	42115	40477.5	32340	34560	33450
Oil & Grease	218	317	267.5	146	304	225
Total Hardness	3108	3200	3154	2300	2870	2585
Total Alkalinity	11500	13600	12550	7400	8700	8050
Fluoride	34	47	40.5	12	25.55	18.775
Nitrate	464	533	498.5	328	449	388.5
Sodium	623	635	629	560	586	573
Potassium	1579	1692	1635.5	1161.13	1353	1257.065
Phosphate	26	39	32.5	22	28	25
Chloride	1080	1877	1478.5	850	1598	1224
Ammonical Nitrogen	1417	1675	1546	1137	1483	1310
Total Iron	41.33	58.18	49.755	32.95	42.78	37.865
BOD_3	11414	13150	12282	9250	12504	10877
COD	27863	32799	30331	20992	28953	24972.5
Heavy Metals						
Lead (Pb)	1.08	2.28	1.68	0.66	1.01	0.83
Copper (Cu)	1.43	1.67	1.55	0.9	1.23	1.06
Chromium (Cr)	0.19	0.43	0.31	0.09	0.12	0.10
Cadmium (Cd)	0.06	0.09	0.07	0.04	0.06	0.05
Nickel (Ni)	0.53	0.68	0.61	0.21	0.52	0.36
Zinc (Zn)	1.63	2.47	2.05	1.50	1.72	1.61

