Environ Monit Assess (2018) 190: 46
https://doi.org/10.1007/s10661-017-6417-1

# Indexing method for assessment of pollution potential of leachate from non-engineered landfill sites and its effect on ground water quality

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Received: 19 May 2017 / Accepted: 12 December 2017 / Published online: 26 December 2017

**Abstract** Dumping of solid waste in a non-engineered landfill site often leads to contamination of ground water due to leachate percolation into ground water. The present paper assesses the pollution potential of leachate generated from three non-engineered landfill sites located in the Tricity region (one each in cities of Chandigarh, Mohali and Panchkula) of Northern India and its possible effects of contamination of groundwater. Analysis of physico-chemical properties of leachate from all the three landfill sites and the surrounding groundwater samples from five different downwind distances from each of the landfill sites were collected and tested to determine the leachate pollution index (LPI) and the water quality index (WQI). The Leachate Pollution Index values of 26.1, 27 and 27.8 respectively for landfill sites of Chandigarh (CHD), Mohali (MOH) and Panchkula (PKL) cities showed that the leachate generated are contaminated. The average pH values of the leachate samples over the sampling period (9.2 for CHD, 8.97 for MOH and 8.9 for PKL) show an alkaline nature indicating that all the three landfill sites could be classified as mature to old stage. The WQI calculated over the different downwind distances from the contamination sites showed that the quality of the groundwater improved with an increase in the downwind distance. Principal component analysis (PCA) carried out established major components mainly from natural and anthropogenic sources with cumulative variance of 88% for Chandigarh, 87.1% for Mohali and 87.8% for Panchkula. Hierarchical cluster analysis (HCA) identifies three distinct cluster types for the groundwater samples. These clusters corresponds to a relatively low pollution, moderate pollution and high pollution regions. It is suggested that all the three non-engineered landfill sites be converted to engineered landfill sites to prevent groundwater contamination and also new sites be considered for construction of these engineered landfill sites as the present dumpsites are nearing the end of their lifespan capacity.

**Keywords** Leachate pollution index · Water quality index · Principal component analysis · Hierarchical cluster analysis

## Introduction

With rapid urbanization and globalization coupled with large population in India there has been rapid change in consumer patterns in India leading massive quantities of generation of Municipal Solid Waste (MSW) (Longe and Balogun 2010; Kolekar et al. 2016). Presently, India generates about 1,43,449 Metric Tons per day (MTPD) of MSW (Rathod et al. 2013; Ashwani and Abhay 2014) with per capita generation rates varying from 0.2 to 0.7 kg/capita/day depending upon generation from rural or urban areas (De et al. 2016; Ahsan et al. 2014). In India, the MSW consists of primarily 40–50% of organics and about 30–50% of inert materials

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(Abd EI-Salam and Abu-Zuid 2015; Jhamnani and Singh et al. 2009; Kale et al. 2010). In cities, the entire management of MSW (collection, transportation, treatment and disposal) comes under the purview of the municipal corporation of the city (Mor et al. 2006). One of the significant difficulties experienced by these municipal corporations is improper treatment and disposal of such voluminous quantities of waste often due to lack of proper infrastructure for treatment purposes and shortage of barren land for disposal purposes (Nagarajan et al. 2012; Shivasharanappa and Huggi 2011).

Land filling of municipal solid waste is considered most economical and viable practice for waste management in many parts of world (Akinbile et al. 2012; Cumar and Nagaraja, 2011). In India, dumping of MSW on non-engineered land fill sites (or open dumpsites) accounts for more than 90% of disposal conditions (Odunlami 2012; Saarela 2003). Even though, treatment processes like segregation, recycling, composting and incineration processes are often used, direct disposal on the landfill sites remain the most preferred way for disposal of solid waste (Talalaj and Biedka 2016). Further, environmental inequality studies show that such waste facilities are often disproportionally located in the most deprived regions or locations where minority groups reside (Forastiere et al. 2011; Ahsan et al. 2014), leading to the unequal pollutant exposure. Unscientific dumping of solid wastes leads to several associated environmental hazards like air, soil and groundwater pollution causing adverse public health impacts (Kalra et al. 2012; Raman et al. 2008; Ranjan et al. 2013). In particular, contamination of groundwater by leachate generated from unlined landfill sites is highly predominant and is most prevalent in developing countries due to disposal of MSW in open landfills (Ahsan et al. 2014; Rafizul et al. 2011, b; Kumar et al. 2002).

The MSW generated in Asian countries including India consists of high fraction of organics and due to tropical climate they get dissolved in rainwater or in runoff generating leachate which depending on soil permeability can cause groundwater contamination (Akinbile et al. 2012; Rafizul et al. 2011c). Leachate consists of cocktail of harmful pollutants including organic (COD, BOD, ammonia compounds), inorganic (calcium, magnesium, iron, chloride, sulfates etc.) carcinogens like heavy metals (cadmium, chromium, zinc, nickel, lead copper) and recalcitrants making it a potential source of pollution (Bhalla et al. 2012, 2014a, b; Eshanthini and Padmini 2015).Characteristic properties of leachate vary, depending on the actual composition of the MSW, precipitation, site hydrology, interaction of leachate with environment, landfill design and operation procedures (Reinhart and Grosh 1998; Singh et al. 2012; Singh et al. 2016). Further, leachate composition is highly influenced by the age of the landfill and degree of waste stabilization (Halim et al. 2010). Contamination of groundwater by leachate is a serious environmental hazard and can stay undetected for long periods (Singh et al. 2016; Talalaj 2014) thereby making it unsuitable for drinking or other miscellaneous purposes (Cumar and Nagaraja, 2011). Hence, extensive research work has been carried out to study the effects of groundwater contamination by leachate (Yadav et al. 2014; Yogendra and Puttaiah 2008).

Characteristics of leachate generated from landfill are highly dependent on the age of the landfill site. In initial phase of the landfill (<5 years), the pH of the leachate varies from 4 to 6.5 primarily due to formation of carboxylic acid (Singh et al. 2008a, b; De et al. 2016). Leachate generated from landfill sites over a long duration is alkaline in nature with pH values in between 8 to 8.5 (Umar et al. 2010). In this context, Leachate Pollution Index (LPI) are often used to classify the toxicity potential of the leachate thereby giving an immediate assessment regarding remedial measures to be carried out at the landfill site (Bhalla et al. 2014a, b; Umar et al. 2010). LPI determines the leachate contamination potential of landfills (closed as well as active) on a comparative scale using an index known as LPI. Once the leachate characteristics from a particular landfill site have been determined, the LPI can be calculated by using weighted linear additive form (Kumar and Alappat, 2004, 2005). Applications of LPI include ranking of landfill sites, resource allocation for landfill remediation, trend analysis, enforcements of standards, scientific research and public information (Kumar and Alappat, 2004, 2009; Bhalla et al. 2014a, b). The LPI index is based on assigning a single number ranging from 5 to 100 (Kumar and Alappat, 2004, 2005, 2009; Umar et al. 2010; De et al. 2016) like a grade which expresses the overall contamination due to leachate. Higher the value of the LPI greater is the toxicity and contamination potential of the leachate.

In the above context, contamination of groundwater from leachate is a potential environmental problem and needs to be addressed. Hence, different methods have been evaluated to monitor the groundwater quality index around municipal solid waste dumping sites (Swamee and Tyagi, 2007; Ilaboya et al. 2014; Liou et al. 2004). The quality of the ground water can be studied scientifically if an accurate estimate of water quality is available in form of an index (Singh et al. 2008a, b; Tyagi et al. 2013). Water quality index (WQI) is one of the simplest and widely used methods to evaluate the quality of groundwater. There exists number of different indexing methods to evaluate the groundwater quality aggregate index such as National Sanitation Foundation Water Quality Index (NSFWQI), Stream Health Index (SHI), Oregon Water Quality Index (OWQI), Bureau of Indian Standards (BIS) 10,500 weighted WQI and sustainable information network (Swamee and Tyagi 2007; Ramakrishnaiah et al. 2009; Tyagi et al. 2013). The quality of ground water depends upon the categorization of the index values achieved. Higher the groundwater quality index value better is the assessment of the groundwater.

The main objectives of the study reported in the paper were the determination of LPI and WQI calculated over a period of three seasons for determining the impact of leachate percolation on the groundwater quality around the municipal solid waste disposal sites of Tricity of Chandigarh, Mohali and Panchkula. Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were also carried out to understand the interrelationships of the results obtained.

## Site location

Chandigarh has a population of 1.05 million as per 2011 census with a growth rate of 17% in the decade (2001–2010) covering an area of 114 Km$^2$. The entire management of solid waste is taken care by Chandigarh Municipal Corporation with a collection efficiency of 70% from households under the purview of Chandigarh Municipal Corporation and about 20% from the slums.

Mohali has a population of 9, 86,147 in 2011 with an area of 1160 Km$^2$. Mohali Municipal Corporation are responsible for management of solid waste in city. The collection efficiency of the MSW generated in the Mohali is similar to collection efficiency as observed in Chandigarh.

Panchkula covers an area of 816 Km$^2$ having a population of 5, 61,293 in 2011, as per the latest Indian census report (Rana et al. 2015; Census 2011). Panchkula Municipal Corporation is looking after the entire management of solid waste with collection efficiency similar to Chandigarh and Mohali cities.

The total MSW generated from the Tricity is about 680 TPD (380 TPD in Chandigarh, 150 TPD in Mohali and 150 TPD in Panchkula) (Rana et al. 2015).The MSW is disposed of in open dump sites located in each of the city leading to possible contamination of groundwater and thereby potential health hazards. Figure 1 shows the map of Tricity along with the location of the open dumpsites.

## Material and methods

### Leachate sampling and analysis

To determine leachate characteristics and pollution potential of the municipal solid waste dumping sites at Chandigarh, Mohali and Panchkula, a monitoring campaign for collection of leachate samples from the dumping sites was carried out in the months of May–June, 2015 (S1); September–October, 2015 (S2) and February–March, 2016 (S3). The leachate samples were collected from three different points within all three municipal solid waste dumping sites in glass and plastic bottles cleaned and pre-soaked in 1 M nitric acid ($HNO_3$) for 24 h and samples were later mixed thoroughly to make a representative sample as reported in various studies (Mor et al. 2006; Eshanthini and Padmini 2015). The samples for heavy metal analysis were preserved by adding few drops of concentrated $H_2SO_4$ in the glass bottles (APHA 2012). A total of twenty seven samples ($n = 9$ for each dumping site) of leachate were collected from each of the three municipal solid waste disposal sites for the three sampling period and were analyzed. Samples were collected in plastic bottles (thoroughly cleaned) and glass bottles (autoclaved to remove any contamination).The collected leachate samples were transported to laboratory and stored in refrigerator at 4 °C temperature till complete analysis.

