Temporal Variation in Leachate Composition of A Newly Constructed Landfill Site in Lahore in Context To Human and Environmental Risks

Mahsoon Ashraf
University of the Punjab
Muhammad Zeshan
University of the Punjab
Sadia Hafeez
University of the Punjab
Rahib Hussain (rahibpcr@gmail.com)
University of the Punjab Quaid-i-Azam Campus: University of the Punjab https://orcid.org/0000-0003-0925-8828
Abdul Qadir
University of the Punjab
Muzaffar Majid
University of the Punjab
Farman Ahmad
Minhaj University Lahore
Sajid Rashid Ahmad
University of the Punjab

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Abstract

The present study was aimed to explore the seasonal and temporal variation in the extent and sources of physiochemical and trace elements in the Lakhodair solid waste Landfill site in Lahore, Pakistan. For the seasonal and temporal study of leachates, systematic composite samples were collected monthly (for one year) and analyzed for physiochemical and trace elements. The concentration of TDS, TSS, COD, NH_3-N, BOD_5, sulfate, sulfides, phenolic compounds, oil and grease were higher than the National Environmental Quality standard (NEQs). The trace elements, namely Mn (1.7 mg/L), and Cd (0.05 mg/L), while in a few samples Fe (14 mg/L), Ni (1.6 mg/L), and Zn (6.7 mg/L) were higher than the NEQs. In Lakhodair leachates, TDS, COD, NH3-N, BOD_5, sulfides, and Cl have a high concentration coefficient (i.e., CC 3 to > 6), which may cause considerable to high contamination, while remaining parameters may cause low to moderate contamination (CC 1 to $\leq$ 3). The lower BOD_5/COD ratio (< 0.1) in the Spring and Autumn seasons, represents the active methanogenesis and anaerobic activities in the Lakhodair landfill site. The anaerobic and methanogenesis enhance the redox reaction as a result CO_2 is emitted and alternatively increases pH, TDS, COD, Cl, BOD_5, NH_3-N, sulfides, phenolic compounds in leachates. However, the lower concentration of some trace elements may be because of an anaerobic process that may immobilize the trace elements. It is presumed that the trace elements in the Lakhodair landfill may be in a metastable state, which is not easy to leach out. It's hereby recommended that Leachate produced in the Lakhodair landfill site need to handle carefully so as to limit the environmental and health implication.

Introduction

Solid waste management and minimization is a global issue being faced by the world especially the developing countries, where the national budget for solid waste management is negligible. Alternatively, global awareness about the impacts of solid waste associated with human health, water, soil, and air are increasing rapidly. Earlier, solid waste management was not a big issue and societies manage their wastes effectively, however increasing population and urbanization rendering solid waste management much more complex (Singh et al. 2014). Due to the financial crisis, both developing and under-developing countries are not focusing to carry out waste management under controlled parameters (Fernando 2019). The major sources of solid waste are domestic wastes (i.e., food waste, housekeeping), agricultural waste (i.e., fertilizers waste, crops residue, farm wastes), commercial wastes (i.e., markets, hospitals, hotels, schools, and offices), Industrial wastes (metals scraps, oils, chemicals, trash), and mining wastes (i.e., rock gangue, soil-gravels, toxic elements) (Artiola 2019, Blengini et al. 2019, Olanrewaju &Ilemobade 2009, Van der Zee et al. 2004).

In Pakistan, the solid wastes generation rate is 0.283 to 0.65 kg/capita/d with an annual growth rate of 2.4 % (Azam et al. 2020). By an instant increase in solid waste, the morbidity rate is increasing with an increasing mortality rate in Pakistan due to improper solid waste management and associated diseases (Nisar et al. 2008). Further, the unplanned disposal and deposition of solid wastes affect the food crops, air, and water quality of Lahore, where the mortality rate is ~ 25,000/ year through waterborne disease (Muhammad &Zhonghua 2014). The local government dealing and handling the SWM, however, the lack of proper financial resources, infrastructure, planning, and unavailability of effective machinery fails to the handling of solid wastes, properly (Batool &Ch 2009). The improper collection and transportation boost the solid waste accumulation in urban territories i.e., streets, streams, roadside, corners, and rivers, which pose serious threats to local inhabitants, groundwater, and to the mesoscale environment (Ferronato &Torretta 2019). The negative impacts of solid wastes in an urban environment is increasing continuously, which need to quantify and comprehend the extent of problems, findings, and appropriate solution.

In developing countries, the rate of solid wastes generation is higher than the developing countries. The solid waste generation in the United States is 2.08 kg/capita/d, Europe 1.5 kg/capita/d, OECD countries (Organization of Economic Cooperation and Development) 1.4 kg/capita/d (Pires et al. 2011), China 1.2 kg/capita/d (Mian et al. 2017), and developing countries generated 0.76 kg/capita/d (United Nations 2002). In London, ~ 267,000 tons of waste is generated daily comprised of 42% non-residential and 58% residential wastes (Asase et al. 2009). A similar situation can be observed in Asian and other developing countries, where the population is increasing with declining the resources for the effective management of solid wastes (Bhuiyan et al. 2018, Ebeke &Etoundi 2017). However, in developed countries, there are enough resources, labor, and technology along with strong legislation to manage the solid wastes in an environmentally friendly way (Hodges et al. 2011, Mian et al. 2017). The effective management and recycling of solid wastes lead to the reduction of greenhouse gases, electricity production, recovery of hydrogen and methane gases, and reuse of environmentally friendly materials (Cheng &Hu 2010, Ryu 2010). International Atomic Energy Agency recovered about 7942 kJ/kg (calorific value) through effective recovery technology applied in effective incineration, which was higher than those reported by World Bank i.e., 7100 kJ/kg (Melikoglu 2013, World Bank 1999). However, in Lahore (Pakistan), about 14,490 kJ/kg energy is probed by using the bomb calorimeter (Azam et al. 2020). Similarly, the final wastes having no longer value can be disposed of safely in a specific landfilling site, which limits the environmental consequences and improves the urban aesthecity (Mian et al. 2017).