*All parameters in mg/l except EC in µS/cm and pH

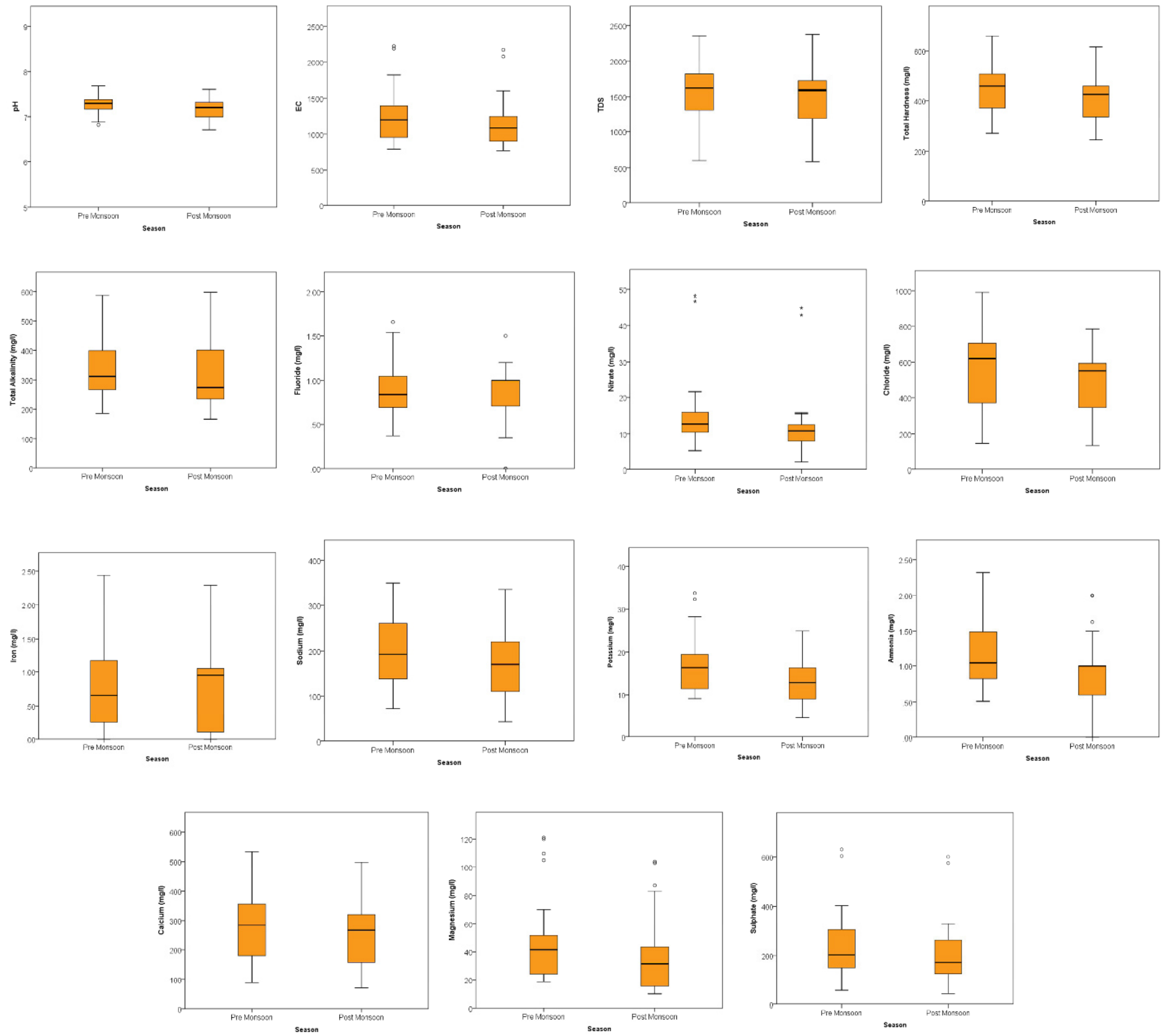

Fig.4. Box plots of various water quality parameters showing seasonal variations

landfills (Lee et al., 2003; Jalali, 2005). The NO_3^- concentration in groundwater sample has ranged (5.15 - 48.20 ± 8.66 mg/l) in pre monsoon and (2.19 - 45 ± 8.13 mg/l) in post monsoon season. Only one sampling point GZ 4 exceeded the maximum permissible limit indicating the anthropogenic point source contribution through landfill leachate (Ali et al., 1998). The NH_4^+ was observed in the range of 0.51–2.33±0.46 mg/l during pre and 0.40–2.03 ± 0.45 mg/l during post monsoon season with less seasonal variation. The significant high concentration in GZ 5, GZ 15 and GZ 17 samples (near landfill site) probably indicates the leachate as contaminant source. The concentration of fluoride was showing less seasonal variation, during pre-monsoon (0.37–1.66±0.30mg/l) and post-monsoon season (0.33–1.50±0.28 mg/l). The Na^+ was found higher during pre monsoon (73 – 350 ± 76.73 mg/l) than post monsoon season (43.47 – 336 ± 76.74 mg/l) was also observed by another researcher (Mor et al., 2006). The higher concentration of Na^+ around the study area indicates it may be originated from weathering and the ions resulted from the dissolution of soil salts or may be originated from the landfill leachate (Singh and Hasnain, 1999). The dominance of sodium and chloride was also observed by other researchers which indicate that the groundwater in the study area is saline in nature. It is probably due to leachate percolation effect from the landfill site (Kumar et al., 2002; Singh et al., 2008; Kumar et al., 2009b). The concentration of K^+ has ranged from 9.07 – 34 ± 6.64 mg/l during pre monsoon and 4.50 – 25.08 ± 5.74 mg/l during post monsoon season which lies within the permissible limits. The similar study was reported that the presence of K^+ in groundwater has been an indicator of leachate percolation effect (Ellis 1980).

The SO_4^{2-} was observed higher in pre monsoon (56 – 631 ± 129.39 mg/l) than post monsoon season (42 – 601 ± 121.53 mg/l). The significant high concentration was found at sampling site of GZ 20 which is very near to landfill. Iron was the only metal which was found above than the WHO permissible limit in groundwater of sampling sites. It ranged from 0 – 2.4 ± 0.82 mg/l in pre monsoon while 0.09 – 2.30 ± 0.66 mg/l in post monsoon. The high concentration of iron can lead to change in the colour of groundwater (Rowe et al., 1997). The seasonal variation was found with different proportion in most of the parameters which are mainly due to the dilution of groundwater during the monsoon season (Rajmohan and Elango, 2004).