The representative leachate samples were analyzed for various physico-chemical, biological and heavy metals including measurement of important parameters like pH, Total dissolved solids (TDS), Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Total kjeldahl nitrogen (TKN), Ammonical nitrogen ($NH_3$-N), heavy metals (iron, copper, nickel, zinc, lead and chromium) chlorides, cyanides and

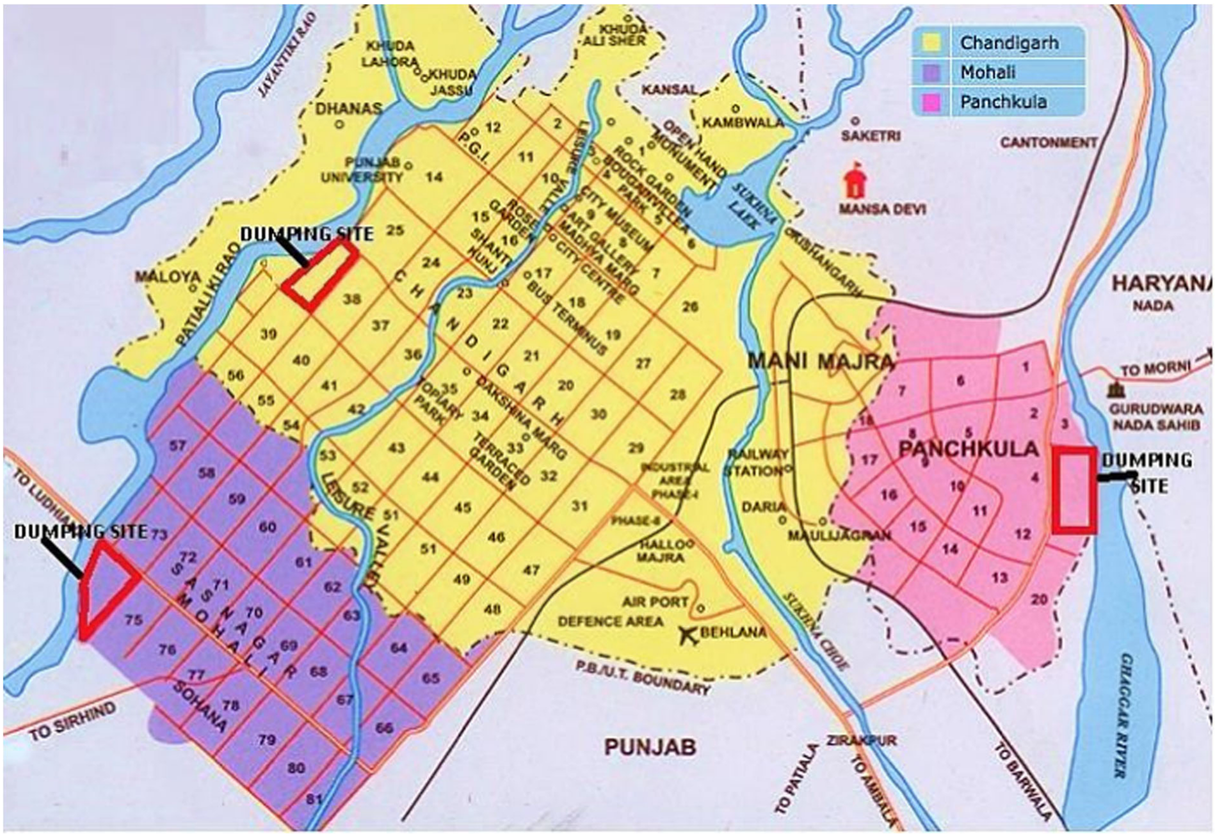

Fig. 1 Shows the map of Tricity along with the location of the open dumpsites

Total coliform bacteria (TCB) (APHA 2012). Though other important parameters like phenolic compounds were also analyzed for the leachate samples, only those values have been reported here which are used for determination of Leachate pollution Index and the results of remaining parameters have been scoped out. Standard analytical procedures were utilized for determining the results. For example, heavy metals were analyzed using Atomic Absorption Spectrophotometer (AAS). COD was determined using the open reflux method as it is more suitable for wide ranges of waste and gives more accurate values (APHA 2012). The pH and TDS concentrations were determined using conductivity meter.

## Groundwater sampling and analysis

To determine possible groundwater contamination due to percolation of leachate into the aquifers, groundwater samples were collected from the vicinity of the three disposal sites of Chandigarh, Mohali and Panchkula during the same monitoring campaign as described in the previous section. The groundwater samples were collected from the hand pumps and other nearby submersibles close to the solid waste dumping sites at different downstream locations (1Km, 2Km, 2.5 Km, 3Km, 4Km and 5Km) from the municipal solid waste dumping sites. Figure 2 shows the sketch of the studied area with groundwater sampling points. A total of fifty four samples ($n = 3$ for each site) were utilized for the study purposes during all the three sampling periods. Groundwater samples were analyzed for various selected parameters like pH, total solids, ammonical nitrogen, phosphate, turbidity, biochemical oxygen demand (BOD), sulfate, total hardness (TH), calcium, magnesium, total alkalinity, nitrates, chlorides, fluorides and electrical conductivity (EC). Groundwater samples were stored in plastic and glass bottles which were thoroughly cleaned and autoclaved to remove any contamination as per standard procedure (APHA 2012). Water was

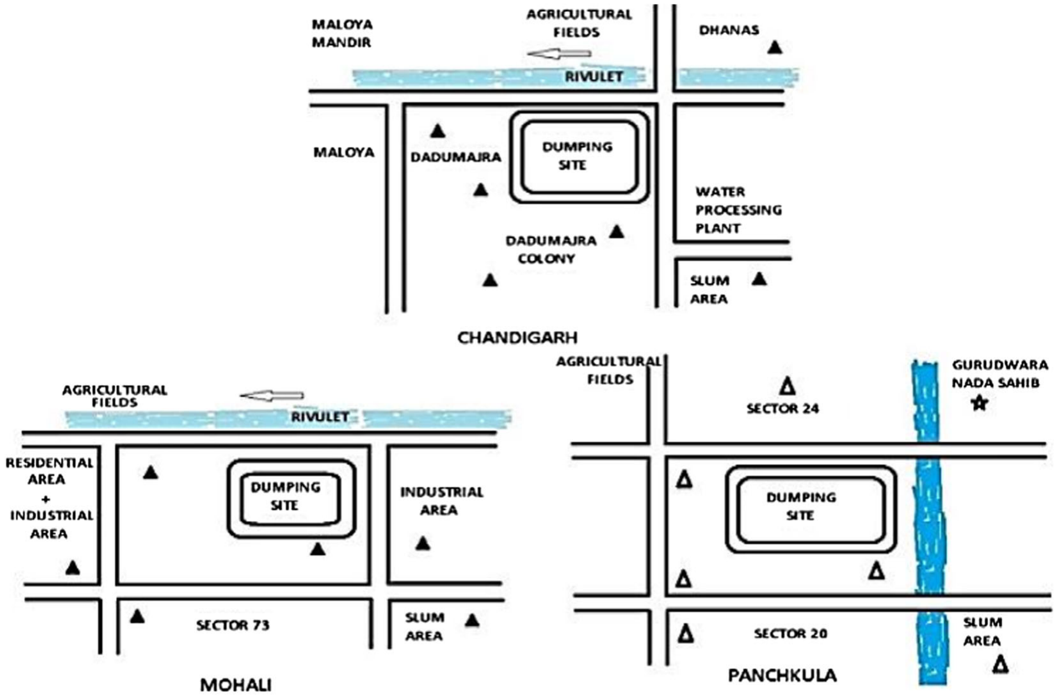

**Fig. 2** Shows the sketch of the studied area with groundwater sampling points

pumped out initially for 2–3 min and sample bottles were rinsed and filled with water. The collected samples were transported to laboratory and stored in refrigerator at 4 °C temperature as per standard procedure (APHA 2012).

## Leachate pollution index (LPI)

The pollution potential of leachate is generally given by an index formulated using Rand Corporation Delphi Technique (Kumar and Alappat, 2004). Delphi method is an organized communication technique which enables the formation of a group judgment (Yadav et al. 2014). LPI signifies the level of pollution concentration of a landfill. The indexing method leads to computation of a single value which varies from **5** (*best value*) to **100** (*worst value*), which expresses the overall pollution potential due to leachate contamination in form of an increasing scale index wherein higher values indicate higher levels of pollution leading to environmental degradation (Bhalla et al. 2014a, b; Kumar and Alappat, 2004). With the help of LPI index, landfills can be ranked as per leachate contamination potential (Kumar and Alappat, 2004). A total of 18 variables are generally utilized for calculation of LPI (Kumar and Alappat, 2004). These variables include pH, TDS, BOD, COD, TKN, Ammonia nitrogen, Total iron, Copper, Nickel, Zinc, Lead, Chromium, Mercury, Arsenic, phenolic compounds, Chlorides, Cyanide and Total coliform bacteria. All the 18 parameters were assigned particular weights based on the significance level of individual pollutants as per study previously undertaken (Kumar and Alappat, 2004; Umar et al. 2010). The averaged sub-index ($p_i$) curves for all the pollutants were drawn to establish the relation between the leachate pollution and concentration of the parameter (Kumar and Alappat, 2004, 2009; Bhalla et al. 2014a, b). The various possible aggregation functions were evaluated by (Kumar and Alappat, 2004; De et al. 2016) to select best possible aggregation function. The LPI is calculated using the equation:

$$LPI = \sum_{i=1}^{n} wipi \qquad (1)$$

Where: LPI = the weighted additive leachate pollution index,

$w_i$ the weight for the $i^{th}$ pollutant variable,
$p_i$ the sub-index value of the $i^{th}$ leachate pollutant variable,

n number of leachate pollutant variables used in calculating LPI

$$\sum_{i=1}^{n} wi = 1 \quad (2)$$

If the data for all the leachate pollutant variables is not available then LPI can be calculated using the following equation:

$$LPI = \sum_{i=1}^{m} wipi \div \sum wi \quad (3)$$

Where: m = number of leachate pollutant variables when data is available ($m < 18, \sum wi < 1$).

## Water quality index (WQI)

Water quality index (WQI) is a method of rating of existing water quality status in a single expression which is helpful for selection of treatment techniques (Swami and Tyagi 2000, 2007; Ilaboya et al. 2014). WQI utilizes the water quality data and helps in modification of the policies formulated by the environmental agencies (Tyagi et al. 2013). It represents the assessment of water quality through determination of physico-chemical and biological parameters of ground water (Kalra et al. 2012). WQI was initially developed by Horton (Horton, 1965; Rafizul et al. 2011, 2011c) and after that concept has been modified by many scientists and researchers (Ramakrishnaiah et al. 2009; Rafizul et al. 2011, 2011c; Tyagi et al. 2013). A general approach for determination of WQI includes parameter selection wherein these parameters are selected based upon their impact on water quality. Once the parameters are fixed, determination of sub-indices of these parameters are quantified which are finally aggregated using an aggregate indexing method by means of different mathematical expressions (Tyagi et al. 2013; Swami and Tyagi 2000). The different variables and the sub-indices used for different parameters were taken from reference tables (Swami and Tyagi 2000; 2007).