Additionally, Landfill leachate released major contamination, especially toxic trace elements, which affect the groundwater through infiltration and surface water through run-off. These leachates can transfer the microbial, chemical, and physical contaminants to water bodies and the environment, which pose serious threats to humans' health and nearby land use (Hui et al. 2006). The open dumping of solid wastes can increase ecotoxicity by the presence of organic compounds, trace elements, ammonia-nitrogen (NH_3-N), and chlorinated inorganic compounds (Bhalla 2013). The major influencing factors of leachates are the composition of waste, decomposition phase, climate, oxygen, landfill hydrology, and microbial activity (Umar et al. 2010). During the hydrolysis phase, aerobic decomposition replaces the sulfate (SO_4^{-2}), nitrate (NO_3^-), iron ($Fe(OH)_3$), and manganese (MnO_2) to produce fatty acids, amino acids, glycerine, and sugar (Rasmey et al. 2020, Veerapagu et al. 2013). In the Acidogenic phase, the fermentation produces volatile fatty acids i.e., propionic acid, butyric acid, and alcohols, which are further converted to acetic acid, H_2, CO_2 as well as the dissolution of trace elements (Fennell et al. 1997, Shi et al. 2019). Leachates further followed the methanogenic phase, where produce methane (CH_4), carbon dioxide (CO_2)/ carbonic acid (H_2CO_3), and bicarbonate (Kubin 2012, Stuart &Klinck 1998, Taylor &Allen 2006).

Most of the landfill sites in Pakistan have not proper SOPs (standard operation procedure), which may cause serious problems to both surface and groundwater, agricultural land, humans, and the environment. The weak policies regarding solid wastes management are one major issue in Pakistan, which alternatively affect human lives and the urban environment (Masood et al. 2014). Similarly, Lahore waste management company has initiated to construct sanitary landfill site at the Lakhodair and in other areas, in Lahore city. Lakhodair Landfill site receiving ~ 5300 tons of solid wastes per day that generate huge quantities of leachates daily (Masood et al. 2014). The solid wastes and leachates in Lakhodair causing serious threats to water bodies, soil, humans, and the environment. However, the leachate composition is changing with the seasons and produces various toxic trace elements and compounds, and other physical pollutants. Therefore, the present study aimed 1) to evaluates the seasonal variations of various physiochemical parameters and toxic trace elements and compounds in Lakhodair landfill site Lahore. 2) To assist in the determination and implementation of the most suitable technique to effectively manage the leachate throughout the year and minimize its negative impacts on the humans and environment.

Materials And Methods

Field survey and sampling

Lakhodair landfill site, Lahore has been selected to study the seasonal variations and the production of toxic matters in leachate composition. Lakhodair waste landfill site is the largest one in Pakistan located on latitude 31° 37′ 36.6″ N and longitude 74° 25′ 07.6″ E spread over an area of about 52 hectares (Khalil et al. 2019) (Fig. 1). The study area is located at a distance of 4.3 km from Ravi River and 1.2 km from Lakhodair village and the city's main road (Fig. 1). The landfill site has a proper bottom liner and leachate collection system. For waste receiving, 06 cells are constructed, of which 02 cells are functional along with 02 leachate collection ponds. Internationally, the landfill site is divided into young, intermediate, and old landfill site with an age (years) of < 5, 5–10, and > 10, respectively (Renou et al. 2008), however, the Lakhodair landfill was fully operated in 2006 and have been considering as old landfill site (Khalil et al. 2019, 2020).

A composite sample (from various portions) was collected systematically from leachate ponds at the start of each month for one year i.e., from February 2017 to January 2018 (Table S1). The samples were collected in a clean plastic bottle rinsed twice with distilled water. All these samples were kept at 5˚C, while duplicate samples were kept at -1˚C for the sake of sample security and data reproduction. For all sorts of sample collection, preservation, and transformation to the chemical Laboratory College of Earth and Environmental Sciences, University of the Punjab, Lahore, standard sampling techniques were followed (Borjac et al. 2019, Eaton et al. 2005, Hussain et al. 2014).

Experimental work

The pH, EC, and TDS in the leachate sample were measured through a digital meter (Lovibond Con-200). Oil and grease were measured through a separating funnel using n-Hexane, COD was measure through the Open Reflux method, BOD_5 was measure digital meter, ionic detergent was measure through colorimetric methods (Gündoğdu et al. 2018, Hussain et al. 2021). For toxic trace elements, a 50 mL leachate sample was transferred to a beaker and reduce the volume up to 15–20 mL through heating. Thereafter, adding 15 mL HNO_3 (conc.) and heated for 30 minutes, then adding 15 mL HCl (conc.) and heated for 30 minutes again and finally diluted to 100 mL. The prepared solutions were further used for the determination of toxic trace elements using atomic absorption and inductively coupled mass spectroscopy (Du et al. 2017, Hussain et al. 2019b)

Phenolic compounds in leachate were determined through Gas Chromatography and Mass Spectrometric method. In detail, 250 mL distilled water was taken in a flask, and add little copper sulfate ($CuSO_4$) solution (10 %). For pH maintenance at 4.0, add H_3PO_4 (10 %), put the solution in the distillation plant, and keep heated. After heating, 100 mL sample took from the distillation plant and adjust pH at 10 ± 0.2 using NH_4OH solution (40 %). Then add 2 mL $K_3Fe(CN)_6$ (8 %) and 2 mL amino-antipyrine 2 % solution and set the absorbance at 510 nm (Gilcreas 1966, Mareai et al. 2020).

Moreover, the obtained data were pass through various software's i.e., excel sheet, origin, SPSS, while the concentration coefficient (CC) were determined through Eq. 1 as suggested by Hussain et al. (2019a).

$$CC = C_n / R_f \quad (1)$$

Where C_n represents the target values in leachates, R_f represents the reference value. For comparison and evaluation, the contamination degrees (i.e., CC) can read as CC < 1 low contamination, CC 1–3 moderate contamination, 3–6 considerable contamination, and CC > 6 indicate high contamination (Table S2).

Results

Leachate samples collected (monthly) from the Lakhodair landfill site were analyzed for various physiochemical parameters and toxic trace elements, which were further arranged monthly and seasonally (Table 1 and Table 2). Most of the parameters, namely TDS, TSS, BOD_5, COD, NH_3-N, sulfate, sulfides, chloride, oil and grease, and some toxic trace elements were higher than the standard permissible level (Table 1). Landfill age and seasons have a marked effect on the composition of leachate due to the degradation of organic and inorganic matters (Kulikowska &Klimiuk 2008, Su et al. 2019).

