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Physico-chemical and biological characterization of urban municipal landfill leachate☆

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ABSTRACT

Unscientific management and ad-hoc approaches in municipal solid waste management have led to a generation of voluminous leachate in urban conglomerates. Quantification, quality assessment, following treatment and management of leachate has become a serious problem worldwide. In this context, the present study investigates the physico-chemical and biological characterization of landfill leachate and nearby water sources and attempts to identify relationships between the key parameters together with understanding the various processes for chemical transformations. The analysis shows an intermediate leachate age (5–10 years) with higher nutrient levels of 10,000–12,000 mg/l and ~2000–3000 mg/l of carbon (COD) and nitrogen (TKN) respectively. Elemental analysis and underlying mechanisms reveal chemical precipitation and co-precipitation as the vital processes in leachate pond systems resulting in accumulation of trace metals. Based on the above criteria the samples were clustered into major groups that showed a clear distinction between leachate and water bodies. The microbial analysis showed bacterial communities correlating with specific factors relevant to redox environments indicating a gradient in nature and abundance of biotic diversity with a change in leachate environment. Finally, the quality and the contamination potential of the samples were evaluated with the help of leachate pollution index (LPI) and water quality index (WQI) analysis. The study helps in understanding the contamination potential of landfill leachate and establishes linkages between microbial communities and physico-chemical parameters for effective management of landfill leachate.

1. Introduction

With rapid urbanisation and population growth municipal solid waste (MSW) generation in urban localities has increased many folds. Leachate, a liquid manifestation from MSW, has been considered as a serious pollutant affecting natural resources as surface and ground waters, human health and hygiene. It is a tainted liquid emanating from the bottom of the solid waste disposal facilities such as landfills that contains both soluble organic and inorganic compounds as well as suspended particles. The composition of landfill leachate depends upon the nature of solid waste buried, chemical and biochemical processes responsible for the decomposition of waste materials and total water content in waste (Fatta et al., 1999). A highly concentrated leachate is generated due to unscientific collection, segregation, and disposal practices of MSW. Dispersal of leachate poses a potential threat to soil and ground water quality (Jorstad et al., 2004; Chian and Dewalle, 1976). In developing nations like India especially the contamination problem is more serious, where the landfills do not have any leachate containment i.e. collection and treatment systems. Therefore, it is essential to adopt appropriate treatment/remedial measures to avoid contamination of the underlying soils and groundwater aquifers from the leachate generated from the landfills.

In India older landfills do not have a barrier system/liner and leachate collection system to restrict the migration of leachate into ground water. These landfills are often observed over permeable

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soils with shallow water tables beneath, enhancing the potential of the leachate to contaminate ground water. Presently there are no scientific leachate collection systems in India and other developing countries (Kumar and Alappat, 2005). Although the municipal solid waste (management and handling) rules 2000, Schedule III – Gazette 22(b) for specifications for landfill base clearly suggests leachate collection and treatment, leachate containment through 1.5 mm HDPE liner and provisions for storm water runoff gutters (MSW, 2000). In developed countries like Canada there are even stringent norms and regulations for leachate collection, containment, treatment and disposal that also emphasize regular monitoring of the surface and ground water in the vicinity of the landfill location (https://dr6j45jk9xcmk.cloudfront.net/documents/1110/66-landfill-standards-en.pdf).

In landfill leachate, numerous hazardous compounds as aromatics, halogenated compounds, phenols, pesticides, heavy metals and ammonium have been identified (Devare and Bahadir, 1994). This presses grave concerns about safety and health of human beings together with other aquatic life forms, impacting its ecology and food chains. Moreover, landfill leachate also imposes significant influence on the mobilization and attenuation through complexation of organic ligands and colloidal matters (Achankeng, 2004) in soil. Hence, it becomes imperative to assess the quality of leachate from MSW landfill. The physico-chemical environment and microbial communities play vital role in transformations of organic and inorganic compounds that helps in leachate decomposition and mineralization. This leads to the treatment of leachate. The presence of trace metals indicates toxicity in landfill leachate and its negative impacts on the growth of beneficial microflora that would have otherwise helped in leachate degradation and treatment. Morphological analysis of the microbial community is essential for identification and further characterization to determine the suitability of the microflora in the degradation of landfill leachate. Advanced tools as scanning electron microscopy (SEM) can be potentially used for rapid identification of the leachate microflora and enumeration (Mahapatra et al., 2014). Understanding various groups of bacterial and other microbial community aids in identifying dominant communities and potential to degrade leachate. These hosts of different bacterial microflora can be potentially used for the treatment of the leachate in-situ. Due to a heterogeneous mixture of municipal solid waste, various types of non-biodegradable organics are also present in landfill leachate. Thus pollution indices are essential for rapid assessment, monitoring and comparison of leachate quality (Kumar and Alappat, 2005). Presently the landfill leachate is gaining a serious attention in the developing countries and to a lesser extent in the developed world with relevance to its toxicity and harmful environmental externalities.

This research paper attempts to characterize landfill leachate through physico-chemical, and biological analysis. A leachate pollution index has been developed for urban landfill localities that can be used as a tool for determining its quality and evaluates its contamination potential. This study also aims to serve as a guideline for the implementation of an appropriate leachate treatment technique for reducing adverse effects on the environment.

2. Materials and methods

2.1. Study area

The Mavallipura landfill site is located north of Bangalore, India at Latitude 13°50′ North, Longitude 77°36′ East in the state of Karnataka. This landfill site has been used as a processing site for the municipal solid waste generated from Bangalore city. The average annual rainfall is 978 mm. Rainy seasons are from June to September and the secondary rainy season is from November to December. Mavallipura village is located about 20 Kilometer away from Bangalore. About 100 acres of land in and around the village are used for dumping Bangalore's MSW by the Bruhat Bengaluru Mahanagara Palike (BBMP–Greater Bangalore Municipal Corporation) that began accepting waste from 2005. Mavallipura landfill site is about 40.48 ha located in Mavallipura village, of which approximately 35 acres is used for landfill. The landfill was maintained at M/s Ramky Environmental Engineers commissioned in 2007 which had the capacity to sustain about 600 tonnes of waste. However, the BBMP has been sending almost 1000 tonnes of garbage from Bangalore city every day. Citizens around Mavalipura village demand that the landfill site must be stopped immediately as it is illegal and unscientifically managed and thus it is now closed for land filling. A little soil cover (0.3 m thickness) has been applied on a daily basis, and MSW is dumped in an unscientific manner that has resulted in steep, unstable slopes, leachate accumulation within the MSW mass, and leachate runoff into nearby water bodies such as pond and opened well.

2.2. Sampling and physico-chemical analysis

Fig. 1 gives the view of (a) sampling locations points on google earth and also shows (b–f) the location of sample points in Mavallipura landfill site. In order to observe the spatiotemporal variations of the geochemistry of leachate and ground waters, three undiluted representative leachate samples (L1 leachate collected directly from landfill, L2 leachate collected from landfill sump, L3 leachate collected from landfill pond) and another two samples of water from the nearby pond (P4) and open well (G5) were collected from downstream of Mavallipura landfill site in the month of April 2012. Three replicates of each of the sample were analyzed for every location. After the sample collections, these landfill sites were abandoned and were restricted to any further treatment and disposal due to agitation in the nearby local communities. Therefore further sampling was not possible, and the analysis was carried out for only one season. The samples were collected in labeled clean bottles that were rinsed thrice before sample collection. The pH and electrical conductivity (EC) were recorded on site at the time of sampling with digital pH meter and digital EC meter, respectively. For the analysis of biological oxygen demand (BOD), 300 ml capacity BOD bottles were used for the collection of samples. For heavy metal analyses, samples were separately collected in prewashed polyethylene containers of 100 ml capacity and acidified (few drops of concentrated nitric acid were added to the leachate sample) onsite to avoid precipitation of metals. The samples were then transported in cooler boxes at a temperature below 5 °C immediately to the laboratory. Leachate samples was stored in a refrigerator at 4 °C before proceeding with the laboratory analysis. Physico-chemical parameters, ionic parameters, trace elements analysis was carried out according to standard methods for the examination of water and wastewater unless otherwise stated (APHA, 1998).

2.3. Statistical analysis

Univariate analysis was performed to know the nature of the sample and extent of spread across mean. Correlation coefficient (r) is computed to explore significant relationships between changes in physico-chemical variables against biological variables (bacterial and algal communities). Multivariate analysis - Detrended Correspondence Analysis (CCA) was performed to understand transitions in biological communities with the varying physico-chemical variables to know relationships among them and identifying the most impacting drivers. Cluster Analysis (CA) was performed in order to

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Fig. 1. The site map and the sampling locations across leachate pond, storage pond and ground water sources.

find out the spatial similarity and patterns across sites. These statistical analyses were carried out using open source statistical package PAST 2.14 (downloaded from http://www.nhm.uio.no/norlex/past/download.html).