For the considered different parameters, variations of sub-indices are generally assumed as uniformly decreasing

$$s = \left(1 + \frac{q}{qc}\right)^{-m} \quad (4)$$

Where.

q quality variable;
$q_c$ characteristic value of q;
m a positive number

and

### Unimodal

$$s = pr + (n+p)(1-r)\left(\frac{q}{q*}\right)^{n} \div p + n(1-r)\left(\frac{q}{q*}\right)^{n+p} \quad (5)$$

Where.

r sub-index for q = 0;
n and p exponents

Different methods for determination of WQI have been formulated including those proposed by National Sanitation Foundation Water Quality Index (NSFWQI), Weight Arithmetic Water Quality Index (WAWQI), Oregon Water Quality Index (OWQI), WQI as per BIS 10500, Canadian Council of Ministers of the Environment Water Quality Index, Stream Health Index (SHI) and Sustainable Information Network, 2005 (Aravind et al. 2015). Aggregating index method is used for identifying effects of municipal solid waste leachate on ground water quality and (Swami and Tyagi 2000, 2007; Bhalla et al. 2013) provides most reliable results for indexing.

In the study, WQI is determined using two methods viz., Oregon water quality index (OWQI) and BIS 10500 standards. Both Oregon water quality index and WQI as per BIS 10500 creates a score which helps to evaluate the water quality by combining the various water quality variables into a single number hence making it easier to categorize the water quality parameters (Cude 2001; Tyagi et al. 2013). The mathematical expression of the WQI method as per OQWI is given by:

$$WQI = \sqrt{\frac{n}{\sum_{i=1}^{n} \frac{1}{SI2}}} \quad (6)$$

The water quality rating evaluated by Oregon water quality index is given in Table 1.

Determination of WQI as based on the BIS 10500 standards, was determined by assigning weights ($w_i$) according to the relative importance of each chemical parameter for drinking purposes and has been summarized in Table 2 (Singh et al. 2016). The parameters like chloride, nitrate, total solids, ammonical nitrogen, sulfate, fluorides and electrical conductivity has been assigned maximum weightage of 5 because of their high

Table 1 Water quality rating as per OWQI

| WQI Value | Rating of water quality |
|---|---|
| 90–100 | Excellent water quality |
| 85–89 | Good water quality |
| 80–84 | Fair water quality |
| 60–79 | Poor water quality |
| 0–59 | Very poor water quality |

significance in maintaining quality of ground water (Singh et al. 2016). Other determined parameters like calcium, magnesium, total hardness and total alkalinity were assigned weight between 1 and 5 depending on their importance in water quality assessment. The relative weight ($W_i$) is computed (Table 2) using following equation:

$$W\,i = \frac{wi}{\sum_{i=1}^{n} wi} \tag{7}$$

Where; $W_i$ = relative weight.

$w_i$ = weight of each parameter, n = number of parameters.

Table 2 Relative weight of chemical parameters for calculating WQI based on BIS 10500 for Tricity

| Chemical Parameters | BIS (mg/l) | Weight ($w_i$) | Relative weight ($W_i$) |
|---|---|---|---|
| TSS | 500 | 5 | 0.1 |
| $NH_3$-N | 0.5 | 5 | 0.1 |
| $SO_4^{2-}$ | 200 | 5 | 0.1 |
| TH | 300 | 4 | 0.08 |
| $Ca2^+$ | 75 | 4 | 0.08 |
| $Mag^{2+}$ | 30 | 3 | 0.06 |
| TA | 200 | 4 | 0.08 |
| $NO_3^{2-}$ | 45 | 5 | 0.1 |
| $Cl^-$ | 250 | 5 | 0.1 |
| EC | 300 | 5 | 0.1 |
| $F^-$ | 1 | 5 | 0.1 |
| | | $w_i = 50$ | $W_i = 1$ |

A quality index ($q_i$) based on the parameters were computed by dividing the concentration of each water sample by its respective standard as assigned by BIS 10500 and multiplying the result by 100:

$$qi = \frac{Ci}{Si} \times 100 \tag{8}$$

Where; $q_i$ = quality rating based on concentration of the $i^{th}$ parameter.

$C_i$ = concentration of each parameter (mg/l), $S_i$ = Indian drinking water standard.

For computing WQI, SI is first determined for each parameter:

SI=$W_i \times q_i$ (9).

Where; SI = sub-index of the $i^{th}$ parameter.

WQI is then determined using following equation:

$$WQI = \sum SI \tag{10}$$

As per the BIS 10500, the water quality index values, the water can be classified into five categories i.e., excellent water (<50); good water (50–100); poor water (100–200); very poor water (200–300); and water unsuitable for drinking purposes (>300).

## Multivariate statistical analysis

Multivariate statistical analysis are often used in environmental monitoring or modeling dataset applications for reducing dimensionality and biasness that will be helpful for the asessment of the data. These statistical tools help in classification, modeling and interpretation of large data sets and allows the reduction of data in the form of extraction of data which will be helpful for the water quality assessment (Gibrilla et al. 2011; Singh et al. 2016). It further helps in understanding huge data sets from environmental monitoring programs giving more quantitative and independent approach of ground water samples by making correlations between chemical parameters and ground water samples (Guler et al. 2002; Manikandan et al. 2014). Multivariate analysis provides unbiased methods to detect the associations between the samples or variables using standardized data. In this study, two multivariate statistical methods were applied viz., Principal component analysis (PCA) and Hierarchical cluster analysis (HCA) using IBM-SPSS statistics V 22.0. Such associations (PCA and HCA) among physico-chemical variables, based on similar magnitudes and variations in chemical and physical compositions may reveal the various effects on ground water (Manikandan et al. 2014; Singh et al. 2016).

Fifteen parameters include pH, total solids, ammonical nitrogen, phosphate, turbidity, biochemical oxygen demand (BOD), sulfate, total hardness (TH), calcium, magnesium, total alkalinity, nitrates, chlorides, fluorides and electrical conductivity (EC). PCA and HCA have been broadly used as they are unbiased methods which can indicate natural associations between samples or variables (Singh et al. 2016; Singh et al. 2008a, b).

### Principal components analysis (PCA)

The principal component analysis (PCA) is a procedure which identify the small variables from a large set of data which are called 'principal components' for analyzing relationships among the observed variables (Singh et al. 2004; 2008a, b). This analysis helps in explaining the maximum amount of variance. It helps in identification of source of pollutants (Gibrilla et al. 2011) and also used to reduce the data (Guler et al. 2002; Manikandan et al. 2014).

### Hierarchical cluster analysis (HCA)

Hierarchical cluster analysis (HCA) is the most common and widely used multivariate statistical analysis method in environmental studies (Singh et al. 2016) as it indicates groupings of samples by ranking or linking inter-sample similarities in data set, creating a cluster tree or dendogram (Diaz et al. 2002). This clustering helps in deciding the level or scale of clustering that is most appropriate for the particular study. Unlike PCA that normally uses only two or three components for display purposes, HCA uses all the information contained in the original data set.

## Results and discussions

### Leachate characteristics

The physical, chemical and biological characteristic of the leachate samples collected during all the three samplings from the dumping sites of Chandigarh, Mohali and Panchkula are summarized in Table 3. The concentrations of tested parameters including pH, TDS, COD, BOD, chlorides, $NH_3$-N, Cu and Ni exceeded the permissible limits for all the three dumpsites for the entire

**Table 3** Leachate Characteristics of the monitoring campaign carried out at different dumpsites

| Parameters | Chandigarh | | | Mohali | | | Panchkula | | | Standards for Disposal | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S1 | S2 | S3 | S1 | S2 | S3 | S1 | S2 | S3 | Inland surface water | Public sewers | Land disposal |
| pH | 9.6 | 9.1 | 9.0 | 8.9 | 9.0 | 9.0 | 8.6 | 9.1 | 9.0 | **5.5–9.0** | **5.5–9.0** | **5.5–9.0** |
| TDS | 3590 | 3669 | 3669 | 3161 | 3280 | 3290 | 3048 | 3100 | 3100 | **2100** | **2100** | **2100** |
| BOD | 360 | 420 | 425 | 470 | 490 | 510 | 310 | 360 | 370 | **30** | **350** | **100** |
| COD | 19,930 | 19,950 | 19,961 | 17,323 | 17,940 | 17,968 | 18,208 | 19,910 | 19,920 | **250** | – | – |
| $NH_3$-N | 1150 | 1200 | 1210 | 1190 | 1239 | 1328 | 1010 | 1022 | 1030 | **50** | **50** | – |
| Total Fe | 11.2 | 12.2 | 12.1 | 7.72 | 7.80 | 7.95 | 8.83 | 8.89 | 8.88 | – | – | – |
| Cu | 3.72 | 3.80 | 3.66 | 3.32 | 4.90 | 4.85 | 2.23 | 2.40 | 2.40 | **3.0** | **3.0** | – |
| Ni | 0.98 | 0.98 | 0.96 | 0.77 | 0.99 | 0.99 | 0.87 | 0.87 | 0.88 | **3.0** | **3.0** | – |
| Zn | 10.41 | 11.60 | 12.2 | 8.4 | 8.6 | 8.7 | 8.39 | 8.41 | 8.60 | **5.0** | **15** | – |
| Pb | 0.64 | 0.66 | 0.70 | 0.07 | 0.07 | 0.08 | 0.11 | 0.19 | 0.20 | **0.1** | **1.0** | – |
| Cr | 0.14 | 0.16 | 0.20 | 2.47 | 3.20 | 3.20 | 0.75 | 0.89 | 0.90 | – | – | – |
| $Cl^-$ | 2136 | 2230 | 2320 | 1659 | 1780 | 1786 | 2012 | 2100 | 2122 | **1000** | **1000** | **600** |
| TCB | $8 \times 10^7$ | $8 \times 10^7$ | $10 \times 10^7$ | $7 \times 10^7$ | $8 \times 10^7$ | $7 \times 10^6$ | $9 \times 10^6$ | $9 \times 10^7$ | $9 \times 10^6$ | – | – | – |

Note: All parameter units are in mg/l except pH and TCB. Bold value indicates the permissible limits for disposal monitoring campaign as specified by the Municipal Solid Waste Management and Handling Rules, 2016 (MoEF Gazette of India 2016) for discharge of leachate samples in inland surface waters, public sewers and land disposal.