Table 1 Evaluation of the physiochemical and trace elements composition (mg/L) in the Lakhodair leachates

Parameters	Minimum	Maximum	Average +STDV	Median	NEQs
pH	8.27	9.18	8.822±0.3	8.835	09
TDS	6736	25640	18533.3±4547.7	18580	3500
TSS	60	920	356.3±239.8	280	400
Oil & Grease	3	40	22.17±12.6	20	10
COD	4553	12620	7192.3±2653.6	5946.5	400
NH_3-N	288	1250	544.3±273	475.5	40
BOD_5	240	4200	1441.7±1242.1	1111	250
Sulfate	16	10400	1259.5±2906.8	320	1000
Sulfides	0.32	21	5.646±6.4	2.465	01
Chloride	350	8097	4506.7±2076.6	4486	1000
Fluoride	0.2	4.2	1.878±1.6	1.46	10
Ionic Detergents	0.009	15.48	3.026±4.5	0.755	20
Total Chlorine	0.03	0.25	0.088±0.1	0.075	1
Arsenic	0	0.05	0.0113±0.02	0	1
Cadmium (Cd)	0	0.15	0.053±0.1	0.04	0.1
Chromium (Cr)	0.03	0.51	0.096±0.1	0.05	1
Copper (Cu)	0.07	0.81	0.218±0.2	0.15	1
Iron (Fe)	0.4	14.1	5.096±3.6	3.64	8
Lead (Pb)	0.012	0.27	0.06±0.07	0.043	0.5
Manganese (Mn)	0.03	11.8	1.679±3.2	1	1.5
Nickel (Ni)	0	1.56	0.356±0.4	0.23	1
Zinc (Zn)	0.19	6.68	4.077±2.4	5.11	5
Silver	0	0.031	0.017±0.01	0.017	1
Barium	0.019	0.16	0.109±0.04	0.128	1.5
Boron	0	15.2	3.383±4.3	1.2	6
Cyanide (CN)	0.007	0.968	0.169±0.3	0.066	1
Phenolic compound	0.138	0.8	0.33±0.2	0.274	0.3
Total Toxic Elements	0.251	13.29	2.258±3.5	1.33	2

STDV-standard deviation, NEQs-National Environmental Quality Standards, Pakistan

Table 2 Seasonal variations in Physiochemical and trace elements (mg/L) of Leachate collected from Lakhodair landfill site, Lahore

Parameters	**Spring**	**Summer**	**Autumn**	**Winter**
PH	8.823 ±0.2	8.767 ±0.4	8.865 ±0.3	8.863±0.290
TDS	18073.3 ±1090	20415 ±3532	21248 ±4084	14674.7 ±6956
TSS	293.3 ±205	430 ±328	426 ±206	274.7 ±243
Oil & Grease	26.7 ±11.5	25 ±10	21.5 ±26	14.3 ±10.4
COD	5850.7 ±373	7584 ±3359	8878 ±4754	6887.7 ±2091
NH_3-N	785 ±409	531 ±247	305 ±24	481 ±9.5
BOD_5	1400.7 ±1328	1588.3 ±1779	829 ±397	1696 ±1172
Sulfate	537.3 ±546	333.75 ±515	490 ±296	3729 ±5787
Sulfides	10.4 ±10.1	1.932 ±1.4	7.145 ±7	4.87 ±5
Chloride	5114.6 ±1760	5323.5 ±1870	5198 ±777	2349 ±2391
Fluoride	2.896 ±1.4	2.027 ±2	0.8 ±0.8	1.38 ±0.9
Ionic Detergents	6.3 ±8	2.744 ±3	0.016 ±0.01	2.103 ±2.3
Total Chlorine	0.13 ±0.1	0.067 ±0.02	0.045 ±0.02	0.1 ±0.03
Phenolic compounds	0.18 ±0.1	0.273 ±0.1	0.379±0.1	0.525 ±0.3
Arsenic (As)	0.003 ±0.01	0.025 ±0.03	0.000 ±0	0.008 ±0.01
Cadmium (Cd)	0.020 ±0.01	0.048 ±0.01	0.150 ±0	0.027 ±0.1
Chromium (Cr)	0.040 ±0.01	0.060 ±0.03	0.100 ±0.01	0.197 ±0.3
Copper (Cu)	0.350 ±0.4	0.165 ±0.1	0.225 ±0.1	0.153 ±0.1
Iron (Fe)	8.033 ±5.5	4.75 ±3.7	2.585 ±0.7	4.293 ±1.1
Lead (Pb)	0.057 ±0.04	0.094 ±0.1	0.036 ±0.02	0.032 ±0.02
Manganese (Mn)	0.900 ±0.5	1.24 ±0.3	5.915 ±8	0.220 ±0.1
Nickel (Ni)	0.447 ±0.1	0.21 ±0.03	0.795 ±1	0.167 ±0.2
Zinc (Zn)	6.200 ±0.4	5.51 ±0.5	3.650 ±0.5	0.333 ±0.2
Silver	0.023 ±0.01	0.014 ±0.001	0.026 ±0.01	0.007 ±0.012
Barium	0.134 ±0.02	0.14 ±0.01	0.073 ±0.1	0.070 ±0.03
Boron	5.867 ±0.8	1.175 ±0.2	0.950 ±0.1	5.467 ±8.1
Cyanide	0.008 ±0.0	0.39 ±0.4	0.152 ±0.1	0.045 ±0.02
Total Toxic Elements	1.356 ±0.2	1.76 ±0.3	6.894 ±9	0.729 ±0.4

Similarly, the analyzed samples showed some compliance with respective standards, and the significant deviations were equally noticed. The physiochemical characteristic of leachate indicates alkaline nature with a pH of 8.27 to 9.18 and NH_3-N 288 to 1250 mg/L, which was higher than the standard permissible level (40 mg L^{-1}) (Table 1). The pH of old landfill leachate is more stable and high than the young one, which indicates the decomposition of humus (organic compounds) and oily wastes (Tanikawa et al. 2018). The TDS was ranged from 6736–25640 mg/L and TSS was 60–920 mg/L, which was higher than those report by Bhalla (2013) i.e., TDS 6863 mg/L. The COD concentration in Lakhodair leachate was 4553–12620 mg/L, which was higher than the NEQs level i.e., 400 mg/L. The source of higher COD is due to the lack of aeration, presence of organic matter, higher temperature, and bacterial community (Noerfitriyani et al. 2018). The Lakhodair landfill is considered to be an old landfill site because of stable leachate pH i.e., 8.3–9.2 (throughout the year) and its age is > 10 years. The pH of mature leachate is mostly stable with slight variation in seasons, however, the pH of the leachate is increasing with decreasing/ decomposition of oil and fatty materials (Khalil et al. 2020, Renou et al. 2008). The concentration of sulfate was 16-10400 mg/L and sulfides was 0.3–21 mg/L, which was both comparably higher than the NEQs i.e., 1000, and 01 mg/L, respectively (Table 1). The highest concentration of sulfate was measured in November i.e., 10400 mg/L, while sulfide in February i.e., 21 mg/L (Table 2).