2.4. *Scanning electron microscopy (SEM)*

The dried suspended solids in leachate were mounted on stubs with a carbon-impregnated film and sputtered with a 15 nm layer of gold coating. Imaging and observations were conducted in the FEI ESEM Quanta 200 (3 imaging modes: HV; LV and ESEM) through a Quanta LV/ESEM (at high pressures with a standard secondary [Evehat–Thorley] and solid state scatters detector) as per discussed protocols (Mahapatra et al., 2014). Specimens were examined with a working distance of 10 mm and a low accelerating voltage of 10/12 kV to reduce beam damage.

2.5. *Energy dispersive X-ray analysis (EDAX)*

Leachate samples were filtered, and the residue was dried with vacuum drier. The samples were then subjected to energy dispersive analysis by X-rays (EDAX) employing a Quanta LV (Environmental SEM: at high pressure, with a standard secondary [Evehat–Thorley] and solid state scatter detector) attached to Energy Dispersive X-ray analysis with an ultra thin window detector (EDAX) for the determination of composition of elements. The High-resolution SEM equipped with a Schottky field emission source with high voltage variable between 200 V and 300 kV was used for taking images of mineral particles as per methods used earlier (Mahapatra et al., 2013a).

2.6. *Microbiological analysis*

50 ml of leachate and water samples were fixed with 70% alcohol. Microscopic analysis especially algae was performed using Light Microscope (Lawrence and Mayo) at 40× with the help of morphological keys as per literature (Prescott, 1959; Desikacharya, 1959). Keys include external appearance, colour, morphological characteristics, size, structure, and orientation of chloroplast, pigment colouration, etc. Images were captured using Caliper Pro software and DIC (Digital Interference Contrast) microscope. Algal images were taken with 100× oil immersion lens. Drop count method was employed for counting algal population (Mahapatra et al., 2013a; Mahapatra, 2015). The relative abundance of algal communities was examined. Samples collected were concentrated by centrifuging 15 ml volume. Algae were enumerated using representative 20 μl of the concentrated sample, where it was placed over the slides with cover slips for microscopic observations and density was computed by the ratio of a number of cells counted in the given quantity of water sample. Bacterio-plankton population was analyzed by first filtering the collected samples with 2.5 μm sieve and then through microscopy.

2.7. *Leachate pollution index (LPI)*

LPI formulation process involves selecting variables, deriving weights for the selected pollutant variables, formulating their sub-indices curves, and finally aggregating the pollutant variables to arrive at the LPI (Kumar and Alappat, 2003). The rating was done on a scale of ‘1’ to ‘5’. The value ‘1’ was used for the parameter that has lowest relative significance to the leachate contamination while value ‘5’ was to be used for the parameter that has highest relative significance (Kumar and Alappat, 2003). The LPI is calculated using the following equations:

$$\mathrm{LPI} = \sum_{i=1}^{n} \mathrm{W_i P_i} \tag{1}$$

where LPI = the weighted additive LPI, $\mathrm{W_i}$ = the weight for the ith pollutant variable, $\mathrm{P_i}$ = the sub-index score of the ith leachate pollutant variable, n = number of leachate pollutant variables used in calculating LPI. Weights are so selected that,

$$\sum_{i=1}^{n} \mathrm{W_i} = 1 \tag{2}$$

However, when the data for all the leachate pollutant variables

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included in LPI are not available, the LPI can be calculated using the concentration of the available leachate pollutants. In that case, the LPI can be calculated by the equation:

$$\mathrm{LPI} = \frac{\sum_{i=1}^{m} W_i P_i}{\sum_{i=1}^{m} W_i} \tag{3}$$

where m is the number of leachate pollutant parameters for which data are available, but in that case, m < 18 and ΣW < 1 contamination from the pollutant to the overall leachate pollution. LPI values have grades that represent the overall leachate contamination potential of a MSW landfill. It is an ascending order scale index; wherein a lower index value indicates a good environmental condition. The Assessment of leachate quality at any early stage may be undertaken to (a) to identify whether the solid waste leachate are hazardous, (b) to identify a suitable landfill design, (c) to develop a sustainable leachate treatment process and d) to foresee the impacts of leachate on ground water by adopting various monitoring and surveillance strategies.

2.8. *Water quality index (WQI)*

Water Quality Index is calculated based on various important parameters like pH, electrical conductivity, TDS, total alkalinity, total hardness, total suspended solids, calcium, magnesium, chloride, nitrate, sulphate, dissolved oxygen and biological oxygen demand. By using standards of drinking water quality recommended by the Bureau of Indian Standards (BIS), Indian Council for Medical Research (ICMR) and World Health Organization (WHO). The unit weight arithmetic index (Brown et al., 1972) was used for the calculation of WQI of the water body. Furthermore, the quality rating of sub-index (q_n) was calculated using the following expression.

$$q_n = 100 \times \frac{(V_n - V_{iw})}{(S_n - V_{iw})} \tag{4}$$

where,

q_n = Quality rating for the nth water quality parameter
V_n = Estimated value of the nth parameter at a given sampling station
S_n = Standard permissible value of the nth parameter.
V_{iw} = Ideal value of the nth parameter [i.e. zero for all parameters except the pH and dissolved oxygen (7 and 8 mg/l respectively)]. Water Quality Index was calculated from the quality rating with unit weight linearly.

$$\mathrm{WQI} = 100 \times \frac{\sum W_n * q_n}{\sum W_n} \tag{5}$$

3. Results and discussions

3.1. *Physiochemical parameter analysis*

Municipal solid waste composition, elapsed time, temperature, moisture and available oxygen are some of the important factors, influencing the leachate quality. The leachate quality with similar waste types may be different in landfills located in varied climatic regions. Furthermore operational practices in landfills also influence the leachate quality. The results of physico-chemical characteristics of the leachate and samples from water bodies in Mavallipura landfill are presented in Table 1.

Table 1
Landfill leachate characteristics.

Characteristics	L1	L2	L3	P4	G5
pH	7.4	7.6	7.5	8.4	7.5
Conductivity, μS/cm	4120	3870	4110	2500	1362
TDS, mg/l	2027	2267	2097	1447	703
COD, mg/l	10,400	12,000	10,800	1080	440
BOD_5, mg/l	1500	1500	3000	105	3
Sulphate, mg/l	40	42	40	10	7
Chloride, mg/l	660	780	760	250	230
Calcium, mg/l	400	440	440	0	320
Alkalinity, mg/l	11,200	10,800	11,000	2000	300
Iron, mg/l	11.16	12.04	11.25	0.16	0.62
Copper, mg/l	0.151	0.008	0.002	BDL	BDL
Silver, mg/l	0.035	0.121	0.119	0.026	0.051
Cadmium, mg/l	0.035	0.032	0.024	BDL	BDL
Chromium, mg/l	0.021	0.024	0.011	BDL	BDL
Lead, mg/l	0.3	0.28	0.22	BDL	BDL
Zinc, mg/l	3	2.4	2.4	1	0.4
Nickel, mg/l	1.339	1.004	0.683	BDL	BDL
Sodium, mg/l	3710	3016	3302	1676	88
Potassium, mg/l	1675	1632	1701	1078	46
Nitrate, mg/l	22.36	28.00	35.09	0.18	1.09
Ammonia nitrogen, mg/l	1803	2593	2170	0.5	0.5

*BDL means below detection limit.

3.1.1. *pH*

pH values of leachate (L1, L2 and L3) of the landfill site were 7.4, 7.6, 7.5 and the pH values of the P4 (pond) and G5 (open well) water samples found to be 8.4 and 7.5. The critical reaction in MSW is the degradation of organic materials to produce carbon dioxide and a small amount of ammonia that further results in the formation of ammonium ions and carbonic acid. The carbonic acid dissociates with ease to produce hydrogen cations and bicarbonate anions, which influence the level of pH of the system. Additionally, leachate pH is also influenced by the partial pressure of the generated carbon dioxide gas that in contact with the leachate. Dissolved materials and gases shift the pH of natural water either to acidic or alkaline side. pH lower than 7 are usually softer waters and the acidity is due to carbonic, humic, fulvic and other organic acids (Mahapatra et al., 2011a,c). pH above 7 can carry a greater load of dissolved substances and are capable of supporting a good plant life. The alkaline nature of leachate is an indicator of the mature stage of the dumping site (Jorstad and Acworth, 2004).