Landfill sites are often classified on the basis of the pH of the leachate generated from such sites. Reported literature mentions that the variation of pH from leachate generated from landfill ranges from 4.5 to 9 (Yadav et al. 2014; Umar et al. 2010) with younger landfills being classified as having pH of leachate generated from them less than 6.5 while a matured landfill has a pH greater than 7.5 (Bhalla et al. 2012, 2014a, b; Rathod et al. 2013). This is primarily because in the initial stages of the landfill the leachate generated has an increased concentration of Volatile Fatty Acids (VFA) resulting lower pH values of about ≤6.5 while in older landfill sites these VFA are converted to methane and carbon dioxide thereby resulting in a more alkaline nature of the leachate characteristics (pH > 7.5) (Talalaj and Biedka 2016). For our study locations, the average pH of the leachate samples from all the three dumping sites over the entire monitoring campaign varied from 9.2 for Chandigarh and 8.9 for Mohali and Panchkula indicating highly alkaline nature and that all the three dumping sites were in methanogenic phase and can be classified as '*old or matured*' landfill sites.

For our study, it was observed that TDS varied in the ranges of 3590 to 3669 mg/L for samples from Chandigarh dumping site, 3161–3290 mg/L for Mohali leachate samples and 3048 to 3100 mg/L for Panchkula leachate samples. TDS comprises mainly inorganic salts and dissolved organics (Umar et al. 2010). The high values of TDS in all the three dumping sites leachate samples are attributed to the leaching of the ions from the dump site (Umar et al. 2010; Rafizul et al. 2011, 2011c). The increase in TDS value increases salinity and thereby increases toxicity by hampering the characteristic composition of water (Ahsan et al. 2014; Bhalla et al. 2012). TDS is one of the parameters taken into account for licensing discharge of landfill leachate in many countries such as U.K. (Umar et al. 2010).

For our study, the COD varied in the range of 19,930 to 19,961 mg/L for Chandigarh, 17,323 to 17,968 mg/L for Mohali and 18,208–19,920 mg/L for Panchkula leachate samples over the entire monitoring campaign. Similarly, the BOD values were within the ranges of 360 to 425 mg/L for Chandigarh, 470 to 510 mg/L for Mohali and 310 to 370 mg/L for Panchkula over the same monitoring campaign. The results show that BOD/COD values were less than 0.1 for all the samples from the three dumpsites over the monitoring campaign. This signifies that almost negligible fractions of organic matter are present in the leachate. This is primarily because the organic fraction of the MSW gets decomposed being converted to biogas (methane and carbon dioxide). During methanogenic phase, the organic strength of the leachate is reduced by methanogenic bacteria such as methanogenic archaea and concentration of VFAs also declines which results in a ratio of BOD/COD less than 0.1 (Umar et al. 2010; De et al. 2016).

The concentration of $NH_3$-N in all the three dumping sites was high ranging amidst 1150 to 1210 mg/L for Chandigarh, 1190 to 1328 mg/L for Mohali samples and 1010 to 1030 mg/L for Panchkula samples over the monitoring campaign. This is primarily due to decomposition of the organic waste releasing to production of biogas with a high fraction of ammonia gas (Mor et al. 2006; Halim et al. 2010). This also indicates that the landfill sites are nearing the end of their lifespan as they are already in the methanogenic phase as also corroborated from the pH results. High concentrations of chloride ion were also observed from all the three sites over the monitoring campaign. Chlorides act as a conservative pollutant as its reaction effects are often negligible (Jhamnani and Singh 2009; Ilaboya et al. 2014).

High concentrations of heavy metals were detected in the leachate samples, like copper which was primarily due to the dumping of toxic waste like metal scrap, batteries, toxic medicines, paints etc. The presence of lead, nickel and very low concentration of cadmium was also reported. Presence of heavy metals in the leachate samples is attributed to the unsegregated MSW in the dumping sites (Kale et al. 2010; Kolekar et al. 2016). Total iron found in the leachate samples from all the landfill sites was also high and were primarily due to the iron and steel based scrap parts being disposed off along with MSW. TCB is the major indicator of organic contamination of the water and wastewater quality. Very high concentrations of TCB were found in all the leachate samples from the three dumping sites. Similar results were obtained in a study conducted on three landfill sites in Malaysia (Umar et al. 2010), which showed presence of very high concentrations of TCB which resulted in high pollution ratings. The high average concentrations of major ions and heavy metals in the leachate depicted that these open dumping sites are a potential source of human and environmental hazards. Leachates produced

**Table 4** LPI of the leachate from Chandigarh, Mohali and Panchkula dumping site

| | LPI (S1) | LPI (S2) | LPI (S3) | Mean LPI |
|---|---|---|---|---|
| Chandigarh | 27.80 | 21.30 | 29.36 | **26.15** |
| Mohali | 25.78 | 27.38 | 27.90 | **27.02** |
| Panchkula | 25.83 | 28.87 | 28.95 | **27.88** |

Bold values denotes the mean LPI of the leachate samples collected over the three seasons

from these dumping sites are heterogeneous in nature due to a mixture of various harmful chemicals. The risk assessment of the leachate is a major environmental issue due to increased number of unscientific disposal sites and with the rising importance of protecting ground water.

## Leachate pollution index

The sub-index ($p_i$) value of the different parameters of the leachate samples for all the three sites were obtained from the sub-index curves based on their concentrations values as per the methodology described by Kumar and Alappat, 2005 to calculate LPI. The "p" values obtained were multiplied with the respective weights assigned to each parameter (Kumar and Alappat, 2005). The methodology for calculation of LPI has already been discussed in an earlier section. In the present study, out of 18, only 13 significant parameters were determined as data for all parameters was not available, LPI has been calculated on the basis of available data and thereby eq. (3) was used to determine the LPI. The LPI values of Chandigarh, Mohali and Panchkula dumping sites are reported in Table 4. LPI gives a mean value which enables to determine if the landfill requires immediate attention in terms remediation measures (Bhalla et al. 2014a, b; Rafizul et al. 2011).

The calculated LPI values obtained for Chandigarh, Mohali and Panchkula dumping sites were 26.15, 27.02 and 27.88 respectively and are shown in Fig. 3. These LPI values are much higher than the standard LPI value of the treated leachate disposal limit of 7.378 to inland surface water (Kumar and Alappat, 2005). Higher values of LPI signify that leachate produced from all these three dumping sites of Chandigarh, Mohali and Panchkula is highly contaminated and proper treatment techniques must be ensured before discharging the leachate. All the three dumping sites do not have any provision of base liners or leachate collection and treatment systems. LPI values indicates the contamination potential due to leachate produced from the landfill sites in the particular areas and act as an important tool for identifying and measuring the hazards caused due to percolation of the leachate in soil strata as well in aquifers.

## Groundwater characteristics

The physico-chemical and biological characteristics of the groundwater samples collected from Chandigarh, Mohali and Panchkula is described in Table 5. Obtained results were also compared to the WHO and BIS standards for drinking water quality. The average pH values for all the ground water samples from Chandigarh, Mohali and Panchkula at various distances were 7.7, 7.8 and 7.1 respectively. The pH values of samples observed are in near neutral range (WHO 2008; BIS 10500 2012). High value of pH in ground water samples can be owed to the landfill utilization for a long time approximately 25 years and generation of stabilized and matured leachate (Umar et al. 2010). Electrical conductivity ranges from 976 to 1861 µS/cm in Chandigarh, 466.6–593.6 µS/cm in Mohali and 566.7–713 µS/cm. High conductivity values in all the samples specify the substantial amount of dissolved ions due to contamination from the leachate (Mor et al. 2006; Manikandan et al. 2014). Total solids (TSS) are defined

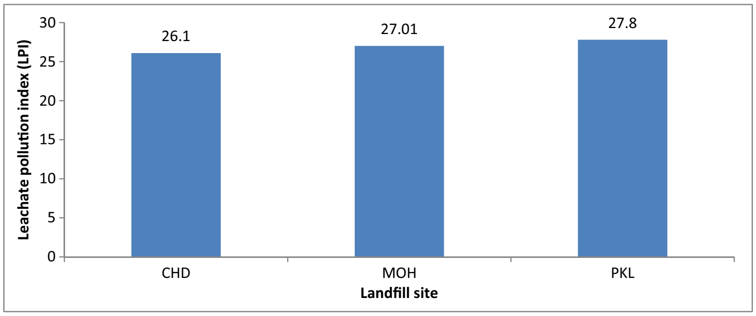

**Fig. 3** Leachate pollution index for three landfill sites

**Table 5** Ground water characteristics at different downstream distances for different seasonal campaigns for Tricity region