Similarly, the chloride concentration was 350–8097 mg/L, while NH_3-N was 288–1250 mg/L, which higher than the standard permissible level i.e., Cl 1000 mg/L and NH_3-N 40 mg/L, respectively (Table 1, Fig. 2). The chloride concentration in young landfill (1 to 2 year old) may range from 200 to 3000 mg/L, while in an old landfill site (5 to 10 year old), the chloride may decrease to 100 to 400 mg/L (Deng &Englehardt 2006). The present study results were consistent with the result of Tatsi andZouboulis (2002). The BOD_5 concentration in the entire year was ranged from 240 to 4200 with an average of 1442 mg/L, which was higher than the NEQs level i.e., 250 mg/L (Table 1). Additionally, BOD_5 in spring was 1400, summer 1588, autumn 829, and winter 1696 in mg/L (Fig. 2). The high concentration in winter was due to the higher availability of oxygen which is inversely proportion to temperature.

The concentration of oil and grease in landfill leachates was ranged from 03 to 40 mg/L with an average of 22 mg/L, which was exotically higher than the NEQs level i.e., 10 mg/L (Fig. 1). The oil and grease in the spring season were 26, summer 25, autumn 21, and winter 14 in mg/L (Fig. 1). The major source of oil and grease is the use of oily compounds in foods. After using oily resources (meat, oil and ghee, baked goods, cheese, butter, and automobile oil), the major portion is being wasted/ disposed of in landfill sites. Further, these oily wastes can pass naturally through various processes and finally add to the local plumbing systems that may affect human health and the surrounding environment (Husain et al. 2014).

Phenolic compounds in Landfill Leachate were 0.138- 0.8 mg/L with an average of 0.3 mg/L, which was equivalent to the NEQs level (Table 1). The highest concentration of phenolic compounds was observed in autumn (0.38 mg/L) and winter seasons (0.5 mg/L), while the lowest values were in the summer (0.27

mg/L) and spring (0.17 mg/L) (Fig. 1, Table S3). The highest concentration of phenolic compound was 0.800 mg/L in December, while the lowest was 0.138 mg/L in April (Fig. 2). The source of phenolic compounds in leachates is the degradation of organic matter especially fruits and flowering plants, which pose harmful threats to groundwater (Anku et al. 2017). Similarly, the concentration of ionic detergent was 0.009 to 15.5 mg/L with an average of 3 mg/L, which was lower than the NEQs level i.e., 20 mg/L (Table 1). However, the concentration in the spring seasons was 6.3, summer 2.7, autumn 0.016, and winter 2.1 in mg/L (Fig. 2, Table S3). The concentration of fluoride was 0.2 to 4.2 with an average of 1.9 mg/L, which was lowered than the acceptable level i.e., 10 mg/L (Table 1). The active source of fluoride is minerals and associated materials, including glass, construction materials, medical wastes, soil plants, and food wastes. Fluoride from the aforementioned sources comes to leachate either through degradation/ or dissolution in leachates (Vithanage &Bhattacharya 2015). The high concentration may cause pandemic fluorosis, which is commonly observed in China, India, and Japan (Hussain &Luo 2018, Yang et al. 2003).

Many chemical species, particularly trace elements have been observed at very low concentrations even lower than the detection limits of respective standards. However, low concentrations of toxic compounds do not always confer the leachate to be less hazardous as large volumes of leachate may contribute substantial quantities of pollutants to the environment. Many compounds are toxic at low concentrations while synergistic effects of the pollutants magnify negative impacts on the environment (Rehman et al. 2018). Some of the heavy and trace elements, which was determined in leachates collected from the Lakhodair landfill site are Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Nickel (Ni), Zinc (Zn), Calcium, Silver, Barium, Boron, Cyanide (CN), and Selenium. The low concentration of toxic trace elements in leachate was due to decreasing the reducing stability with increasing pH (Charlatchka &Cambier 2000). Among the major elements, Zn concentration was 0.196.68 mg/L (avg. 04 mg/L), Fe was 0.4–14.1 mg/L (avg. 5.1 mg/L), Mn 0.03–11.8 mg/L (avg. 1.8 mg/L), and Ni 0-1.56 mg/L (avg. 0.34 mg/L), while Cd concentration was 0–0.15 mg/L (avg. 0.053 mg/L) (Table 1 and Fig. 3a). The sources of Pb, Mn, Fe, Cd, and Zn in leachates are commercial and daily household wastes. In landfill sites, the degradation of organic matter plays a crucial role in trace metal dissolution and mobility of elements (Wu et al. 2011), which were correlated significantly with chemical oxygen demand, oil and grease. Similarly, the concentration of Cr was 0.03–0.51 mg/L (avg. 0.096 mg/L), Cu 0.07–0.8 mg/L (avg. 0.22 mg/L), and Pb 0.012–0.27 mg/L (avg. 0.06 mg/L) (Fig. 3). The concentration of Ag in Lakhodair landfill was 0-0.03 mg/L (avg. 0.017 mg/L), Ba 0.019–0.16, B 0–15 mg/L, and CN 0.14–0.97 mg/L (avg. 0.17 mg/L) (Table 1 and Fig. 3). The concentration of total toxic metal was 0.25-13 with an average of 2.26 mg/L, which was higher than the accepted level i.e., 2 mg/L (Table 1). The source of trace elements in leachates is electronic waste, glass materials, hazardous waste, metals, textile, and plastic waste (Masood et al. 2014). The decomposition/ degradation of inorganic and organic material may also dissolve the trace elements from solid wastes and added to leachates, which pose significant impacts on the surrounding environment, groundwater, and as well as infrastructure, and construction materials (Abdus-Salam 2009). The high concentration of total toxic elements was due to the dissolution of the toxic metal, which is strongly correlated with high pH and electrical conductivity (Banar et al. 2006).