3.1.2. *Alkalinity*

Alkalinity is caused by bicarbonate, carbonate and hydroxyl ions. For landfill leachate, total alkalinity values are often found to be significantly higher. This is because of the biochemical decomposition, and dissolution process occurring within landfill and disposal sites. The biodegradation processes of organic matter produces significant amount of bicarbonate, which represents dissolved carbon dioxide which is also the major components of alkalinity (Mahapatra, 2011b). In this investigation, the Mavallipura leachate samples (L1, L2, L3) was found to have significantly high alkalinity values. The high alkalinity observed in this study reflects the level of biodegradation process taking place within the disposal sites. The presence of significant amounts of ash and slag from the combustion of wood, agricultural residues can potentially increase alkalinity in leachate greatly in Mavallipura landfill sites. High alkalinity values observed in this study therefore imply that there a fair chances of groundwater contamination. This might produce unpleasant odour in the water sample that is unacceptable for many users (Meenakumari, 2004).

3.1.3. *Conductivity and total dissolved solids*

These parameters are influenced by the total amount of

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dissolved organic and inorganic materials present in the solution, and are used to demonstrate the degree of salinity and mineral contents of leachate. Total mineral content further reflects the strength and overall pollutant load of the leachate. The salt content in the leachate is due to the presence of potassium, sodium, chloride, nitrate, sulphate and ammonia etc. Extremely high values for conductivity are attributable to high levels of cations and anions. High concentrations of total dissolved solids may reduce water clarity, which contributes to light limitation resulting in a decrease in photosynthesis and leads to an increase in water temperature. This affects the growth and development of the biotic components as photosynthetic bacteria and algae. High TDS limits the growth and may lead to the death of many aquatic organisms. Electrical conductivity is an indicator of dissolved inorganic ions in ground water; pond (P4) and open well (G5) showed high values (values of <400–800 μS/cm: clean ground waters) in the close vicinity of landfill site implying possible cross contamination of the leachate with the ground waters.

3.1.4. Major anions

The level of inorganic elements present in leachate is dependent principally on the ease of leaching inorganic constituents present in the MSW and the stabilization process in the landfill. In this investigation, Mavallipura landfill leachate sample was found to have considerably high concentrations of all the major anions like chlorides, nitrates, sulphates where concentration of chloride was highest, while sulphate was lowest. High chloride content in the leachate sample reflects the presence of significant amount of soluble salts in the municipal solid waste materials of the study area. High chloride content in Mavallipura landfill leachate sample can be attributed to landfill dumps, sewage ingress, and domestic effluents including animal waste disposed to the site. High concentrations of chlorides were also observed in the pond (P4) and open well (G5) close to the landfill site. Excess of chloride in water is usually taken as an index of pollution and considered as a tracer for groundwater contamination (Loizidou and Kapetanios, 1993).

A high chloride content in ground water can be from pollution sources such as domestic effluents, fertilizers, septic tanks, and leachate (Mohr et al., 2006). High chloride content in ground water causes diseases related of heart and kidney. Sulphate in landfill leachate is sourced primarily from the decomposition of organic matter, soluble waste, such as construction wastes or ash, synthetic detergents and inert waste, such as dredged river sediments. Nitrates represent the most oxidized form of nitrogen found in the natural system. It is often regarded as an unambiguous indicator of domestic and agricultural pollution. In leachate sample, it is formed primarily as a result of oxidation of ammonium to nitrite and subsequently, to nitrates by nitrification process. The knowledge of nitrates and phosphates is important in predicting the nutrient status of waters as these ions are important plant nutrients which usually appear as a result of decomposition and mineralization of organic matter.

3.1.5. Major cations

Constituents as calcium, magnesium, sodium, and potassium are considered to be major cations typically present in leachate. Derived from the waste material through mass transfer processes, the concentration of these cations in leachate is specific to the composition of the waste mass and the prevailing phase of stabilization in the landfill (Christensen et al., 2001). The high concentration of sodium around the landfill indicates the impact of leachate. The high concentration of sodium causes renal, cardiac and circulatory diseases (Mohr et al., 2006). Despite few inputs from agricultural activities, the high concentration of potassium has been reported to be an indication of the leachate effect (Eillas, 1980). Calcium is one of the most common cations found in groundwater aquifers, as it dissolves from rocks, such as limestone, marble, calcite, dolomite, gypsum, fluorite, and apatite. Magnesium is one of the principal cations associated with water hardness (Harmsen, 1983). Calcium concentrations were noticeably high in open well (G5).

Sodium and potassium are both present at considerably high concentrations in all the samples. Sodium and potassium are not affected significantly by microbiological activities within the landfill site. These ions play a major role in plant physiology and are most likely derived from vegetable residues and domestic wastes. Increased concentration of potassium in ground water is often considered as an indicator of leachate pollution (Christensen et al., 2001). The primary source of potassium is due to weathering and erosion of potassium bearing minerals such as feldspar and leaching of fertilizer. It can have adverse health effects from exposure to increased potassium in drinking water. Excess potassium causes kidney failure, heart disease, coronary artery disease, hypertensions, and diabetes. Sodium and potassium being dominant cations are not significantly affected by microbiological activities within the landfill site. Ammonium ions can enter the aquatic environment via municipal effluent discharges and excretion of nitrogenous wastes from animal and indirect means such as air deposition, nitrogen fixation, and runoff from the agricultural lands. High ammonia levels in water bodies make it difficult for aquatic organisms to sufficiently excrete the toxicant, leading to a toxic build up in internal tissues and blood and potential death. It affects the environmental factors such as pH and temperature, can affect growth and development of aquatic animals. Furthermore, the accuracy of the analysis was verified by ion balance method. The ratios of the sum of the molar concentrations of anions and cations should be nearer to 1. From the ionic balance ratio, it is confirmed that the ratios of molar concentrations are near to 1 supporting the accuracy of various parameters determined.

3.1.6. Ion composition

Piper diagram helps in grouping similar cations and anions and characterization of water types (Piper and Darrah, 1994). The Piper diagram reveals the composition of different ions (explains ionic-chemistry) in percentage and also identifies the hydrogeochemical facies. By grouping sodium (Na^+) + potassium (K^+) together, the major cations were displayed on the trilinear Piper diagram (Freez and Cherry, 1979). Similarly, carbonate (CO_3^{2-}) + bicarbonate (HCO_3^-) are grouped together along with sulphates and chlorides resulting in three groups of the major anions. Central diamond shape area is a matrix transformation of the graph of anions (sulphate + chloride/total anions) and cations (sodium + potassium/total cations), which represents the total ionic. A few conclusions can be drawn from the piper diagram of the collected leachate samples (Fig. 1 of Supplementary material). Firstly, it indicates a predominance of select cations as Na and K in comparison to Ca and Mg. Secondly, bicarbonates and carbonates are the dominant anions found in the leachate samples compared to sulphates and chlorides. The analyzed sample can be thus categorized as the $Na-HCO_3$ type leachate. The analysis also showed large percentages of the samples within the $Ca-SO_4$ category followed by the $Na-HCO_3$ type. However, anions like sulphates were very meager in concentrations compared to other anions.

3.1.7. BOD and COD

The BOD_5/COD ratio indicates the age of the waste fill (Hui, 2005) and the changes of biodegradable compounds in the leachate. Any water, having its BOD_5/COD ratio more than 0.63, can hence be considered to be quite controlled due to biological activity (Naveen et al., 2013). The value of COD and BOD_5/COD can

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characterize the age of the landfill. A comparison of the values of COD and BOD_5/COD of the present studies with the earlier study (Hui, 2005) showed that the age of all the leachate is between 5 and 10 years. This was confirmed with the actual age of dumping of MSW. Similar studies carried earlier (Slomczynska and Slomezynski, 2004; Bhalla et al., 2012) showed that the physico-chemical characteristics of leachate are highly variable over the course of a landfills life. Thus, the age of the landfill has a significant effect on leachate composition. The young leachate primarily comprises of undecomposed organic compounds that are readily biodegradable, giving rise to refractory compounds that accumulate with the exploitation of landfill and are resistant to biochemical degradation. Higher organic matter in leachate samples leads to high emissions if they are not treated, that further increases the green house gas (GHG) foot print of the area (Ramachandra and Mahapatra, 2015). The results of the present study were similar to studies conducted earlier (Granet et al., 1986) that showed low BOD_5/COD (~0.1) indicative of a stabilized leachate. Unlike the present study where the BOD_5/COD values of the leachate samples were ranging from 0.1 to 0.5. The studies conducted by (Chian and Dewalle, 1976) reported BOD_5/COD of 0.5–0.7 indicating large amounts of biodegradable organic matter.