| Parameters | X- distance(Km) | Chandigarh | | | Mohali | | Panchkula | | | | Standards | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S1 | S2 | S3 | S1 | S2 | S3 | WHO | BIS |
| pH | 1 | 7.8 | 9.1 | 9.1 | 8.8 | 8.9 | 9.2 | 7.8 | 7.8 | 8.1 | - | **6.5–8.5** |
| | 2 | 7.6 | 8.2 | 8.3 | 8.4 | 8.3 | 8.3 | 7.6 | 7.6 | 7.7 | | |
| | 2.5 | 7.3 | 8 | 8 | 8 | 7.9 | 7.9 | 7.5 | 7.5 | 7.5 | | |
| | 3 | 7.1 | 7.9 | 7.96 | 7.9 | 7.7 | 7.2 | 7 | 7.2 | 7.3 | | |
| | 4 | 7.2 | 7.4 | 7.7 | 7.9 | 7.6 | 7 | 6.6 | 6.6 | 6.7 | | |
| | 5 | 6.8 | 7.2 | 7.1 | 7.6 | 6.6 | 6 | 6 | 6 | 6 | | |
| TSS | 1 | 643.2 | 680.1 | 687 | 783. | 788. | 789 | 582.4 | 590 | 592.1 | - | **500** |
| | 2 | 1191 | 1200 | 1200 | 626.7 | 642 | 650 | 577.6 | 531.2 | 530 | | |
| | 2.5 | 677.7 | 770.2 | 787 | 597.7 | 599 | 599 | 550 | 500 | 500 | | |
| | 3 | 597.7 | 600.9 | 632.1 | 550 | 562.7 | 568.1 | 491 | 489.2 | 460 | | |
| | 4 | 492.6 | 510 | 517 | 494 | 500 | 500 | 376 | 299.7 | 299 | | |
| | 5 | 482.6 | 550 | 555 | 492 | 521.9 | 530.1 | 330 | 249.6 | 236.1 | | |
| Ammonical Nitrogen ($NH_3$-**N)** | 1 | 1.36 | 1.4 | 1.41 | 0.77 | 0.96 | 1.22 | 1.68 | 0 | 0 | | **0.5** |
| | 2 | 0.96 | 0.98 | 0.99 | 0.13 | 0.27 | 0.9 | 0.78 | 0.79 | 0.8 | | |
| | 2.5 | 0.38 | 0.39 | 0.39 | 0 | 0 | 0 | 0.15 | 0.15 | 0 | | |
| | 3 | 0.21 | 0.3 | 0.31 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| | 4 | 0.2 | 0.22 | 0.27 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| | 5 | 0.1 | 0.19 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| Phosphate | 1 | 0.7 | 0.9 | 0.99 | 0 | 0 | 0 | 0.007 | 0.007 | 0.008 | | |
| | 2 | 0.06 | 0.09 | 0.09 | 0 | 0 | 0 | 0.006 | 0.99 | 0 | | |
| | 2.5 | 0.04 | 0.06 | 0.06 | 0 | 0 | 0 | 0.001 | 0.998 | 0 | | |
| | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| Turbidity | 1 | 10 | 10 | 9 | 9 | 10 | 10 | 10 | 10 | 10 | - | **1** |
| | 2 | 7 | 7 | 7 | 9 | 9 | 9 | 10 | 10 | 10 | | |
| | 2.5 | 6 | 7 | 8 | 8 | 9 | 10 | 9 | 9 | 9 | | |
| | 3 | 4 | 6 | 6 | 8 | 8 | 8 | 7 | 7 | 7 | | |
| | 4 | 2 | 4 | 5 | 7 | 8 | 8 | 7 | 8 | 8 | | |
| | 5 | 2 | 2 | 3 | 6 | 7 | 7 | 4 | 4 | 3 | | |
| Biochemical Oxygen Demand (BOD) | 1 | 530 | 610 | 620 | 535 | 600 | 600 | 520 | 580 | 600 | | **5** |
| | 2 | 410 | 440 | 440 | 410 | 440 | 470 | 505 | 550 | 590 | | |
| | 2.5 | 320 | 350 | 370 | 330 | 360 | 360 | 420 | 460 | 490 | | |
| | 3 | 290 | 310 | 360 | 310 | 330 | 350 | 310 | 390 | 390 | | |
| | 4 | 250 | 300 | 310 | 290 | 330 | 340 | 220 | 270 | 270 | | |
| | 5 | 240 | 290 | 320 | 210 | 280 | 300 | 210 | 220 | 230 | | |
| Sulfate | 1 | 75.19 | 87.2 | 89.1 | 52.9 | 57.3 | 64 | 35.6 | 46.2 | 59.9 | | **200** |
| | 2 | 75.17 | 80.15 | 87.5 | 52 | 54.1 | 61.6 | 35.1 | 44.7 | 59.1 | | |
| | 2.5 | 74.6 | 80.1 | 87.2 | 50 | 51.6 | 61 | 34.3 | 42.6 | 58.7 | | |
| | 3 | 74.2 | 75.5 | 82 | 46.9 | 50.09 | 59 | 32.7 | 39.9 | 48.1 | | |
| | 4 | 73.9 | 77.2 | 80.1 | 46.1 | 47.1 | 56.1 | 30.1 | 36.3 | 44.2 | | |
| | 5 | 73.1 | 76.4 | 79 | 40.2 | 41.3 | 50 | 30 | 33 | 43.9 | | |
| Total Hardness (TH) | 1 | 280 | 355 | 492 | 220 | 296 | 335 | 210 | 218 | 290 | - | **300** |
| | 2 | 260 | 335 | 340 | 215 | 290 | 320 | 208 | 210 | 265 | | |
| | 2.5 | 255 | 310 | 310 | 202 | 275 | 310 | 195 | 200 | 240 | | |
| | 3 | 235 | 275 | 300 | 195 | 200 | 300 | 160 | 182 | 232 | | |

**Table 5** (continued)

| Parameters | X- distance(Km) | Chandigarh | | | Mohali | | Panchkula | | | | Standards | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S1 | S2 | S3 | S1 | S2 | S3 | WHO | BIS |
| | 4 | 230 | 260 | 265 | 190 | 185 | 298 | 142 | 160 | 225 | | |
| | 5 | 210 | 225 | 240 | 190 | 180 | 272 | 115 | 145 | 200 | | |
| Calcium | 1 | 40.2 | 65.1 | 97.8 | 56.7 | 78.1 | 94.6 | 59.2 | 68.4 | 89.9 | | **75** |
| (Ca) | 2 | 37.3 | 60.2 | 95.1 | 52.1 | 72.4 | 92.1 | 56.5 | 66.5 | 89 | | |
| | 2.5 | 30 | 58.7 | 90 | 50 | 68.6 | 92 | 53.8 | 64.8 | 86.2 | | |
| | 3 | 28.5 | 58.1 | 84.6 | 50 | 50 | 88.3 | 53.6 | 62.9 | 84.3 | | |
| | 4 | 27.6 | 58 | 82.8 | 40.8 | 46 | 82.2 | 40.5 | 60.6 | 82.1 | | |
| | 5 | 27.4 | 58 | 80 | 36.6 | 41.8 | 82 | 36.6 | 56.5 | 80.9 | | |
| Magnesium | 1 | 83.1 | 88 | 95.5 | 82.1 | 94.6 | 96.1 | 77.6 | 86.1 | 89.8 | | **30** |
| (Mg) | 2 | 80.9 | 86.3 | 94.2 | 80.1 | 92.9 | 90.9 | 74.5 | 85.3 | 86.9 | | |
| | 2.5 | 75.6 | 83.9 | 93.8 | 80 | 91.1 | 88.6 | 72.9 | 82.6 | 86.3 | | |
| | 3 | 75 | 82 | 93.6 | 77.1 | 90 | 86.9 | 71 | 80.8 | 84.2 | | |
| | 4 | 72.8 | 80 | 92.1 | 74 | 86.3 | 84.1 | 67.5 | 77.7 | 83.6 | | |
| | 5 | 71.7 | 77.7 | 90.9 | 68.6 | 86.1 | 82 | 61.6 | 74.1 | 80.1 | | |
| Total Alkalinity | 1 | 484 | 492 | 524 | 388 | 428 | 464 | 312 | 365 | 396 | **-** | **200** |
| (TA) | 2 | 481 | 490 | 500 | 386 | 425 | 462 | 310 | 361 | 391 | | |
| | 2.5 | 390 | 485 | 486 | 380 | 418 | 455 | 290 | 350 | 382 | | |
| | 3 | 392 | 450 | 464 | 345 | 400 | 440 | 276 | 325 | 375 | | |
| | 4 | 390 | 410 | 443 | 332 | 395 | 425 | 252 | 308 | 370 | | |
| | 5 | 386 | 395 | 424 | 325 | 390 | 419 | 236 | 300 | 358 | | |
| Nitrates | 1 | 4.7 | 9.2 | 28.7 | 5.5 | 6.9 | 15.9 | 6 | 8.8 | 21.2 | **50** | **45** |
| | 2 | 3.2 | 9.2 | 20.1 | 5.1 | 6.6 | 15.8 | 5.4 | 7.6 | 21 | | |
| | 2.5 | 3 | 9.0 | 20 | 4.8 | 6.2 | 15.0 | 5 | 7.2 | 17.6 | | |
| | 3 | 2.9 | 8.6 | 17.1 | 4.6 | 6.0 | 14.2 | 4.9 | 7 | 17.1 | | |
| | 4 | 2 | 8.3 | 11.9 | 4.0 | 5.6 | 14.1 | 4.6 | 6.9 | 16.9 | | |
| | 5 | 1.8 | 8.0 | 10.9 | 3.9 | 5.2 | 11.3 | 4.2 | 6.8 | 16 | | |
| Chlorides | 1 | 86.1 | 93.2 | 114.2 | 88.9 | 101.7 | 111 | 79.8 | 88.4 | 95.4 | **250** | **250** |
| | 2 | 84.9 | 90.9 | 107 | 87.3 | 100 | 107.6 | 75.5 | 86.9 | 94.3 | | |
| | 2.5 | 83.2 | 90 | 98.9 | 86.9 | 99.1 | 101 | 73.1 | 83.6 | 93.8 | | |
| | 3 | 81.7 | 88.7 | 96.4 | 86.3 | 94.6 | 98 | 70.9 | 82 | 93.6 | | |
| | 4 | 80.9 | 86.9 | 93.6 | 83.1 | 93.2 | 95.6 | 69.6 | 81.7 | 93 | | |
| | 5 | 80 | 86.3 | 91.7 | 80.8 | 91.2 | 90.8 | 67.1 | 80 | 90.1 | | |
| Fluorides | 1 | 0.1 | 0.1 | 0.06 | 0.07 | 0.1 | 0.1 | 0.15 | 0.18 | 0.18 | **1.5** | **1.0** |
| | 2 | 0.01 | 0.07 | 0.07 | 0.01 | 0.0 | 0.1 | 0.1 | 0.10 | 0.9 | | |
| | 2.5 | 0.03 | 0.174 | 0.18 | 0.09 | 0.1 | 0 | 0.01 | 0.1 | 0.01 | | |
| | 3 | 0.03 | 0.13 | 0 | 0.01 | 0.1 | 0.1 | 0 | 0 | 0 | | |
| | 4 | 0.06 | 0.1 | 0.01 | 0 | 0.0 | 0 | 0 | 0 | 0 | | |
| | 5 | 0 | 0 | 0 | 0 | 0.01 | 0 | 0 | 0 | 0 | | |
| EC | 1 | 1005 | 1059 | 1861 | 498.2 | 562.2 | 597.7 | 582.4 | 624.9 | 720.1 | **-** | **300** |
| | 2 | 1000 | 1045 | 1840 | 493.8 | 558 | 597.1 | 580 | 619 | 713 | | |
| | 2.5 | 992 | 1040 | 1822 | 493.6 | 550 | 593.6 | 577.5 | 613.6 | 709.1 | | |
| | 3 | 981 | 1025 | 1812 | 477 | 547.6 | 592.1 | 575.2 | 609.1 | 700.6 | | |
| | 4 | 980 | 1000 | 1811 | 472 | 542.7 | 586 | 568.1 | 600 | 692 | | |
| | 5 | 976 | 1000 | 1802 | 466.6 | 540 | 580 | 566.7 | 598.3 | 686 | | |

Bold value indicates the permissible limits for groundwater as amount of inorganic and some part of organic materials which are present in water (WHO 2008; BIS 10500 2012). TSS aids in determining the salinity and general quality of water. Average concentration of TSS in all the samples from Chandigarh, Mohali and Panchkula were found to be 710 mmho/cm, 600 mmho/cm and 455 mmho/cm respectively. High TSS values were reported in almost all the samples of ground water from all the three cities. Very high and very low values of TSS are objectionable for drinking purposes (Raman and Narayanan, 2008; Eshanthini et al. 2015).

Biochemical oxygen demand (BOD) determines the amount of organic pollutants present in the water (Longe and Balogun 2010). BOD was reported in all the groundwater samples indicating the effect of percolation of leachate on the aquifer. Organic contamination due to leachate was indicated by the presence of ammonical nitrogen. Average values of ammonical nitrogen range from 0.241–0.57 mg/l and were reportedly higher in ground water samples from Chandigarh and Mohali.