Leachate from Lakhodair landfill has a high concentration of some elements than corresponding standards/ NEQs i.e., Zinc, Boron, Manganese, Nickel, and Cyanide (Table 2 and Fig. 3). A surge in the zinc values was observed in the spring season and the lowest was measured in the winter season. The highest concentration was measured in April 2017 i.e., 6.680 mg/L, and the lowest concentration was 0.190 mg/L in November 2017 (Table 2). The maximum trend of boron was observed in winter (i.e., 15.2 mg/L in November) and the minimum trend was observed in the summer (i.e., zero). The highest concentration of Mn was 11.80 mg/L in October 2017 and the lowest was 0.030 mg/L in December 2017 (Table 1). The highest peak of nickel was in the autumn season i.e., October 1.560 mg/L, while the lowest was in winter i.e., 0.000 mg/L. Cyanide was high in the summer season i.e., 0.968 mg/L in July, while the lowest in the spring season i.e., 0.007 mg/L in March 2017 (Table 2).

Discussions

Lahore is one of the major city of Pakistan continuously facing solid wastes generation problems for the last 20 years. These wastes are generated from various sources including household waste, industrial waste, commercial wastes, and hospital wastes, which have been collected and disposed of improperly. Approximately, 0.5 to 0.7 kg/capita/day along with an average of ~ 5301 tons/day (entire Lahore city) has been generated in Lahore (Banar et al. 2006, Khan et al. 2019). It was reported that the pilot cause of solid wastes generation in bulk production and product consumption without applying proper/ or adopted final disposal, safely. Additionally, the disposal of wastes in a landfill for a long time will alternatively generate harmful leachates, which pose negative impacts on humans and the surrounding environment (Mikhailov et al. 2017).

The present study's physiochemical parameters and few toxic elements were comparably higher than the NEQs (Pak-EPA 2000) and international reputed studies (Borjac et al. 2019, Kanmani &Gandhimathi 2013, Kjeldsen et al. 2002, Shrestha et al. 2020). The pH concentration in Lakhodair leachates was 8.86 in autumn followed by winter i.e., 8.863, which was strongly correlated with TDS and oil & grease production. The high TDS may cause considerable to high contamination (Fig. 4a), while oil and grease may cause moderate to considerable contamination (Fig. 4f). The source of TDS and oil & grease are biological degradations of organic matter, animal wastes, chicken wastes, and dissolution of elements in landfill solid wastes (Palmafleming et al. 2000).

The concentrations of COD were higher in autumn i.e., 8878 mg/L, which was higher than the NEQs level i.e., 400 mg/L (Fig. 3a). The COD is strongly correlated with oil & grease and BOD_5. The high COD and BOD represent the presence of organic matter and animal wastes, and inversely, there will be less availability of non-biodegradable compounds (Zainol et al. 2012). Further, the average concentration of both COD (7192.3 mg/L) and BOD_5 (1441.8) mg/L) were comparably higher than the NEQs level (Table 1). This high COD caused high contamination throughout the year (CC > 6), which represents the presence and degradation of complex organic compounds and oily wastes (Kulikowska &Klimiuk 2008). The concentration of NH_3-N was 1250 mg/L in February, while the lowest concentration was in September i.e., 288 mg/L (Fig. 2i), which was consistent with the results of those reported by Aziz et al. (2004). In Lakhodair, the NH_3-N may cause high contamination (CC > 6) (Fig. 4e), which considerably may affect the soil, water, and the surrounding environment (He et al. 2011). The presence and production of NH_3-N in the leachates is a major issue, especially in the optimization of solid wastes leachates. The major source of NH_3-N is agriculture wastes, animal's wastes, and food wastes, which commonly produced free nitrogen radicle, nitrogen oxides. The NH_3-N is may further induced soil acidity, leaves damaging and affect soil habitat, while it can also produce NOx (nitrogen oxides) pollution through nitrification and denitrification (He et al. 2011, Wang &Zeng 2018).

Similarly, the Lakhodair landfill has a high concentration of sulfides, sulfate, and chlorides, while a somewhat lower concentration of fluorides and ionic detergents when compared with NEQs (Table 2, Fig. 2 and Fig. 3). Sulfides in Lakhodair leachate are producing through the decomposition of complex organic compounds/ or either through the addition of an anionic surfactant or detergent soap, which contaminated the soil/ or releases in the form of H_2S gas (Selberg et al. 2007). The contamination coefficient of sulfides was exhibited in moderate to high contamination (i.e., CC 1 to > 6) (Fig. 4h), while chloride was included in considerable to high contamination i.e., CC 3 to > 6 (Fig. 4d). Similarly, the sulfate value was lower in Feb, March, June, July, May, and Oct., while the sulfide concentration was high in the aforementioned months (Fig. 5). However, the sulfate was grouped negatively (-0.24) in the F2 of factor analysis (FA), while sulfides were positively in the F2 i.e., 0.12 (Table 3, Fig. 5). The study revealed that the sulfate in Lakhodair leachate was reduced to sulfide by the availability of an anaerobic environment and reducing bacteria, which was also reported by Chatterjee et al. (2017), Lee et al. (2014). The reduction of sulfate, Cr, and B was an important feature of FA analysis, which was proved through the cluster analysis (Fig. 6).

Table 3 Exploratory factor analysis of physiochemical trace elements in Lakhodair leachates

Specification	F1	F2	F3	F4	F5	F6
pH	0.260	-0.178	-0.090	0.295	-0.116	0.040
TDS	-0.228	0.224	0.236	-0.139	-0.232	0.039
TSS	-0.252	0.128	-0.257	-0.010	0.040	0.266
COD	-0.346	0.150	0.061	-0.046	-0.009	-0.057
NH_3-H	0.233	0.155	-0.012	0.136	0.184	0.407
BOD5	-0.149	0.101	-0.267	-0.172	0.194	0.266
Sulfate	0.031	-0.240	0.380	-0.062	0.062	0.043
Sulfides	-0.035	0.118	-0.022	0.338	0.383	0.282
Chloride	-0.123	0.388	-0.073	-0.156	-0.042	-0.138
Fluoride	0.297	0.233	-0.037	0.202	0.125	-0.044
Ionic Detergents	0.084	0.231	0.094	-0.245	0.268	-0.349
Cyanide	0.185	0.034	-0.060	0.085	-0.446	0.054
Phenolic compound	-0.081	-0.280	-0.271	0.189	0.133	-0.140
Arsenic	0.247	0.107	-0.077	0.034	-0.221	-0.203
Cadmium	-0.211	-0.045	0.207	0.203	-0.337	-0.051
Chromium	-0.067	-0.241	0.371	-0.054	0.045	0.075
Copper	0.078	0.280	0.143	0.020	0.210	-0.334
Iron	0.308	0.175	0.187	0.113	0.177	-0.151
Lead	0.293	0.125	0.030	0.142	-0.233	0.060
Manganese	-0.268	0.141	0.079	0.377	-0.078	-0.141
Nickel	-0.238	0.206	0.076	0.372	0.061	-0.057
Zinc	0.059	0.337	0.022	-0.045	-0.194	0.206
Silver	-0.084	0.154	0.338	0.240	-0.044	0.259
Barium	0.161	0.160	0.083	-0.363	-0.121	0.319
Boron	0.072	-0.117	0.425	-0.079	0.212	0.136
Eigenvalue	5.396	5.003	3.861	2.697	2.634	2.231
Variance %	0.216	0.200	0.154	0.108	0.105	0.089
Cumulative	0.216	0.416	0.570	0.678	0.784	0.873