The BOD and COD values are relatively low in the open well sample and also the ratio of BOD_5/COD in the pond (0.097) is much higher than that of (0.006) open well. This is mainly due to relatively high COD values in the pond. This can be possibly due to contamination of pond with leachate from nearby MSW landfill. Assuming that the pond (P4) sample is partially contaminated with the leachate, the relatively lower BOD_5/COD values may be due to contribution by algae. Moreover the pond (P4) sample is characterized not only by low BOD and COD values but also by lower BOD_5/COD ratio. Prolific growth of algae in the ponds provided a green coloured appearance to the pond water (P4). High density of these algae can result in high photosynthetic activity thereby generating voluminous oxygen that help in oxidation of the contaminants in the lake at the same time providing oxygen for the heterotrophic bacteria that in turn helps in aerobic treatment of organic matter present in these ponds (Mahapatra et al., 2011a,b,c). The presence of algae for the production of oxygen and primary productivity is essential for any healthy water body (Granet et al., 1986; Mahapatra et al., 2011b). BOD_5 to COD ratio revealed medium aged leachate samples (5–10 years). However earlier studies on leachate samples showed high concentration of organic constituents that were beyond the permissible limits (Ehrig, 1989).

3.2. Heavy metal and elemental analysis of solids

The metal analysis showed high concentrations of iron in the leachate, followed by zinc, and nickel. The concentrations of chromium, copper, cadmium and lead were low. These trace elements are considered to be dangerous pollutant. In a living system they are capable of disrupting normal functions of a cell by virtue of their capacity to form strong metallic bonds with a number of functional macromolecules at the same time causing clump formation. Minute concentrations of chromium can cause nausea and vomiting and is also toxic to crops. Lead causes anemia, brain damage, anorexia, mental deficiency, vomiting and even death in human beings (Maddock and Taylor, 1977; Bulut et al., 2006) and is toxic even at lower concentrations. Cadmium has been reported to cause agonistic and antagonistic effects on hormones and enzymes leading to lots of malformations like renal damage (Lewis, 1991; Donalson, 1980) and are toxic at low concentrations also (Kale et al., 2010). Both cadmium and lead have been classified as carcinogens (USEPA, 1999). Other trace metals, such as Ni, Zn, Cu have also been reported for various health problems with possibility of bio-accumulation in the food web (Langston, 1990).

The oven dried leachate solids showed the presence of trace metals as Hg, Sn, Cr, Ni, Zn, Co and Fe as shown in the SEM-EDXA analysis. High S percentage (~8%) at a low redox value indicate the possible formation of metal sulphides. Leachate ponds at anaerobic conditions with a higher quantum of sulphates with the availability of organic C promote the growth of sulphate reducing bacteria. Most of the heavy metals react with hydrogen sulphide and leads to the formation of highly insoluble metal sulphides (Mahapatra, 2015). Bacterial sulphate reduction results in the precipitation of dissolved metals as metal sulphide solids. Other trace metals as copper, lead, zinc, cadmium, etc., also form highly insoluble sulphide compounds in contact with the low concentration of hydrogen sulphide. Most of the trace elements are readily fixed as sulphides and get accumulated in soils, and because this process is largely irreversible, repeated applications of amounts more than plant needs eventually results in soil contamination rendering it non-productive (Ahmed, 2012).

Heavy metals often get removed from the aqueous leachate phase through physical forces of settling, flocculation and sedimentation attributed to the specific gravity of the particulate matter (ITRC, 2003). Flocculation is enhanced by high pH, suspended matter, ionic strength and by the presence of algal groups (Matagi et al., 1998). Apart from the physical processes, the chemical removal processes mostly the adsorption, oxidation and hydrolysis of metals, precipitation and co-precipitation play a critical role in concentrating heavy metals. During sedimentation, heavy metals are adsorbed to the soil particles by either cation exchange or chemisorption. Heavy metals are mostly adsorbed to the clay and organic matter present in the leachate by electrostatic attraction (Patrick and Verloo., 1998).

The SEM EDXA analysis showed the presence of clay-like substances as they comprise of Aluminium phyllosilicates with Al (~6%), Si (~8%) and O (~36%) that can help in metal trapping through cation exchange capacity. The total capacity of a soil for retaining or holding exchangeable cations is called cation exchange capacity (CEC). CEC influences the soil's ability to hold onto essential nutrients and provides a buffer against soil acidification. CEC increases with certain substrates with increasing clay and organic matter content. Cation exchange involves the physical attachment of cations (positively charged ions) to the surfaces of clay and organic matter by electrostatic attraction. However, chemisorption represents a stronger and permanent form of bonding than cation exchange. High incidence of Fe in leachate also indicates the formation of insoluble compounds through hydrolysis and oxidation that can occur in leachate ponds. This leads to the formation of a variety of oxides, oxo-hydroxides, and hydroxides (Woulds and Ngwenya, 2004). Iron removal depends on pH, oxidation–reduction potential and the presence of various anions (ITRC, 2003).

Precipitation depends on the solubility product K_{sp} of the metal involved, pH of the redox environment and concentration of metal ions and relevant anions. In this study precipitation from a saturated solution of a sparingly soluble heavy metal salt could have taken place at the low redox conditions. Similarly there are ample chances of co-precipitation which is also an adsorptive phenomenon in rapidly settling systems largely in the presence of Fe where usually heavy metal co-precipitates with secondary minerals in leachate ponds. Metals as Cu, Ni, Zn, Mn, etc., are co-precipitated in Fe oxides (Stumm and Morgan, 1981). Metals become associated with iron oxides as a result of co-precipitation and adsorption phenomena (Stumm and Morgan, 1981). SEM-EDXA analysis shows high C and O values with a higher incidence of Ca and other divalent cations. This can lead to the formation of $CaCO_3$ and other trace metal carbonates. Carbonate formation can take place when

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Table 2
Elemental composition.

Samples		C	N	O	Mn	Na	Mg	Al	Si	P	S	Cl	K	F	Ca	Fe
L1	a)	53.85	5.49	31.05	1.47	7.11	0.56	0.05	0.04	0.04	0.1	0.1	0.12	0	0	0
	b)	50.24	4.12	36.52	0	5.97	1.17	0.03	0.06	0.09	0.08	0.51	0.41	0.64	0.17	0
L2	a)	55.66	2.17	26.87	0	8.4	0.36	0.1	0.1	0.06	0.09	3.09	1.31	0	0.07	1.73
	b)	57.28	5.01	22.53	0	5.83	0.26	0	0.11	0	0.27	5.01	3.7	0	0	0
L3	a)	50.96	5.76	30.72	0	5.86	2.27	0.13	0.21	0.28	0.23	1.01	1.18	0.58	0.8	0
	b)	61.35	3.34	12.84	0	11.53	0.12	0.16	0.39	0.24	0	5.54	1.82	0	0.43	0.78

*a) and b) represents two samples taken from each leachate location.

bacterial production of bicarbonate alkalinity in sediments is substantial (ITRC, 2003). Carbonate precipitation is especially effective for the removal of lead and nickel (Lin, 1995).

The elemental composition was determined by SEM-EDXA analysis where two representative EDXA analyses were performed per sample and is provided in Table 2. The analysis showed a common trend of high quantities of C in all the samples i.e. from L1 to L3 indicating higher organic C (50–61%) in the sample that also correlates with high COD, and BOD values analyzed during the physico-chemical analysis. The C can also exist in the form of metal carbonates as indicated in section 5. The N values ranged from 2.2 to 5.8% also indicating the presence of organic matter. Higher oxygen values ranging from 22 to 37% revealed organic matter and minerals in the form of oxides and hydroxides. Among the cations, Na predominated in all the leachate samples (5.8–12%). And among the anions, Cl levels were relatively high (up to ~5%) compared to other anionic radicals. The elemental composition of the leachate solids is given in Table 2.