Most of the contaminants in groundwater samples decrease with radial distance which indicates its origin from the landfill. It is

Table 5. Variables loading on factors resulting from the varimax rotation for groundwater quality during pre and post monsoon season

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
	Pre Monsoon								
1	7.69	64.13	64.13	7.69	64.13	64.13	6.00	50.01	50.01
2	1.35	11.26	75.39	1.35	11.26	75.39	3.04	25.38	75.39
	Post Monsoon								
1	7.18	59.87	59.87	7.18	59.87	59.87	5.47	45.60	45.60
2	1.41	11.77	71.64	1.41	11.77	71.64	2.14	17.84	63.44
3	1.02	8.53	80.17	1.02	8.53	80.17	2.00	16.73	80.17

supported by the fact that the regional groundwater flow direction is towards the southeast however local groundwater flow pattern is towards the north that is outward away from the landfill (CPCB, 2004). In groundwater aquifer system, the dispersion and diffusion of contaminants are assisted by the groundwater flow pattern. But there is variation in groundwater quality along with the depth as a movement of leachate in groundwater differs with hydraulic gradient and faster along X-Y coordinates as compared to the Z coordinate.

Heavy Metals: Heavy metals considered as the most undesirable component which is hazardous even if it found in traces in groundwater. The groundwater samples were also analyzed for heavy metals like Fe, Zn, Cu, Pb, Ni, Cr, and Cd. The iron concentration ranged from 0-2.44 mg/l and 0.09-2.3 mg/l during pre and post monsoon season respectively which exceeds the standard permissible limit of WHO. Its presence may indicate that it gets contaminated through leaching from landfill which may originate due to iron scraps waste dumped at the landfill. The high concentration of iron may alter the colour of groundwater (Rowe et al., 1997). The copper concentration has ranged from 0-0.051 mg/l and 0-0.038 mg/l in pre and post monsoon respectively which exceeds the standard permissible limit of WHO in the samples of pre monsoon season. It may be due to regular dumping of electronic waste and leaching of minerals found locally (Mishra et al., 2016; Kumari et al., 2017). The concentration of nickel was found in the range of 0-0.012mg/l and 0-0.013mg/l where as that of zinc ranged from 0-0.387mg/l and 0-0.386 mg/l in pre and post monsoon seasons respectively. The maximum concentration of lead was almost equal to standard permissible limit ranged from 0-0.012 mg/l during pre monsoon while 0-0.007 mg/l in post monsoon season. Although the chromium was found well within the standard permissible limit (0-0.01 mg/l and 0-0.008 mg/l) in both the sampling season, its presence in groundwater may be attributed to dumping of chromium-based cement, asbestos waste, waste from chemical plants, paints or pigments (insoluble Cr [VI]) and can also be from topsoil and rocks nearby. While traces of cadmium level (0-0.002 mg/l) was found in groundwater samples during both the season. Presence of various heavy metals indicates that various type of waste is regularly dumped at the landfill site of Ghazipur. A number of researchers have examined and found the presence of these metals in leachate as well as in groundwater near landfills (Moturi et al., 2004; Mor et al., 2006; Ogundiran and Afolabi, 2008). Most of the heavy metal was found within the standard limit in groundwater samples except copper and lead. This may probably specifies that these metals may get absorbed through the nearby soil strata or through the organic matter present in the soil.

Principal Component Analysis / Factor Analysis (PCA/FA)

The Kaiser- Mayer-Olkin (KMO) and Barlett's test was executed to test the suitability of data before applying Principal Component Analysis (PCA/FA). In the present study, the result obtained from KMO test was 0.820 and Barlett's sphericity test was also observed significant at 0.00 ($P<0.01$). It clearly indicates the appropriateness and usefulness of PCA which can significantly reduce the dimensionality in a dataset (Hutcheson and Sofroniou, 1999).