Similarly, the FA analysis showed 6 distinct factors with an effective Eigenvalue > 1 with a systematic decrease in the original concentration. The lower percent variation of the entire FA was due to the limited number of samples, which may cause errors up to 30 % in evaluation (Hussain et al. 2019b, Osborne &Costello 2004). Similarly, the F1 was negatively loaded with TDS, TSS, COD, BOD_5, Cl, CN, phenolic compound, Mn, Ni, and Ag (Fig. 5), which revealed the redox reaction mainly controlled by methanogenesis and anaerobic reaction (Lyu et al. 2018). To prove the methanogenesis and anaerobic reaction in Lakhodair landfill, the BOD_5/COD taking under consideration, which was lower than 0.1 in the months of March-November, while higher winter i.e., December, January, and February (Table S1). The lower ratio of BOD_5/COD (0.1) indicated the methanogenic phase of the landfill (Kulikowska &Klimiuk 2008). During multistage anaerobic redox reaction in Lakhodair leachates, the CO_2 was emitted and alternatively increase TDS, COD, Cl, and BOD_5, which is consistent with the result of those reported by Kamaruddin et al. (2015), Linville et al. (2017). Additionally, the NH_3-N, sulfides, ionic detergents, Ba, F, Fe, Cu were positively appeared in F2 (Fig. 5), which was comparatively undergoes/ followed the same redox reaction either increase or decrease in the reactants (Fig. 6). The elements in 2nd cluster of Fig. 6 were mainly controlled by ammonium redox (at an anaerobic condition) followed by nitrification and denitrification, which surely convert the NH_4-N to NH_3-N (Breisha 2010, Taghizadeh-Toosi et al. 2012). The concentration of NH_3-N was increased in spring (785 mg/L) and summer (531 mg/L) (Fig. 3b, Table S3) revealed a strong correlation with pH and temperature. The high temperature at Lakhodair areas may induce the production of ionized NH_3, which are extremely toxic to the surrounding environment and living organisms (Purwono et al. 2017). The high toxicity and concentration NH_3-N was exhibited in high contamination level (i.e., CC > 6) (Fig. 4e). Similarly, the high pH/ alkalinity provides a favorable environment for bacterial growth where CO_2 will be emitted to the atmosphere and the leachates will be converted to alkaline. At the same time, denitrification will be started to form NH_3 (Daigger 2011, Purwono et al. 2017).

The F4 is loaded with pH, phenolic compounds, CN, Pb, and As, which is mostly generated through the degradation of petrochemical, liquor, agricultural wastes, fruits, vegetable decomposition, and hydrocarbons (Martinez-Avila et al. 2014, Shirahigue &Ceccato-Antonini 2020). The phenolic compound is mostly controlled by normal pH and low temperature. The highest phenolic compounds were found in the winter season i.e., 0.53 mg/L (Fig. 2h). During bacterial degradation, especially the fermentation process, the organic matter (fruits, vegetables) is converted to phenolic compounds, CN, and antioxidants with the presence of Pb as a catalyst (Shin et al. 2015). However, the low As availability in Lakhodair leachate was also part of biological degradation and redox reaction with a specific pH, which was consistent with the result of those reported by Blakey (1984). The present study proved that F4 of factor analysis is mainly controlled by the biogenic process and followed the same reaction/ group, which was also proved through cluster analysis (Fig. 6).

Additionally, the Lakhodair landfill leachate has toxic trace elements in a lower range than NEQs. The lower concentration of trace elements maybe because of solid waste restraining capability/ or lack of environmental conditions for the dissolution of trace elements (Prechthai et al. 2008). The lower concentration of trace elements in the Lakhodair landfill site because of the anaerobic process, which immobilizes the trace elements and retains the solid wastes in a landfill site. He et al. (2006) reported that the anaerobic activity restrains the production of free cations and immobilizes the trace elements. The present study presumed that elements in oxidizable/ reducible form trickling under specific conditions. The presence of trace elements in the Lakhodair landfill may be in a metastable state, which is not easily to leach out.

Conclusions

The high concentration of physiochemical and few trace elements in the Lakhodair landfill was evolved through anaerobic degradation of dumping wastes. The lower BOD_5/COD (< 0.1) was observed in March, April, September, October, and November indicated methanogenesis and anaerobic redox reaction in leachates. Further, the anaerobic activities enhance the production of TDS, BOD_5, COD, Cl, NH_3-N, phenolic compounds, and sulfides. The high contents of NH_3-N in the Spring season was 785 mg/L and Summer 531 mg/L revealed the dependent correlation with temperature and pH. The high temperature at Lakhodair with stable pH may induce the production of ionized NH_3-N through denitrification and nitrification. The anaerobic activity immobilizes the trace elements, resulting in the lower elemental contents available in Lakhodair leachates. The lower concentration of trace elements in Lakhodair leachates revealed the metastability of trace elements, which reduced their dissolution and percolation capability. The contamination factor revealed that TDS, NH3-N, COD, Cl, BOD_5, and sulfides may cause considerable to high contamination (CC 3 to > 6), while remaining chemical species may cause low to moderate contamination (CC 1 to ≤ 3). The lower concentrations of toxic compounds do not always confer the leachate to be less hazardous while an enormous volume of leachates entering into the environment. The study concluded that the leachates in Lakhodair produce toxic elements/ compounds, which pose serious threats to humans and the surrounding environment. The study recommended installing a cost-effective and environmentally friendly system to reduce the pollutants in leachates to a satisfactory level before their final disposal.