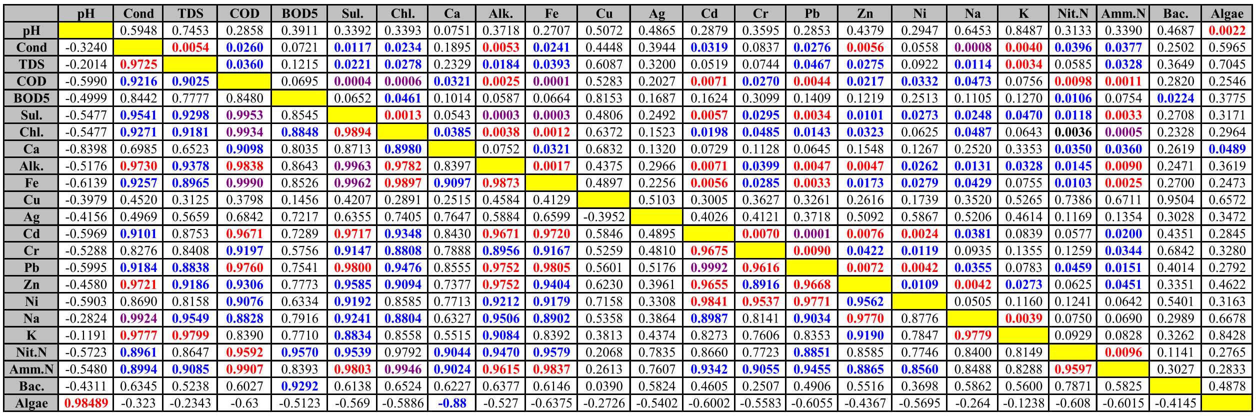
3.3. *Statistical relationship*

The data collected from various locations were analyzed with Paleontological Statistics software (PAST 2.14). Correlation analysis was performed and is elucidated in Table 3, and the level of significance is assessed at three different confidence intervals as mentioned in Table 3. Firstly at high confidence levels (~99.9% i.e. $p < 0.001$) Sulphide, Chloride and Fe are significantly correlated with COD. Fe and sulphates correlated with alkalinity. The heavy metals like Pb were significantly correlated with Cd. Ions as Na and Cl were significantly correlated with Conductivity and the presence of Ammo.-N respectively. Correlation at 99% and 95% can be viewed from Table 3.

Multiparametric tests like detrended correspondence analysis (DCA) help in reduction of the dimensionalities which is because of a complex relationship of the species to the environment and the physico-chemical parameters and helps in establishing linkages through correlations between environmental, biological, and chemical variables with the help of ordination axis. The steps to run DCA have been provided in Appendix 1 in the supplementary material. The detrended correspondence analysis indicated a unimodal response of variance. Usually, such statistical analysis is used to show affinities and differences between species and sites to avoid the arc-shaped distribution of the samples when there is a single strong gradient affecting the samples (Gauch, 1982). Some environmental parameters in the form of physico-chemical variables were considered to interpret the patterns observed with DCA: mainly biological and chemical variables in leachate were considered: nitrates, nitrites, ammonium, phosphates, BOD, COD total bacterial and algal counts. The contribution of the environmental, biological and chemical variables to explain species-sites variance obtained in the DCA was analyzed by Pearson correlations using environmental variables and values of the locations in the ordination Axes 1 and 2 in the multivariate analysis. Neither the environmental nor the biota data were transformed for the analysis.

Results from the DCA analysis for coverage values of samples collected from the various locations are elucidated in Fig. 2. The leachate samples are distributed along the plane defined by the two first axes. Axes 1 and 2 account for 80.98% of the total variance of the data set (73.61% and 7.37%, for axes 1 and 2, respectively). On the first axis, samples were dominated by algal species i.e. *Spirulina*

Table 3
Correlation analysis of various physico-chemical parameters of the leachate samples.



	pH	Cond	TDS	COD	BOD5	Sul.	Chl.	Ca	Alk.	Fe	Cu	Ag	Cd	Cr	Pb	Zn	Ni	Na	K	Nit.N	Amm.N	Bac.	Algae
pH		0.5948	0.7453	0.2858	0.3911	0.3392	0.3393	0.0751	0.3718	0.2707	0.5072	0.4865	0.2879	0.3595	0.2853	0.4379	0.2947	0.6453	0.8487	0.3133	0.3390	0.4687	**0.0022**
Cond	-0.3240		**0.0054**	**0.0260**	0.0721	**0.0117**	**0.0234**	0.1895	**0.0053**	**0.0241**	0.4448	0.3944	**0.0319**	0.0837	**0.0276**	**0.0056**	0.0558	**0.0008**	**0.0040**	**0.0396**	**0.0377**	0.2502	0.5965
TDS	-0.2014	**0.9725**		**0.0360**	0.1215	**0.0221**	**0.0278**	0.2329	**0.0184**	**0.0393**	0.6087	0.3200	0.0519	0.0744	**0.0467**	**0.0275**	0.0922	**0.0114**	**0.0034**	0.0585	**0.0328**	0.3649	0.7045
COD	-0.5990	**0.9216**	**0.9025**		0.0695	**0.0004**	**0.0006**	**0.0321**	**0.0025**	**0.0001**	0.5283	0.2027	**0.0071**	**0.0270**	**0.0044**	**0.0217**	**0.0332**	**0.0473**	0.0756	**0.0098**	**0.0011**	0.2820	0.2546
BOD5	-0.4999	0.8442	0.7777	0.8480		0.0652	**0.0461**	0.1014	0.0587	0.0664	0.8153	0.1687	0.1624	0.3099	0.1409	0.1219	0.2513	0.1105	0.1270	**0.0106**	0.0754	**0.0224**	0.3775
Sul.	-0.5477	**0.9541**	**0.9298**	**0.9953**	0.8545		**0.0013**	0.0543	**0.0003**	**0.0003**	0.4806	0.2492	**0.0057**	**0.0295**	**0.0034**	**0.0101**	**0.0273**	**0.0248**	**0.0470**	**0.0118**	**0.0033**	0.2708	0.3171
Chl.	-0.5477	**0.9271**	**0.9181**	**0.9934**	**0.8848**	**0.9894**		**0.0385**	**0.0038**	**0.0012**	0.6372	0.1523	**0.0198**	**0.0485**	**0.0143**	**0.0323**	0.0625	**0.0487**	0.0643	**0.0036**	**0.0005**	0.2328	0.2964
Ca	-0.8398	0.6985	0.6523	**0.9098**	0.8035	0.8713	**0.8980**		0.0752	**0.0321**	0.6832	0.1320	0.0729	0.1128	0.0645	0.1548	0.1267	0.2520	0.3353	**0.0350**	**0.0360**	0.2619	**0.0489**
Alk.	-0.5176	**0.9730**	**0.9378**	**0.9838**	0.8643	**0.9963**	**0.9782**	0.8397		**0.0017**	0.4375	0.2966	**0.0071**	**0.0399**	**0.0047**	**0.0047**	**0.0262**	**0.0131**	**0.0328**	**0.0145**	**0.0090**	0.2471	0.3619
Fe	-0.6139	**0.9257**	**0.8965**	**0.9990**	0.8526	**0.9962**	**0.9897**	**0.9097**	**0.9873**		0.4897	0.2256	**0.0056**	**0.0285**	**0.0033**	**0.0173**	**0.0279**	**0.0429**	0.0755	**0.0103**	**0.0025**	0.2700	0.2473
Cu	-0.3979	0.4520	0.3125	0.3798	0.1456	0.4207	0.2891	0.2515	0.4584	0.4129		0.5103	0.3005	0.3627	0.3261	0.2616	0.1739	0.3520	0.5265	0.7386	0.6711	0.9504	0.6572
Ag	-0.4156	0.4969	0.5659	0.6842	0.7217	0.6355	0.7405	0.7647	0.5884	0.6599	-0.3952		0.4026	0.4121	0.3718	0.5092	0.5867	0.5206	0.4614	0.1169	0.1354	0.3028	0.3472
Cd	-0.5969	**0.9101**	0.8753	**0.9671**	0.7289	**0.9717**	**0.9348**	0.8430	**0.9671**	**0.9720**	0.5846	0.4895		**0.0070**	**0.0001**	**0.0076**	**0.0024**	**0.0381**	0.0839	0.0577	**0.0200**	0.4351	0.2845
Cr	-0.5288	0.8276	0.8408	**0.9197**	0.5756	**0.9147**	**0.8808**	0.7888	**0.8956**	**0.9167**	0.5259	0.4810	**0.9675**		**0.0090**	**0.0422**	**0.0119**	0.0935	0.1355	0.1259	**0.0344**	0.6842	0.3280
Pb	-0.5995	**0.9184**	**0.8838**	**0.9760**	0.7541	**0.9800**	**0.9476**	0.8555	**0.9752**	**0.9805**	0.5601	0.5176	**0.9992**	**0.9616**		**0.0072**	**0.0042**	**0.0355**	0.0783	**0.0459**	**0.0151**	0.4014	0.2792
Zn	-0.4580	**0.9721**	**0.9186**	**0.9306**	0.7773	**0.9585**	**0.9094**	0.7377	**0.9752**	**0.9404**	0.6230	0.3961	**0.9655**	**0.8916**	**0.9668**		**0.0109**	**0.0042**	**0.0273**	0.0625	**0.0451**	0.3351	0.4622
Ni	-0.5903	0.8690	0.8158	**0.9076**	0.6334	**0.9192**	0.8585	0.7713	**0.9212**	**0.9179**	0.7158	0.3308	**0.9841**	**0.9537**	**0.9771**	**0.9562**		0.0505	0.1160	0.1241	0.0642	0.5401	0.3163
Na	-0.2824	**0.9924**	**0.9549**	**0.8828**	0.7916	**0.9241**	**0.8804**	0.6327	**0.9506**	**0.8902**	0.5358	0.3864	**0.8987**	0.8141	**0.9034**	**0.9770**	0.8776		**0.0039**	0.0750	0.0690	0.2989	0.6678
K	-0.1191	**0.9777**	**0.9799**	0.8390	0.7710	**0.8834**	0.8558	0.5515	**0.9084**	0.8392	0.3813	0.4374	0.8273	0.7606	0.8353	**0.9190**	0.7847	**0.9779**		0.0929	0.0828	0.3262	0.8428
Nit.N	-0.5723	**0.8961**	0.8647	**0.9592**	**0.9570**	**0.9539**	0.9792	**0.9044**	**0.9470**	**0.9579**	0.2068	0.7835	0.8660	0.7723	**0.8851**	0.8585	0.7746	0.8400	0.8149		**0.0096**	0.1141	0.2765
Amm.N	-0.5480	**0.8994**	**0.9085**	**0.9907**	0.8393	**0.9803**	**0.9946**	**0.9024**	**0.9615**	**0.9837**	0.2613	0.7607	**0.9342**	**0.9055**	**0.9455**	**0.8865**	**0.8560**	0.8488	0.8288	**0.9597**		0.3027	0.2833
Bac.	-0.4311	0.6345	0.5238	0.6027	**0.9292**	0.6138	0.6524	0.6227	0.6377	0.6146	0.0390	0.5824	0.4605	0.2507	0.4906	0.5516	0.3698	0.5862	0.5600	0.7871	0.5825		0.4878
Algae	**0.98489**	-0.323	-0.2343	-0.63	-0.5123	-0.569	-0.5886	**-0.88**	-0.527	-0.6375	-0.2726	-0.5402	-0.6002	-0.5583	-0.6055	-0.4367	-0.5695	-0.264	-0.1238	-0.608	-0.6015	-0.4145	