The PCA analysis was executed on the large data set of hydro-geochemical parameters of groundwater near the landfill site to find out the parameters that have a maximum and significant effect on the groundwater quality. On the basis of Eigenvalue only 2 factors are extracted which explains 75.4% of the variance in pre monsoon while 3 factors extracted explaining 80.1% of the variance in post monsoon season contained in the original data set. The Eigenvalue for factor 1 and factor 2 are 7.69 and 1.35 respectively in pre monsoon whereas 5.47, 2.14 and 2.00 for factor 1, 2 and 3 respectively in post monsoon season. Table 5 illustrate the Eigenvalues, percentage variance, cumulative percentage variance and component loading (unrotated and varimax rotated) of extracted factors of pre and post monsoon season respectively. Kaiser's varimax rotation was applied and factor loadings were classified as per absolute loading values of >0.75 as 'strong', 0.75-0.50 as 'moderate', 0.50-0.30 as 'weak' (Liu et al. 2003).

Factor I of PCA matrix illustrated by strong positive loading of Na^+, Cl^-, TDS, EC, SO_4^{2-}, K^+, Mg^{2+}, Ca^{2+} and F^- in near groundwater of landfill, which contribute 50.02% of the total variance in pre monsoon samples while 45.60 % of total variance in post monsoon season due to dilution of various ions with rainwater inflow (Table 5). High load of Ca^{2+} and SO_4^{2-} indicate probable reason of weathering (rock mineral) in the groundwater system as gypsum dominates around the study area (CGWB, 1995, Drever, 1997). The strong loading of Na^+ and K^+ may be due to natural weathering of rock minerals (mica) and different ion-exchange process in groundwater system near landfill (Drever, 1997, Srivastava and Ramanathan, 2008). The strong loading

Table 6. Extracted values of principal components of groundwater near the landfill during pre and post monsoon season

Parameters	Pre Monsoon		Post Monsoon		
	Component				
	1	2	1	2	3
EC	.86		.90		
TDS	.77		.79		
F^-	.62		.60		
NO_3^-		.82		.94	
Cl^-	.78	.53	.71		
Fe		.78		.66	
Na^+	.82		.82		
K^+	.90		.77		
NH_4^+		.61			.94
Ca^{2+}	.57	.59			.50
Mg^{2+}	.89		.82		
SO_4^{2-}	.91		.95		

of Cl^- with alkali earth metals (Ca^{2+} and Mg^{2+}) also indicates the anthropogenic inflow from leaching of leachate as there is no other natural source of chloride around the landfill site (Kumar and Alappat, 2005b). The spatial distribution of chloride near the landfill also shows the landfill as a point source of the contaminant. The strong loading of TDS and EC in the study area are mainly due to Na^+, K^+, Mg^{2+} and Ca^{2+} which plays an important role. The fluorite minerals present in the bedrock near study area may contribute towards the high load of fluoride as it is the major carrier of fluoride (Rama Rao 1982, Drever 1997). The high TDS in nearby groundwater increases the ionic strength and consequently leads to more solubility of fluorite (CaF_2) (Handa, 1975; Srivastava and Ramanathan,, 2008). It can also be due to weathering of primary rock (mica), ion-exchange process or leaching of landfill contaminants (Drever 1997; Sujatha 2003). Whereas, strong loading of Na^+, Cl^-, SO_4^{2-}, K^+, Ca^{2+}, and Mg^{2+} may indicate the anthropogenic inflow of pollutant from continuous leaching of landfill leachate in the groundwater system (Kumar and Alappat, 2005a).

Factor II characterized by strong loading of nitrate and moderate loading of iron in the groundwater which accounts for 25.38% of the variance in pre monsoon while 17.84% of the variance in post monsoon season. The strong nitrate loading indicates the source is anthropogenic as there is no other source of nitrate other than landfill site in the study area except few slums. It also indicates an anthropogenic inflow from municipal landfill leachate (Kumar and Alappat, 2005b), and may also be due to fertilizers from agricultural land (Mahlknecht et al., 2004). The high load of nitrate is mainly found in the nearby groundwater samples (GW 4) which indicate landfill as the only source of nitrate percolation in groundwater (Jalali, 2005). The strong loading of Fe and moderate loading of Cl^- with alkali metals shows an anthropogenic input, possibly percolated from industrial effluent dumped in a landfill site (Kumar and Alappat, 2005b).