Declarations

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Compliance with ethical standards

Competing interests The authors declare that they have no conflict of interest.

Ethical approval Not Applicable

Consent to participate I am free to contact any of the authors involved in the research to seek further clarification and information.

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Author Contributions Muhammad Zeshan, Sadia Hafeez, Mahsoon Ashraf, and Abdul Qadir proposed the main concept, fieldwork, laboratory work, and involved in the write-up. Rahib Hussain and Sajid Rashid Ahmad assisted in Fieldwork, experimental design, and scientific work rectification and proofread. Muzaffar Majid and Farman Ahmad are involved in experimental work, data analysis, and mapping.

Available of Data and materials The datasets used and/or analyzed during the current study are available in the attached supplementary file/ from the corresponding author on request.

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Figures

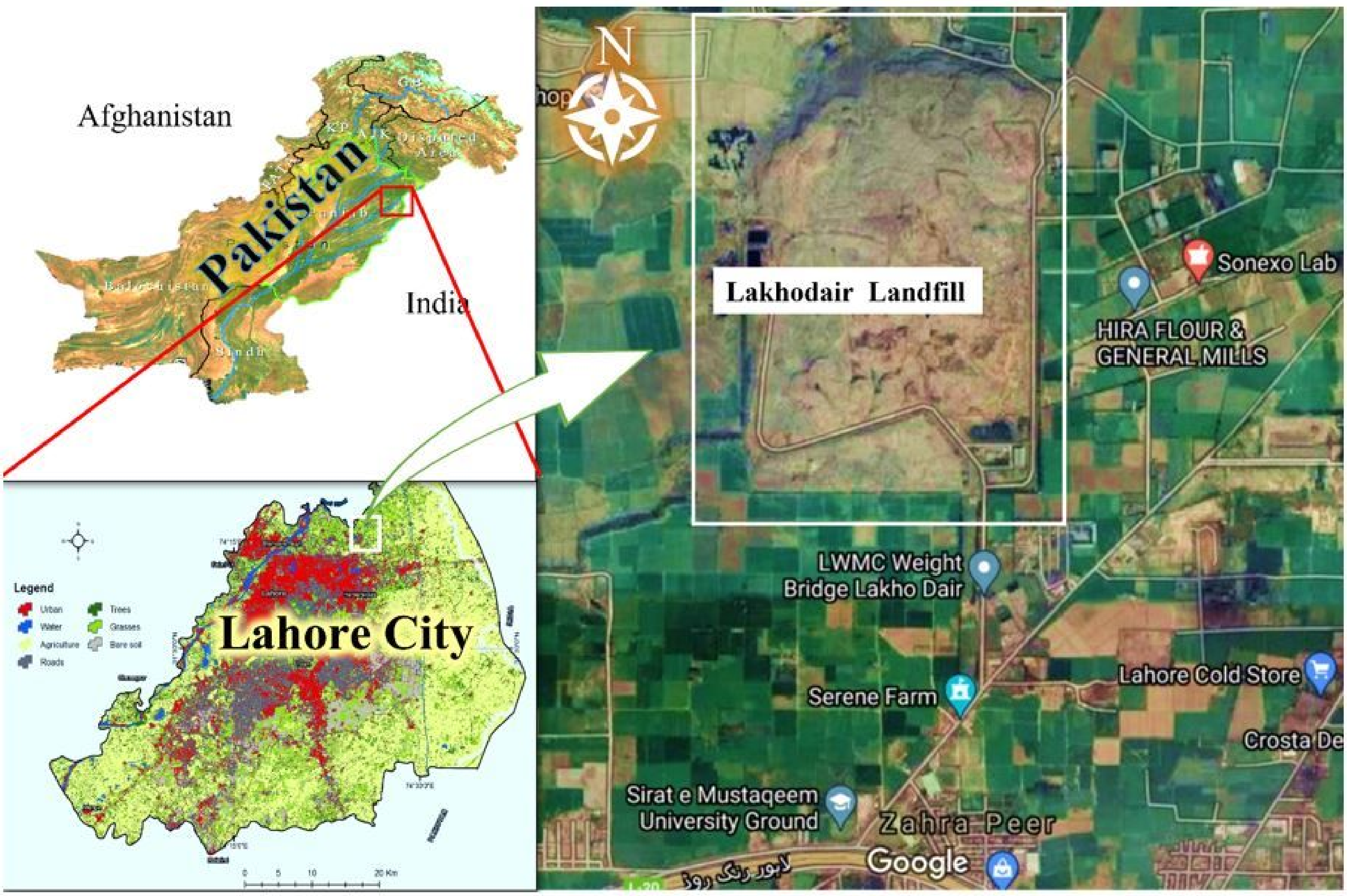

Figure 1

Location map of newly constructed landfill site (Lakhodair landfill), Lahore, Pakistan