BLUE – Significance at $p < 0.05$

RED – Significance at $p < 0.01$

PURPLE – Significance at $p < 0.001$

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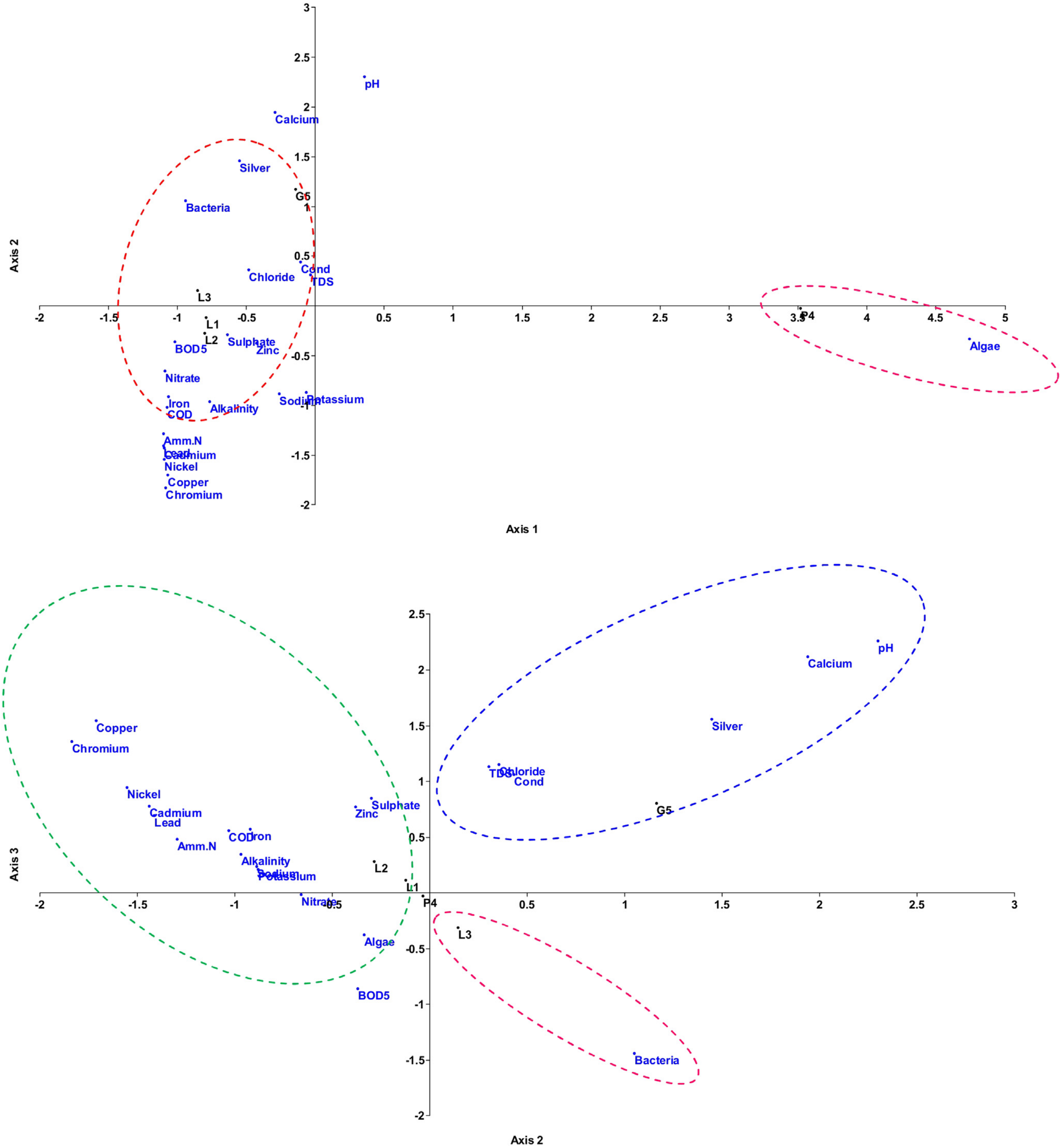

Fig. 2. Detrended correspondence analysis (DCA) ordination plot showing the distribution of samples and species on ordination Axis 1, Axis 2 and Axis 3.

sp. collected from location 4 i.e. P4, situated close to the ordination axis (Fig. 2), are opposed to samples dominated by bacteria. The Axis 2 explains the variability of the bacterial population in relation to L3. This explains higher bacterial abundance at L3. A big central group is represented by the mostly the abundance of metals, with other ionic parameters links to samples L1 and L2 are situated with values between axis 2 to 3 (see Fig. 3).

The loadings on Axis 1 indicated that the axis is positively impacted with location P4 and algal abundance. Similarly, loadings on Axis 2 indicate strong correlations between location G5 with pH and Ca values. However, loadings on Axis 3 indicate a high correlation between metals and other physico-chemical parameters and negative correlations with the microbes. The cluster analysis helped in grouping the samples based on spatial similarities of the five locations with varied concentrations and nature in the leachate ponds, surface and ground water samples. The Wards method showed two separate clusters that illustrate variations in the nature and type of the samples based on (a) physico-chemical parameters (b) trace metal concentrations and (c) biological sample abundance and distribution. The results showed Cluster I (~55% similarity)