Hardness of samples varies from 142 to 492 mg/l. Many samples of ground water from Chandigarh and Mohali areas shows that source water is 'Very Hard'; above 300 mg/L of $CaCO_3$ (WHO 2008; BIS 10500 2012). All other ground water samples are 'Moderately Hard'; lie between 75 and 150 mg/L of $CaCO_3$ (WHO 2008; BIS 10500 2012). The average total alkalinity from all the three areas ranges from 331 to 450 mg/l. Reported values of alkalinity are more than the desirable limit in all the samples. Highly alkalinity and hardness in water are the two main parameters which affect the palatability of water. Concentration of sulfate ranges from 73.1–89.1 mg/l for Chandigarh, 40.2–64 mg/l for Mohali and 30–59.9 mg/l for Panchkula which is much below than the WHO standard limit of 250 mg/l. High Sulfate concentration leads to biological corrosion and can cause dysentery in infants (Chidanand et al. 2013).

The samples reported very low concentration of nitrate ranging from 8.37–10.2 mg/l, high concentration indicates the impact of leachate and may lead to methaemoglobinemia. Values of chloride varies between 80 and 114.2 mg/l for Chandigarh, 80.8–111 mg/l for Mohali and 67.1–95.4 mg/l for Panchkula, high concentration of chlorides indicates the groundwater contamination due to the percolation of domestic effluents, septic tanks (Mor et al. 2006). The average fluoride concentration for all the three cities of Chandigarh, Mohali and Panchkula were found to be less than the standard permissible limits and ranges from not detectable (ND) to 0.096 mg/l.

The contamination of ground water samples in all the three cities of Chandigarh, Mohali and Panchkula is owed to the percolation due to leachate. Leachate percolation in the ground water can be a result of composition of leachate, rainfall, depth and distance from the source of pollution (Mor et al. 2006; Abd EI-Salam and Abu-Zuid 2015). Ground water samples collected in the study were collected from different distances from the dumping sites of Chandigarh, Mohali and Panchkula. Ground water samples collected from the close vicinity of dumping sites were found to be more contaminated than that of the farther away samples (>3 km). This can be attributed to the fact that the gravitational movement of viscous fluid like leachate is hindered due to mass of solid soil matter (Mor et al. 2006) and with increasing time leachate penetrates deeper and spread over long distances. The ground water quality improves with the increase in the distance of the sampling sites from the source of pollution i.e. dumping sites.

## Water quality index (WQI)

WQI is one of the most effective tools to provide feedback on the quality of water to the policy makers and environmentalists (Anilkumar et al. 2015; Ashwani and Abhay 2014) by giving a single value. In the present study WQI is calculated using two methods viz., OWQI and WQI determined on the BIS 10500 standards and values for all the three cities of Chandigarh, Mohali and Panchkula respectively were calculated using eq. (6) for OWQI and eq. (10) for standards for drinking purposes as recommended by BIS 10500. The values of WQI and the classification as per OWQI obtained for Chandigarh, Mohali and Panchkula are shown in Table 6. The values obtained for WQI of each city were compared to the standard values of WQI as per OWQI in Table 2. The values of WQI obtained using the methodology based on BIS 10500 have been summarized in Table 7 and the classification of water quality have been summarized in Table 8.

It is observed from Table 8 that the ground water quality in Chandigarh within a 5 km vicinity of the dumpsite experiences poor quality of groundwater with the exception in monitoring campaign over the S1 wherein it experienced a *good* water quality value at distances greater than 2.5 km. The poor quality of groundwater is primarily because Chandigarh has the

**Table 6** Average WQI as per OWQI for Tricity

| Distance/Monitoring | Chandigarh | Mohali | Panchkula |
|---|---|---|---|
| OWQI | 74 | 60 | 72 |
| Water Quality Classification | Poor Water Quality | Poor Water Quality | Poor Water Quality |

more concentration of industries than Mohali and Panchkula. The overall water quality in Mohali could be classified as good as observed from Table 8. Seasonal variation showed that the overall water quality in monitoring campaigns S1 and S2 were of good quality with poor quality of water observed in S3. The quality of groundwater was classified as poor quality for downstream distances of 2 km for monitoring campaigns during S1 and S2 and till 3 km for S3. Thereafter the water quality improved to good standards. Further, with increase in downstream distance it was observed that the quality of groundwater improved. Similarly, it was observed from that the overall quality of groundwater was classified as good for Panchkula (Table 8). Seasonal variation showed that for all the monitoring campaigns poor quality of water existed till downstream distance of 2 km after which the quality of the water increased to *good.* The WQI results revealed that the ground water samples from the nearby location to the dumping sites are affected due to leaching of ions from the leachate. With the increase in downstream distance of the groundwater sources from the dumpsite the WQI and also the quality of the groundwater keeps on improving. Another important observation was that though groundwater classification for Mohali and Panchkula were '*good*', the mean WQI values of 97 and 92 respectively for Mohali and Panchkula shows that for all practical purposes they are on the borderline of being classifed from *good* to *poor* water quality. A simple regression analysis between LPI and WQI for the three sites were found to be 0.35 for Chandigarh, 0.58 for Mohali and 0.22 for Panchkula respectively.

Further, it is important to note that while the results obtained from (OWQI) shows that the existing groundwater quality from the Tricity Region is 'poor quality' the groundwater quality evaluated using the BIS method showed that the groundwater quality for Chandigarh was poor quality but for Mohali and Panchkula were classified as good quality. However, the groundwater quality for Mohali and Panchkula is very close to being graded poor as the WQI values are on the borderline conditions.

## Multivariate statistical analysis

### *Principal components analysis (PCA)*

PCA is a data alteration method that reveals simple primary structures which are assumed to be present within a dataset (Ranjan et al. 2013). PCA when applied to the present dataset of the study gave a comparison of compositional patterns between the examined waste systems and helped to identify the factors that influence each other. The numbers of components were based on Kaiser Normalization in which components having Eigen values greater than unity were retained (Singh

**Table 7** WQI for Tricity as per BIS 10500

| Distance/ Monitoring | S1 | | | S2 | | | S3 | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CHD | MOH | PKL | CHD | MOH | PKL | CHD | MOH | PKL | CHD | MOH | PKL |
| 1 km | 132 | 107 | 120 | 149 | 119 | 97 | 185 | 142 | 110 | 155 | 123 | 109 |
| 2 km | 131 | 88 | 100 | 144 | 111 | 108 | 178 | 126 | 125 | 151 | 108 | 111 |
| 2.5 km | 103 | 82 | 83 | 121 | 92 | 88 | 155 | 103 | 99 | 126 | 92 | 90 |
| 3 km | 98 | 81 | 82 | 110 | 90 | 87 | 145 | 100 | 95 | 118 | 90 | 88 |
| 4 km | 97 | 73 | 72 | 104 | 87 | 81 | 140 | 99 | 87 | 114 | 86 | 80 |
| 5 km | 94 | 72 | 70 | 101 | 82 | 78 | 135 | 92 | 81 | 111 | 82 | 76 |
| **Average WQI** | **109** | **84** | **88** | **122** | **97** | **90** | **156** | **110** | **99** | **130** | **97** | **92** |

Bold values indicate the calculated the WQI for the three study locations for the three monitoring campaigns carried out for three different seasons

**Table 8** Water quality classification for Tricity as per BIS 10500

| Distance/ Monitoring | S1 | | | S2 | | | S3 | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CHD | MOH | PKL | CHD | MOH | PKL | CHD | MOH | PKL | CHD | MOH | PKL |
| 1 km | Poor quality | Poor quality | Poor quality | Poor quality | Poor quality | Poor quality | Poor quality | Poor quality | Poor quality | Poor quality | Poor quality | Poor quality |
| 2 km | Poor quality | Good quality | Poor quality | Poor quality | Poor quality | Poor quality | Poor quality | Poor quality | Poor quality | Poor quality | Poor quality | Poor quality |
| 2.5 km | Poor quality | Good quality | Good quality | Poor quality | Good quality | Good quality | Poor quality | Poor quality | Good quality | Poor quality | Good quality | Good quality |
| 3 km | Good quality | Good quality | Good quality | Poor quality | Good quality | Good quality | Poor quality | Poor quality | Good quality | Poor quality | Good quality | Good quality |
| 4 km | Good quality | Good quality | Good quality | Poor quality | Good quality | Good quality | Poor quality | Good quality | Good quality | Poor quality | Good quality | Good quality |
| 5 km | Good quality | Good quality | Good quality | Poor quality | Good quality | Good quality | Poor quality | Good quality | Good quality | Poor quality | Good quality | Good quality |
| **Average WQI** | **Poor quality** | **Good quality** | **Good quality** | **Poor quality** | **Good quality** | **Good quality** | **Poor quality** | **Poor quality** | **Good quality** | **Poor quality** | **Good quality** | **Good quality** |

Bold values indicate the representative quality of the groundwater for the three study locations for the three monitoring campaigns carried out for three different seasons

et al. 2016). The contribution of the component is considered to be significant only when it has a corresponding value of Eigen greater than unity (Manikandan et al. 2014; Singh et al. 2016). Three principal components were obtained with Eigen values greater than unity in case of Chandigarh and Panchkula cities accounting for almost 88% and 87.8% of total variance respectively in the ground water dataset whereas for Mohali, two components with Eigen values greater than unity accounting 87.1% of total variance in the ground water dataset. Figs. 4, 5 and 6 shows the plot of loadings for various components of Chandigarh, Mohali and Panchkula respectively. Principal component loading for these components with variance is given in Tables 9, 10 and 11 for all the three cities of Chandigarh, Mohali and Panchkula respectively.

### *Component 1*

The first component in Chandigarh and Panchkula cities is dominated by high positive loading in electrical conductivity, calcium, magnesium, nitrates and sulfates and for Mohali by fluorides, chlorides, nitrates, total dissolved solids and ammonical nitrogen. The moderate positive loading is shown in pH, turbidity and total hardness accounting for 62.76%, 62.14% and 51.97% of the total variance in first components of Chandigarh, Mohali and Panchkula cities respectively. This specifies that these ions are accountable for occurrence of high electrical conductivity, total dissolves solids and hardness. High pH or alkaline environment is responsible for the presence of fluoride in ground water of Mohali city. Presence of hardness in the form of calcium and magnesium in ground water samples can be attributed to the leaching of the minerals and anthropogenic factors which are dominant controlling factors of the loading. Presence of sulfate is the indication of the impacts caused mostly due to the agricultural practices, domestic sewage and animal excreta. Negative loading of pH can be linked with the sulfate as the latter being the acidic ion depicting the lower values of pH (Ashwani and Abhay 2014; Singh et al. 2016).