Factor III of PCA factor matrix of groundwater is illustrated by the strong positive loading of NH_4^+ and moderate loading of Ca^{2+}, which contributes 16.73 % of the total variance in post monsoon season samples. The strong loading of ammonium indicates the anthropogenic source of contamination from leachate percolation and also probably from abattoir waste dumped in the landfill.

Correlation Coefficient Matrix

The correlation analysis is very helpful in bivariate method to understand the degree of relationship within two hydro geochemical parameters (Kumar et al., 2006). The value of correlation coefficient always lies between -1 to +1. The subsequent interpretation is done on the basis of correlation analysis results. A high correlation coefficient either positive or negative indicates the good relationship whereas zero indicates no relationship between two variables. Table 7 shows the correlation matrix of collected groundwater samples during pre and post monsoon.

Most of the parameters show a good correlation with EC for both pre and post monsoon season. A good correlation during pre and post monsoon season has been observed between EC- TDS (0.86-0.84), EC-TH (0.90-0.88), EC-Cl^- (0.82-0.74), EC-Na^+ (0.87-0.84), EC-K^+ (0.88-0.82), EC-Mg^{2+}(0.82-0.78) and EC-SO_4^{2-}(0.88-0.89). It indicates that these ions are contributing for high EC and it may be due to contamination from the landfill leachate (Rao, 2002). A strong positive correlation has been found between TDS-TH (0.97), Cl^- (0.91), Na^+ (0.85) and K^+ (0.80). Total hardness shows a strong correlation with Cl^- (0.92), Na^+ (0.88) and K^+ (0.79), which possibly indicates

Table 7. Correlation matrix of groundwater quality during pre and post-monsoon season

	pH	EC	TDS	TH	TA	F^-	NO_3^-	Cl^-	Fe^{2+}	Na^+	K^+	NH_4^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}
Pre-monsoon															
pH	1														
EC	-0.19	1.00													
TDS	-0.18	**0.86**	1.00												
TH	-0.21	**0.90**	**0.92**	1.00											
TA	-0.28	0.60	0.50	0.53	1.00										
F^-	-0.14	0.45	0.48	0.56	0.56	1.00									
NO_3^-	-0.19	0.37	0.39	0.44	0.11	0.12	1.00								
Cl^-	-0.26	**0.82**	**0.92**	**0.92**	0.61	0.60	0.44	1.00							
Fe^{2+}	0.09	0.49	0.64	0.61	0.26	0.40	**0.53**	**0.62**	1.00						
Na^+	-0.27	**0.87**	**0.84**	**0.88**	0.62	**0.66**	0.42	**0.93**	**0.61**	1.00					
K^+	-0.39	**0.88**	**0.81**	**0.80**	0.62	0.43	0.07	0.74	0.39	**0.77**	1.00				
NH_4^+	-0.38	0.46	0.55	0.45	0.48	0.20	0.25	0.59	0.46	0.60	0.46	1.00			
Ca^{2+}	-0.27	0.60	0.68	0.67	0.63	0.54	0.40	0.73	0.59	**0.80**	**0.60**	0.62	1.00		
Mg^{2+}	-0.27	**0.82**	**0.71**	**0.79**	0.55	0.43	0.16	0.73	0.31	**0.80**	**0.80**	0.30	0.61	1.00	
SO_4^{2-}	-0.18	**0.88**	**0.81**	**0.85**	**0.73**	0.69	0.27	**0.86**	0.46	**0.88**	**0.80**	0.37	**0.58**	0.80	1.00
Post-monsoon															
pH	1.00														
EC	-0.42	1.00													
TDS	-0.41	**0.84**	1.00												
TH	-0.47	**0.88**	**0.97**	1.00											
TA	-0.46	0.43	0.38	0.46	1.00										
F^-	-0.12	0.38	0.41	0.43	0.38	1.00									
NO_3^-	-0.20	0.34	0.35	0.38	0.00	0.03	1.00								
Cl^-	-0.45	**0.74**	**0.92**	**0.93**	0.44	0.42	0.46	1.00							
Fe^{2+}	-0.09	0.41	0.59	0.59	0.14	0.30	0.54	0.65	1.00						
Na^+	-0.41	**0.84**	**0.86**	**0.89**	0.51	**0.50**	0.42	**0.90**	**0.63**	1.00					
K^+	-0.53	**0.82**	0.81	**0.81**	0.43	0.37	0.06	0.69	0.41	**0.71**	1.00				
NH_4^+	-0.44	0.18	0.44	0.35	0.15	0.11	0.12	0.47	0.44	0.41	0.47	1.00			
Ca^{2+}	-0.14	0.44	0.59	0.61	0.54	0.44	0.42	0.66	0.55	**0.62**	**0.51**	0.48	1.00		
Mg^{2+}	-0.36	**0.78**	**0.72**	**0.80**	**0.71**	0.33	0.24	**0.73**	0.38	**0.85**	**0.65**	0.20	0.61	1.00	
SO_4^{2-}	-0.38	**0.89**	**0.79**	**0.85**	0.53	0.64	0.23	**0.76**	0.36	**0.88**	0.71	0.19	0.48	**0.77**	1.00