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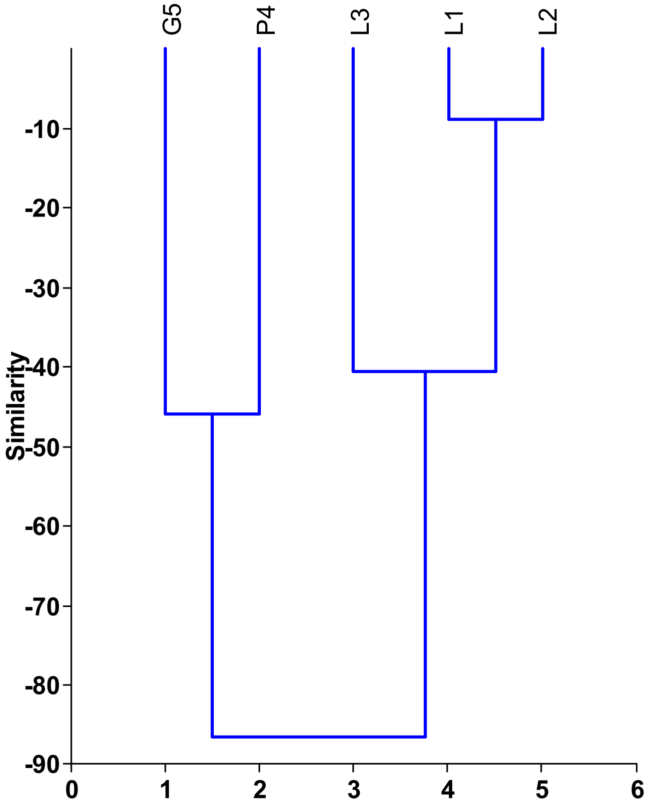

Fig. 3. Cluster analysis.

comprised of two samples P-4 and G-5. Cluster II comprised of a sub-cluster that consisting of samples L1 and L2 and a lone sample L3. The sub-cluster and the lone sample L-3 were having ~60% similarity. However, the samples within the sub-cluster that comprise of L1 and L2 had a similarity value of >90%. This indicates L1 and L2 are more or less leachate sample of a similar nature while leachate sample L3 is slightly different as it located a little away from the landfill. This matches with the similarity of the samples considering its physico-chemical characteristics. The L3 samples have more organic matter and thus are different from the samples L1 and L2. Contrary to these samples the G5 and P4 samples are completely different. Also, G5 and P4 are different within the cluster I. The cluster analysis shows a clear cut distinction between the samples collected from the leachate ponds (L1-L3) and surface and ground water (P4 and G5), that proves dissimilarity in their nature. Such analysis helps in identification of impacted sites for better management practices.

3.4. Biological sample analysis

Biological analysis data are a more reliable assessment of long-term ecological changes in the quality of pond systems compared to its rapidly changing physico-chemical characteristics that are faster to analyze (Mahapatra, 2015). Biological indicators can portray the changes in water bodies that help in understanding the systems dynamics and aids in identifying key drivers by causal effect relationships (Mahapatra and Ramachandra, 2013; Mahapatra et al., 2013b,c). Biological communities exposed to pollutants integrate both past and present environmental phenomena.

The leachate samples collected from locations L1 to L3 were studied through the scanning electron microscope. The results showed (Fig. 4) that the leachate samples were dominated by bacteria especially different kinds of bacillus i.e. individual bacillus cells, diplo-bacillus and strepto-bacillus followed by coccus, spirochete and vibrio and the total bacterial count ranged from 3 to 4 log orders. Some filamentous cyanobacteria were also observed in the leachate samples. A complete bacterial analysis requires high throughput bio-molecular tools or culture based assays. Classification using advanced molecular analysis of the bacteria present in leachate samples has been carried out by Zhang et al. (2011). Detailed phylogenetic analysis of the bacterial population is presently being undertaken that will be communicated shortly.

However the samples collected from the Pond (P4), were prolifically dominated by *Spirulina* sp. with a very high cell count of 10^5 cells/ml. The abundance of *Spirulina* was significantly correlated with high ionic conductivity, pH and dissolved oxygen (Mahapatra et al., 2013b). The sample collected from the open well (G5) showed (Fig. 4) low bacterial counts but revealed the presence of different algal species mostly comprising of green algae and euglenoids. In short the microbial analysis revealed myriads of bacterial populations mainly bacillus, coccus, and spirochete. Contrary to this the surface water in the pond samples showed higher incidence of single species of cyanobacteria i.e. Cyanophyceae indicating an altogether different environment compared to the leachate sites. The open well samples, however, showed different algal populations with low bacterial counts.

3.5. Leachate pollution index (LPI)

LPI values have been calculated for leachate samples of Mavallipura landfill site as per the procedure summarized in Table 4. Mercury, arsenic, and cyanide have not been identified in the leachate samples. Hence, no weightage for these trace metals were provided for LPI calculation. In this study, a detailed analysis of total coliform bacteria and phenolic compounds has not been carried out. The highest leachate pollution index was observed in L1 owing to potential toxicity and higher metal, inorganic and organics concentrations. Significantly high ammo.-N and organic-N were recorded in these samples pressing on immediate treatment for the stalled leachate fractions in these MSW landfill sites. Earlier studies have showed that high ammonia and alkalinity are toxic for duckweeds (Clement and Merlin, 1995). High N also poses a greater risk of nutrient enrichment and consequent eutrophication in receiving waters and is more harmful to aquatic animals in gaseous ammonia form. The ammonia in the gaseous form produces odor problems in the nearby area (Moreno et al., 2014). Generally, phenolic compounds are found to be very less in most of the Indian landfill leachates (Devnita Polley, 2013). Thus in this study to bring out the effect of background pollution index, LPI has been calculated.

It can be seen that the LPI value for the L1 is the highest while the LPI value for the L3 is found to be the lowest. Higher LPI presses the need for treatment of Mavallipura landfill leachate, followed by continuous monitoring. Aerobic biological treatment process with extended aeration is required for treatment of Mavallipura leachate as it has a high organic strength. The high ammo.-N can be treated by nitrification followed by denitrification. Comparatively lower values of LPI for L3 are attributable to low concentrations of heavy metals in the leachate. However, the individual contaminants shall meet the discharge standards before discharge of leachate into any surrounding water bodies. The results indicate that the L1 and L2 have relatively high LPI value in comparison with the L3 and forms a different group/cluster, evident from the cluster analysis and therefore are not stabilized, with relatively high contamination potential and needs physico-chemical and biological treatment to prevent any further detrimental effects on surrounding eco-system and water environment. Mavallipura leachate samples can, therefore, pose a threat to the environment and human health and

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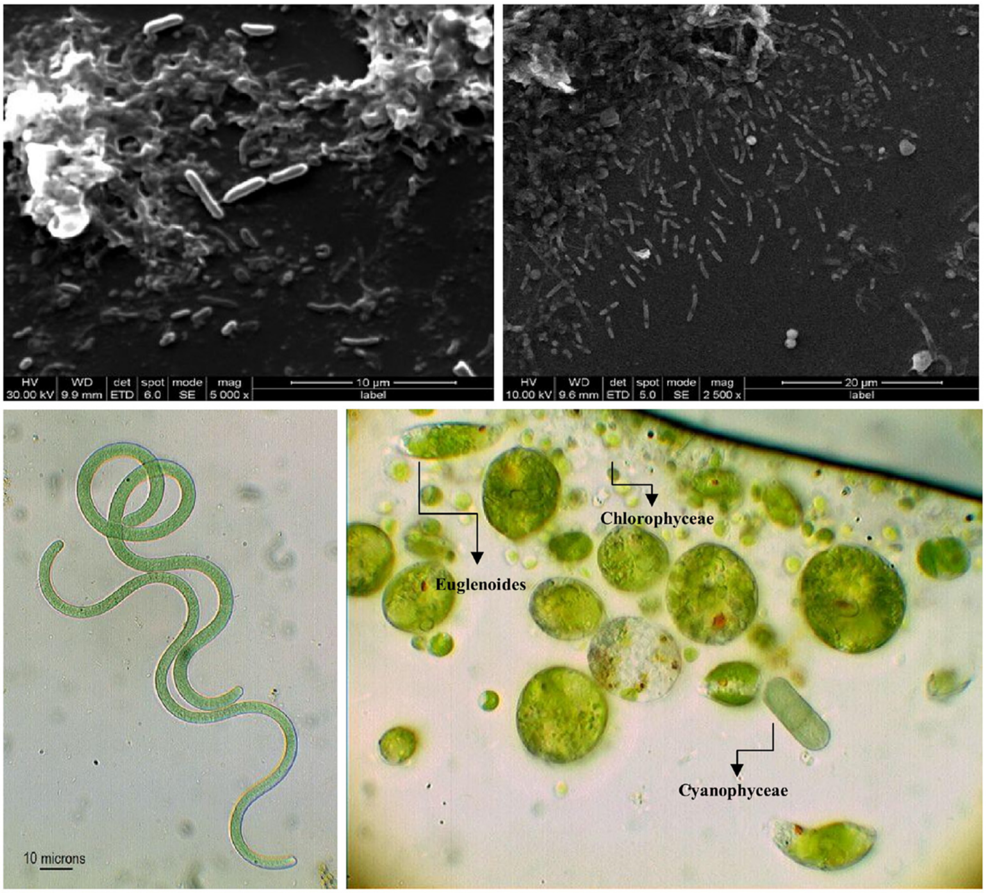

Fig. 4. SEM image microbiological analysis and Microbial biomass images in water bodies.

hence, measures and continuous monitoring must be ensured. Similar studies conducted on leachate samples (Devnita Polley, 2013) for Dhapa landfill site (KLS), Kolkata, India showed a relatively high LPI (40.32) on the other hand relative low LPI values of ~26 were observed (Slomczynska and Slomczynski, 2004) that further decreases to ~7.03 upon treatment that was under permissible limits.