### *Component 2*

The second component is dominated by the presence of sulfate, ammonical nitrogen, turbidity, biochemical oxygen demand, total hardness, pH, electrical conductivity and magnesium, accounting for 17.94%, 24.99% and

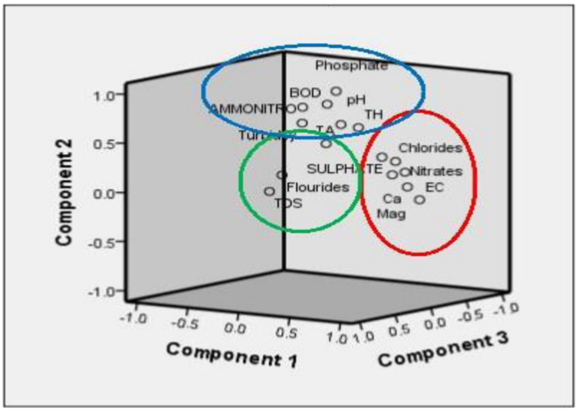

**Fig. 4** Plot of loadings for the components with varimax normalized rotation for Chandigarh City

22.87% of the total variance for Chandigarh, Mohali and Panchkula respectively. The high loading in pH is related to the low sulfate ions as pH is negatively correlated with the sulfate (Singh et al. 2016). Presence of total harness, ammonical nitrogen and alkalinity may be due to the leaching of minerals in the ground water along with other anthropogenic activities. Agricultural activities may also contribute to the phosphate contamination in the ground water as phosphate is mainly used as fertilizer. The high positive loading in ammonical nitrogen can be attributed to the impacts due to animal excreta and sewage from domestic activities.

### *Component 3*

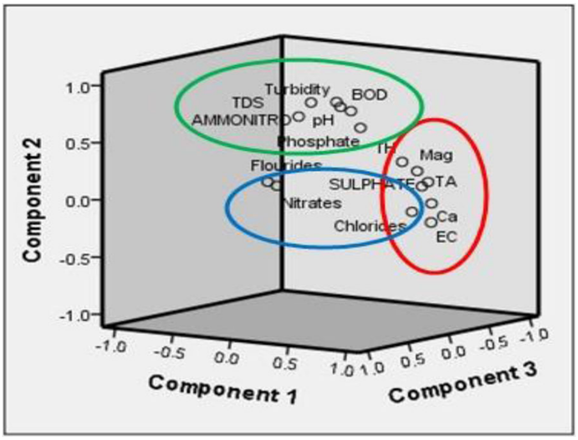

**Fig. 6** Plot of loadings for the components with varimax normalized rotation for Panchkula City

Component three explaining 7.31% and 1.96% of total variance for Chandigarh and Panchkula respectively has strong positive loading on phosphate and fluoride. Generally, alkaline environment is responsible for the presence of fluoride in ground water (Manikandan et. 2014). Sometimes weathering of fluoride bearing rocks can also cause excessive presence of fluoride. The presence of phosphate contamination in ground water is attributed to the excessive use of fertilizers, sewage and landfill discharge from domestic waste.

### *Hierarchical cluster analysis (HCA)*

HCA is the most widely multivariate statistical tool used in environmental studies (Diaz et al., 2002; Gibrilla et al. 2011). It helps in grouping the ground water samples based on the similarities in their chemical composition (Gibrilla et al. 2011). In the study, HCA is applied to all

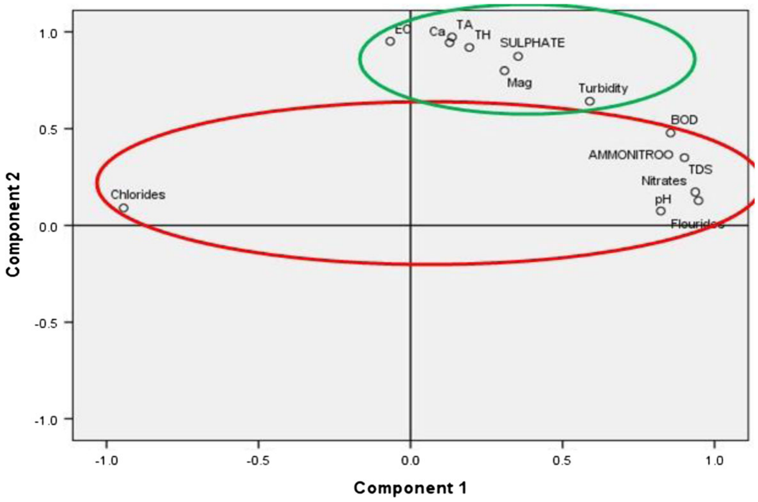

**Fig. 5** Plot of loadings for the components with varimax normalized rotation for Mohali City

**Table 9** PCA loadings of variables of significant principal components for Chandigarh city

| Parameters | Rotated Component Matrix | | |
|---|---|---|---|
| | Component 1 | Component 2 | Component 3 |
| Calcium | *0.964* | – | – |
| EC | *0.953* | – | – |
| Nitrates | *0.929* | – | – |
| Magnesium | *0.896* | – | – |
| Chlorides | *0.885* | – | – |
| Sulfate | *0.808* | *0.429* | – |
| Phosphate | – | *0.982* | – |
| BOD | – | *0.914* | – |
| Ammonical nitrogen | – | *0.880* | – |
| Turbidity | – | *0.752* | *0.518* |
| pH | *0.480* | *0.743* | – |
| Total Hardness | *0.572* | *0.704* | – |
| TDS | – | – | *0.850* |
| TA | *0.497* | *0.583* | *0.594* |
| Fluorides | – | – | *0.569* |
| Eigen Value | 9.413 | 2.691 | 1.096 |
| % of variance | 62.755 | 17.937 | 7.309 |
| Cumulative % | 62.755 | 80.692 | 88.001 |

**Table 10** PCA loadings of variables of significant principal components for Mohali city

| Parameters | Rotated Component Matrix | |
|---|---|---|
| | Component 1 | Component 2 |
| Fluorides | *0.947* | – |
| Chlorides | *−0.944* | – |
| Nitrates | *0.937* | – |
| TDS | *0.901* | – |
| BOD | *0.855* | *0.478* |
| Ammonical Nitrogen | *0.848* | – |
| pH | *0.823* | – |
| TA | – | *0.973* |
| EC | – | *0.951* |
| Ca | – | *0.944* |
| TH | – | *0.919* |
| Sulfate | – | *0.873* |
| Magnesium | – | *0.800* |
| Turbidity | *0.590* | *0.642* |
| Eigen Value | 8.700 | 3.498 |
| % of variance | 62.140 | 24.984 |
| Cumulative % | 62.140 | 87.123 |

**Table 11** PCA loadings of variables of significant principal components for Panchkula city

| Parameters | Rotated Component Matrix | | |
|---|---|---|---|
| | Component 1 | Component 2 | Component 3 |
| Calcium | *0.987* | – | – |
| EC | *0.973* | – | – |
| TA | *0.958* | – | – |
| Sulfate | *0.946* | – | – |
| Magnesium | *0.902* | – | – |
| TH | *0.860* | *0.402* | – |
| TDS | – | *0.863* | – |
| Turbidity | – | *0.863* | – |
| pH | – | *0.845* | – |
| BOD | *0.460* | *0.816* | – |
| Ammonical nitrogen | – | *0.680* | – |
| Phosphate | – | *0.518* | *−0.458* |
| Chlorides | – | – | *−0.937* |
| Fluorides | – | – | *0.926* |
| Nitrates | – | – | *0.915* |
| Eigen Value | 7.795 | 3.431 | 1.956 |
| % of variance | 51.966 | 22.874 | 13.043 |
| Cumulative % | 51.966 | 74.841 | 87.884 |

the three cities of Chandigarh, Mohali and Panchkula. The classification of ground water samples into clusters is based on a visual observation of the dendogram and is represented in Figs. 7, 8 and 9 for Chandigarh, Mohali and Panchkula respectively. A dendogram helps in understanding the correlation among the various elements. HCA was applied to bulk concentrations data using ward's method with Euclidian distances as criterion for formation of the clusters of elements (Gibrilla et al. 2011). Ward's method of analysis uses the variance approach to evaluate the distances between clusters and helps to minimize the sum of squares of clusters that can be formed at each step (Singh et al., 2004). Grouping of sampling points in accordance with the concentration of constituent's ions is done by cluster study (Guler et al., 2002). In this study, for all the three cities the classification of all the 45 ground water samples (15 samples for each of the three cities) into clusters is formed. The three different clusters for Chandigarh, Mohali and Panchkula cities are formed: **cluster 1** (sampling sites 1, 11, 7, 10, 13 for Chandigarh;

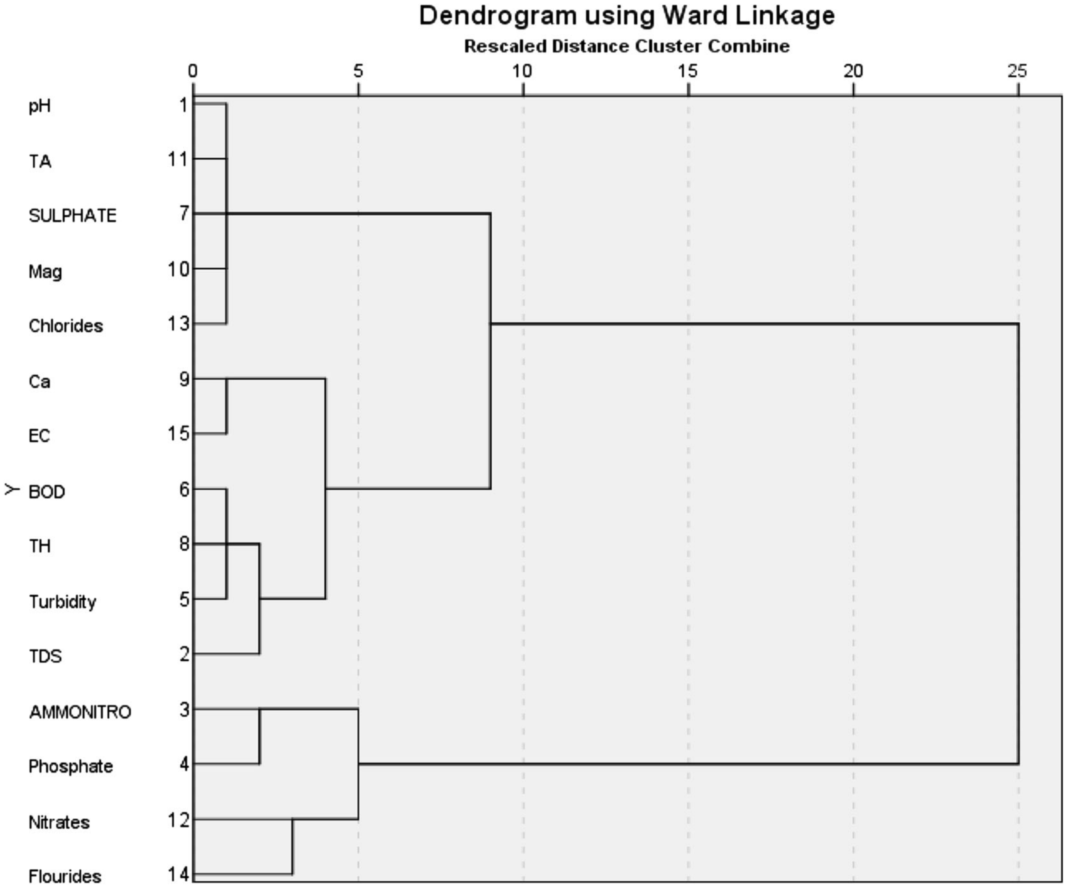

**Fig. 7** Hierarchical dendogram for ground water samples in Chandigarh City

sampling sites 27, 29, 18–19 for Mohali; sampling sites 42, 44, 33–34 for Panchkula), **cluster 2** (sampling sites 9, 15, 6, 8, 5,2 for Chandigarh; sampling sites 26, 30, 25, 20, 22, 16–17 for Mohali; sampling sites 40, 45, 41, 31 for Panchkula) and **cluster 3** (sampling sites 3–4, 12, 14 for Chandigarh; sampling sites 23–24, 21, 28 for Mohali; sampling sites 32, 35–36, 43 for Panchkula). These all respective sites for all the three cities of Chandigarh, Mohali and Panchkula respectively have similar characteristic features which corresponds to low, medium and high pollution region.