that the hardness of groundwater is mainly because of these pollutants. Sodium showed good correlation with Cl^-(0.93) possibly indicates inflow of pollutants into the groundwater through anthropogenic sources while the moderate correlation with iron (0.61) and fluoride (0.66) indicating pollutant inflow from landfill leaching (Kumar and Alappat, 2005a). Calcium shows moderate correlation with sulphate can be explained by the gypsum rich geology of study area and it is the major source of calcium. Whereas Ca^{2+} and Mg^{2+} show moderate correlation with sodium and potassium during post monsoon season may be because of ion-exchange process occurred in the groundwater aquifer system (Mahlknecht, 2004). A moderate correlation exists between nitrate and iron (0.53) which indicates some anthropogenic source. The Na^+ shows a strong correlation with Cl^- (0.90) indicates its anthropogenic source and it also shows the groundwater near Ghazipur landfill possibly of Na-Cl type (CPCB, 2000).

CONCLUSION

The Ghazipur landfill is one of the oldest among four landfill sites in the national capital which was saturated since 2004. The average 50 m height of mountain trash is a bare reminder of poor waste management and administrative apathy. The geology of the study area is underlain by younger alluvium which is more vulnerable to contamination through pollutants leaching. The statistical interpretation along with spatio-temporal variation of groundwater quality near study site indicates high groundwater contamination. This contamination is mainly contributed by the leaching of pollutants from the Ghazipur landfill. Most of the samples were found with a high concentration of EC, TDS, Cl^-, SO_4^{2-}, NO_3^-, Na^+, Fe indicates that these are due to leaching of pollutants from nearby landfill which is considered an anthropogenic source. The concentration of pollutant decreases with the distance along with groundwater flow direction towards the north, which indicates Ghazipur landfill as the point source of contamination. The statistical analysis along with graphical have also been applied among the whole dataset. The tempo-spatial variation in groundwater quality was analyzed using a multivariate statistical technique which shows consistent percolation of landfill pollutants into nearby groundwater aquifer. The chief factors affecting the groundwater quality during pre and post monsoon season was extracted with the help of Principal component analysis. It is evident from the results of PCA/FA that major groundwater pollutants emerge from salts group, minerals group, inorganic, and organic pollutants. This study shows that the groundwater chemistry of the aquifer system was influenced by the Ghazipur landfill. Thus, multivariate statistical techniques are helpful in the present study to clearly illustrate about ground water quality, major pollutant and its possible sources which could be very useful for regular monitoring strategies and effective management of groundwater resource to avoid the further deterioration. Some local residents have extracted the groundwater for domestic purposes which should be avoided at least from the close proximity area of the landfill site and alternative efforts should be made to supply clean water from other safer source. Further, more wells must be constructed at different depth and distance to investigate and monitor the groundwater quality regularly.

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