3.6. Water quality index (WQI)

The surface water bodies near the Mavallipura landfill site are important sources of water for human activities. Unprecedented and continuous lobbying of MSW in the nearby landfill site can affect the water quality and thus the health of the local community. In the present purview of MSW disposal, with steep and unstable slopes, there can be ample chances of leachate runoff to the low lying water bodies. This also affects the ground water quality in the immediate vicinity. Therefore, WQI that surrogates and weights the water quality offers a useful representation of the overall quality of water for public use, gauzing the appropriateness of the water for further use and other utilitarian values. Table 5 shows the calculations for WQI values of pond (P4) and open well (G5) samples near the same landfill area.

Water quality index of the present water body is established from necessary physico-chemical parameters. The values of various physico-chemical parameters for calculation of water quality index are presented in Table 5. Based on earlier studies this water quality rating clearly shows that the status of the water body is eutrophic, and it is unsuitable for drinking and also observed that the pollution load is relatively high. Similar observations were recorded earlier (Yogendra and Puttaiah, 2008), where low DO, high BOD, and nitrates showed high WQI and thus nutrient enrichment in the urban water body Gopishettykere, in Shimoga town, Karnataka. High concentrations of sulphates, chlorides, and nitrates observed from the present study indicate unsuitability of this water for

Table 4
Leachate pollution index for the landfill leachate.

Pollutant, mg/l	Significance	L1	Pi Wi	L2	Pi Wi	L3	Pi Wi
pH	3.509	7.40	0.28	7.60	0.28	7.50	0.28
TDS	3.196	2027	0.40	2267	0.28	2097	0.50
BOD5	3.902	1500	3.36	1500	3.37	3000	3.68
COD	3.963	10,400	4.96	12,000	4.98	10,800	3.73
TKN	3.367	2330	5.04	3070	5.02	2593	4.55
Amm. Nitrogen	3.250	1803	5.10	2593	5.10	2170	5.10
Iron	2.830	11.16	0.22	12.04	0.00	11.25	0.00
Copper	3.170	0.15	0.25	0.01	0.25	0.00	0.25
Nickel	3.321	1.34	0.26	1.00	0.26	0.68	0.31
Zinc	3.585	3.00	0.28	2.40	0.28	2.40	0.28
Lead	4.019	0.30	0.31	0.28	0.32	0.22	0.32
Chromium	4.057	0.02	0.64	0.02	0.64	0.01	0.64
Chlorides	3.078	660	0.25	780	0.26	760	0.27
Mercury	3.923	BDL	–	–	–	–	–
Arsenic	3.885	BDL	–	–	–	–	–
Cyanide	3.694	BDL	–	–	–	–	–
Total			21.34		21.26		20.13
Final LPI value using Eq (3).			**30.10**		**29.99**		**28.39**

*BDL means below detection limit.

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Table 5
Water Quality index for the landfill pond & open well.

Parameters	Weightage	Pond sample	Wn x q_n	Well sample	Wn x q_n
pH	0.219	8.4	20.44	7.5	7.3
Elect. Conductivity	0.371	2500	309.17	1362	168.4
Total Dissolved Solids	0.0037	1447	1.07	703	0.52
Total alkalinity	0.0155	2000	25.83	300	3.875
Total hardness	0.0062	1500	3.10	1000	2.067
Total Suspended Solids	0.0037	1697	1.26	1384	1.02
Calcium	0.025	0	0.00	320	10.67
Magnesium	0.061	1500	305.00	200	40.67
Chlorides	0.0074	250	0.74	230	0.68
Nitrate	0.0412	0.18	0.02	1.09	0.09
Sulphate	0.01236	10	0.08	7	0.057
Dissolved oxygen	0.3723	2.7	65.52	2.1	72.97
BOD	0.3723	105	338.83	3	62.05
$\mathbf{WQI = \Sigma W_n \times q_n / \Sigma W_n}$			**716.55**		**245.28**

domestic use.

The above water quality is also supported by the variations in physiochemical parameters. Total dissolved solids and electrical conductivity were found to be very high. Major anions like chloride are one of the most important parameters in assessing the water quality. The higher concentration of chlorides indicates a higher degree of organic pollution. The concentration of dissolved oxygen indicates the distribution of flora and fauna. Biochemical oxygen demand (BOD) indicates the organic load in water bodies. Higher BOD values are found in the polluted water. The results revealed that quality of ground water resources in Mavallipura landfill is deteriorating day by day; largely as a result of the poor practice of solid waste management. Hence, an effective precautionary plan is required for the sustainable management, which can be used as a guideline in the regulation and supervision of ground water operations. The WQI values elucidate poor ground water in these areas and necessitate immediate action and investigations for identifying possible sources of contamination and consequential deterioration. Moreover, proper management strategies and effective precautionary plans are required for the appropriate treatment and management of solid waste that safeguards our future water resources.

The present study highlights the present status and the quality of the landfill leachate, through various characterization techniques and shows high organic matter, inorganic nutrients and trace metals in leachate that can potentially contaminate the surface and the ground water resources precipitation through runoff and leaching respectively. Diverse microbial population found in the study can further screened for biological treatment of landfill leachate. This study shows a need for better collection, containment and treatment of the landfill leachate to avoid environmental externalities and health hazards that addresses sustainable waste management in cities. Such type of studies would lead to devising vital strategies with proper actions and management plan for abating environmental pollution and safeguarding the future water resources.

4. Recommendation and protection measures

- Voluminous generation of leachate could be minimized by restricting water flow into the landfill through surface water diversion and reducing water accumulation in these landfill sites by frequent pumping and also by laying soil cover on a day to day basis. A low-permeability cover aids in restricting water infiltration into the landfill area. For suitable management of leachate, effective containment of leachate with improved collection facilities is necessary.
- Leachate produced during the landfill process has to be meticulously collected and treated with advanced microbial technologies as activated sludge process, sequential batch reactor, anaerobic baffled reactors, moving bed biofilm reactor, anaerobic filters, algal bioreactors and other biofilm-based technologies. This also helps in checking the deterioration of groundwater resources from these MSW landfill sites.
- The bacterial assemblages and algal communities found in the present study have to be further explored, and the potential for leachate treatment and bioenergy generation has to be tested by batch operations for further applications.
- As a part of upstream processing, it is equally important to ensure that only non-recyclable and inert waste is disposed of, and no hazardous and bio-medical waste is entertained in landfills. Thus, adequate waste segregation and utilization with bioprocesses like anaerobic digestion/composting for organic waste treatment and management and incineration for biomedical waste can be followed by land filling. Furthermore, adequate liners or barriers have to be installed in these landfill sites with proper capping for effective containment of the landfill wastes.
- Lastly, to infer high concentrations of organics, inorganic ions, trace metals and bacterial population coupled with towering LPI values necessitates immediate actions for leachate treatment and disposal and thus emphasizes on the requirement of continuous monitoring and surveillance strategy. The characterized leachate samples in the study that were observed to have high organic strength would require a hybrid dual-phase treatment process with initial anaerobic (phase I) and final aerobic (phase II) for complete removal of pollutants and other organic matter.

5. Summary and conclusions

Leachate analysis of Mavallipura landfill showed a high concentration of organic and inorganic constituents. Heavy metals concentration was in traces indicating that the waste dumped is predominantly municipal waste. Physico-chemical analysis showed significantly high salinity and alkalinity. Based on BOD_5/COD ratio the Mavallipura landfill leachates were found to be medium aged. Elemental analysis revealed the dominance of C followed by O and N compared to other elements indicating abundant organic matter in the samples. A clear distinction between the leachate samples and pond waters was observed through the cluster analysis. Furthermore, the microbiological analysis also revealed a substantial difference between the compositions of microflora in the

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samples. High LPI values indicated that leachate generated from landfill site are not stabilized and mature, and are still undergoing decomposition and thus have high chances to cross contaminate nearby surface and ground waters. Based on the various analysis performed in the study possible linkages between the leachate and nearby water bodies was observed. Water quality in water bodies was found poor and enriched with ions and nutrients making it unsuitable for any use.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.envpol.2016.09.002.

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