In cluster 1, five samples for Chandigarh City and four samples each for Mohali and Panchkula cities respectively are grouped and characterized by low polluted regions. In Chandigarh city, these samples are characterized by low pH, sulfate, magnesium and chloride whereas for Mohali and Panchkula the low values of these samples are characterized in nitrates, ammonical nitrogen, fluorides and phosphates. The ground water which falls under cluster 1 is not much polluted.

In cluster 2, six samples from Chandigarh, seven samples from Mohali and four samples from Panchkula are grouped characterized by moderate polluted region. Members of this cluster have presence of calcium, magnesium, electrical conductivity, biochemical oxygen demand, alkalinity and turbidity. The water samples shows moderate salinity with presence of total dissolved solids. This water can be classified as mixed water type (Singh et al. 2016).

In cluster 3, four samples each from Chandigarh and Mohali, and seven samples from Panchkula are grouped and characterized by the sites which are closer to the landfill sites and are found to be highly polluted owing to impact from domestic waste. The samples are characterized by presence

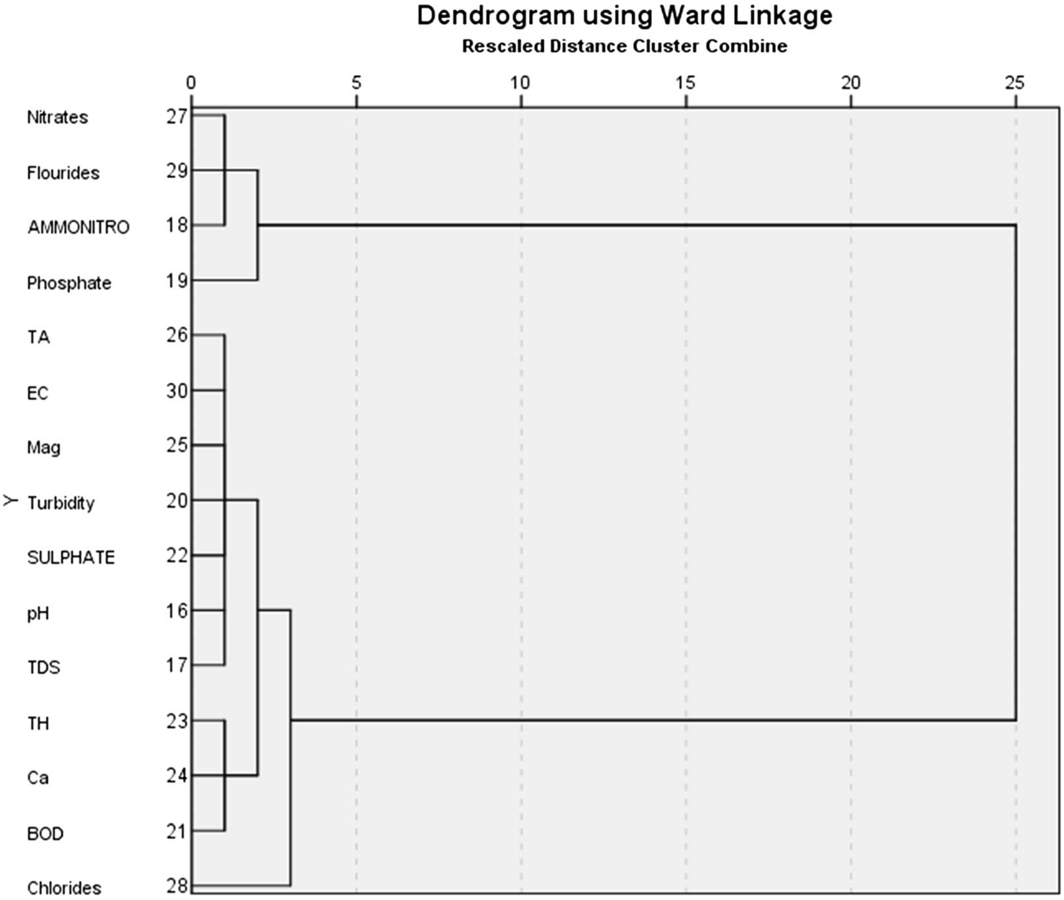

**Fig. 8** Hierarchical dendogram for ground water samples in Mohali City

of high ammonical nitrogen, nitrates, sulfates, hardness, fluorides and total dissolved solids.

## Conclusion

The present study reveals the extent to which open dumping of MSW has led to the contamination of the nearby ground water due to percolation of the leachate into it. In this context, first the physico-chemical properties and toxicity of the leachate from the three dumpsites of the study location were evaluated. The leachate derived from municipal solid waste dumping sites of all the three cities of Chandigarh, Mohali and Panchkula demonstrates exceedingly high values for all physico-chemical and biological parameters analyzed. In the present study LPI values of 26.15, 27.02 and 27.88 were obtained for Chandigarh, Mohali and Panchkula respectively signifying high levels of toxicity. High values of LPI obtained in all the landfill sites indicated that the leachate generated is toxic and proper treatment procedures must be ensured. The leachate generated affects the ground water quality in the adjacent areas through percolation in the sub-soil. The ground water quality of nearby sites of municipal solid waste landfill sites are of poor quality since they are contaminated due to leachate. The ground water quality improves with the increase in distance from the source of pollution. The WQI indicated the majority of the ground water samples belong to poor quality of water using the OWQI method for the study locations but were classified poor only for Chandigarh while Mohali and Panchkula showed good water quality characterestics using WQI-BIS 10500 method. However, in reality the

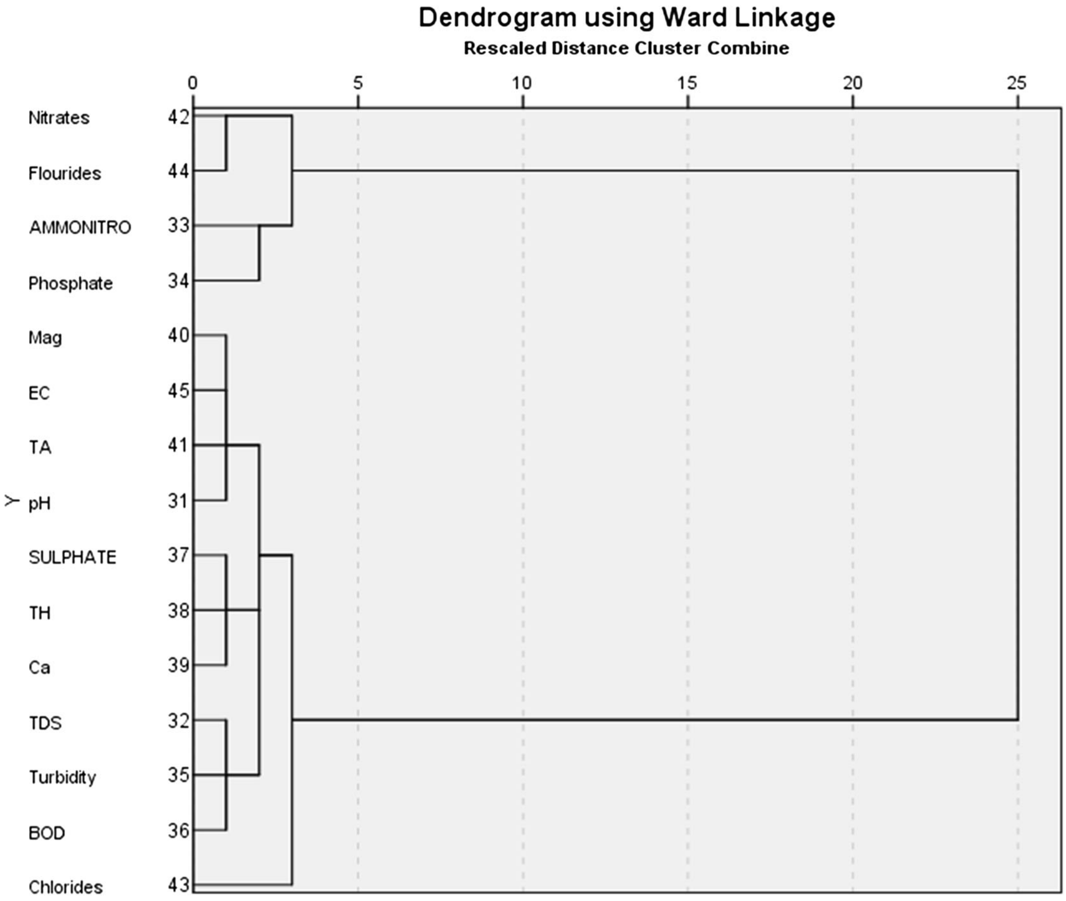

**Fig. 9** Hierarchical dendogram for ground water samples in Panchkula City

groundwater conditions for Mohali and Panchkula are on the cusp of being graded 'poor' from 'good' quality as there WQI values are very close to the borderline classifications. It was further concluded that quality of groundwater improved with downstream distances with poor quality being characterized as good quality. Multivariate statistical technique (PCA and HCA) suggests that the components of the PCA accounts for 88%, 87.1% and 87.7% of the total variance in the dataset for Chandigarh, Mohali and Panchkula cities respectively. The components in Chandigarh and Panchkula cities is dominated by high positive loading in electrical conductivity, calcium, magnesium, nitrates and sulfates and for Mohali by fluorides, chlorides, nitrates, total dissolved solids and ammonical nitrogen. Cluster analysis helped to group 15 sampling sites each for Chandigarh, Mohali and Panchkula into three clusters of similar characteristics. It further helps to examine the quality of water and sources of pollution. In the future, it is recommended to have an engineered landfill sites for each of the three cities which can control the impact of leachate on the ground water.

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