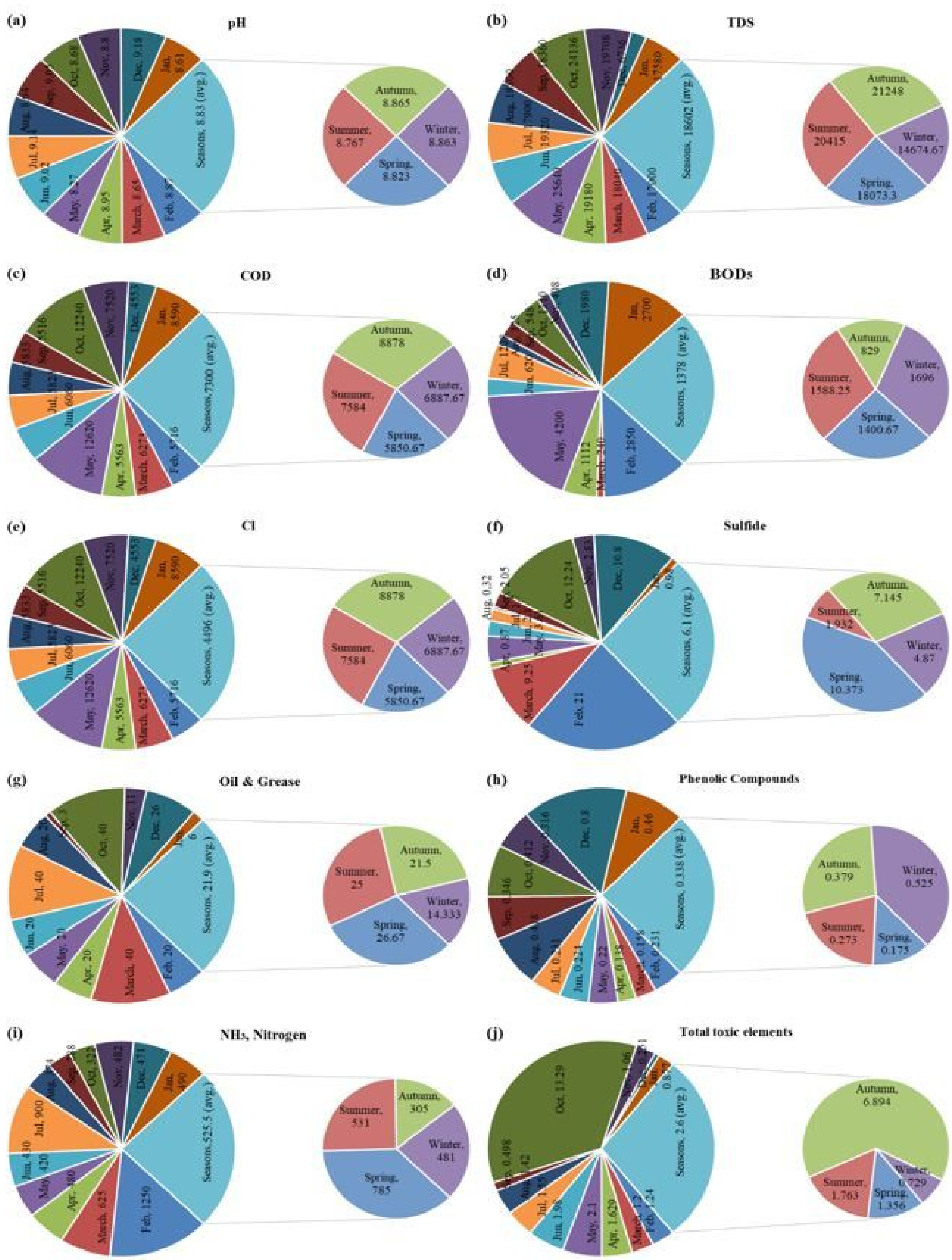

Figure 2

Seasonal and Temporal diversity of contamination in Lakhodair Landfill site, Lahore

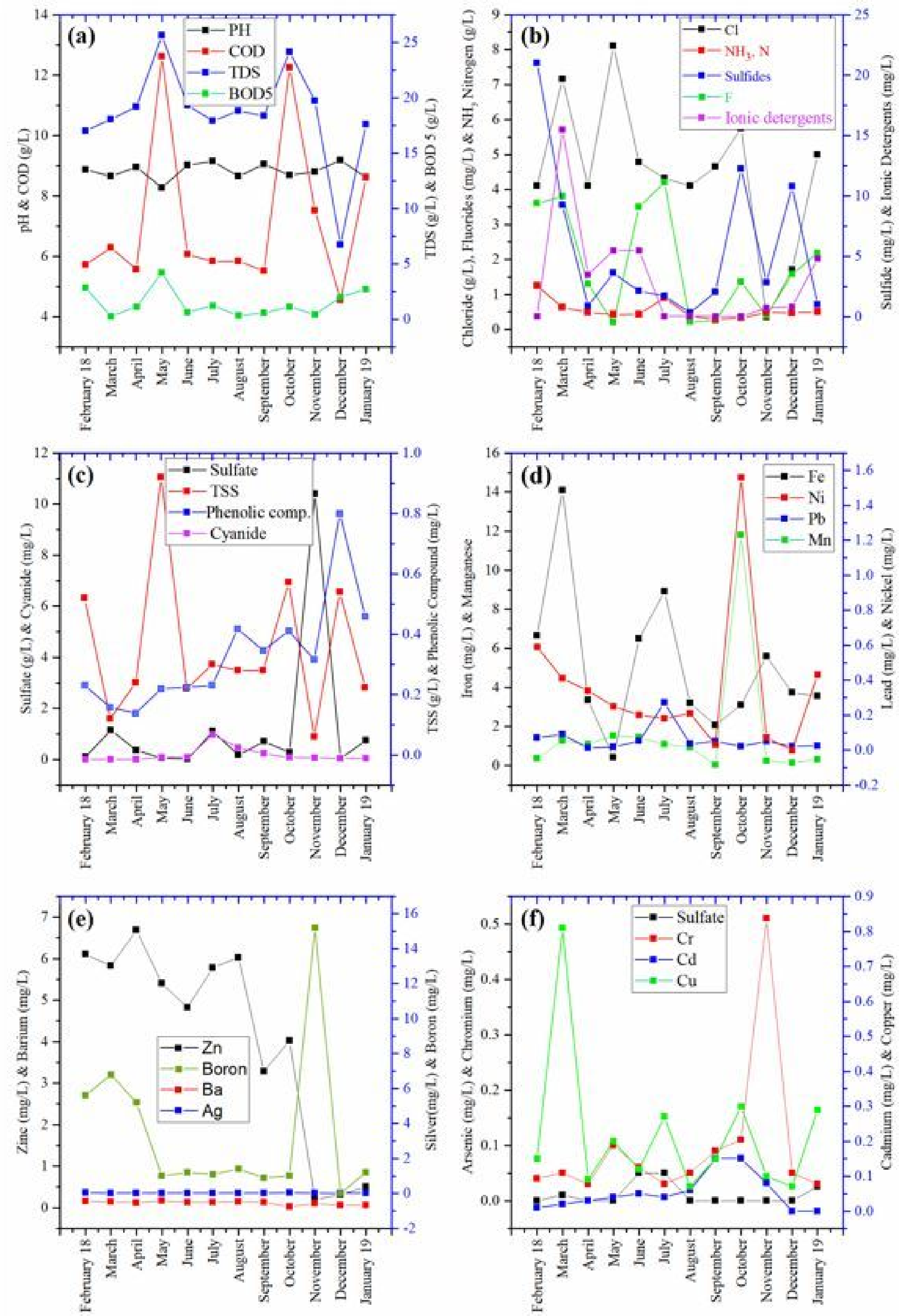

Figure 3

Monthly distribution and comparison of the chemical composition of Lakhodair landfill leachates

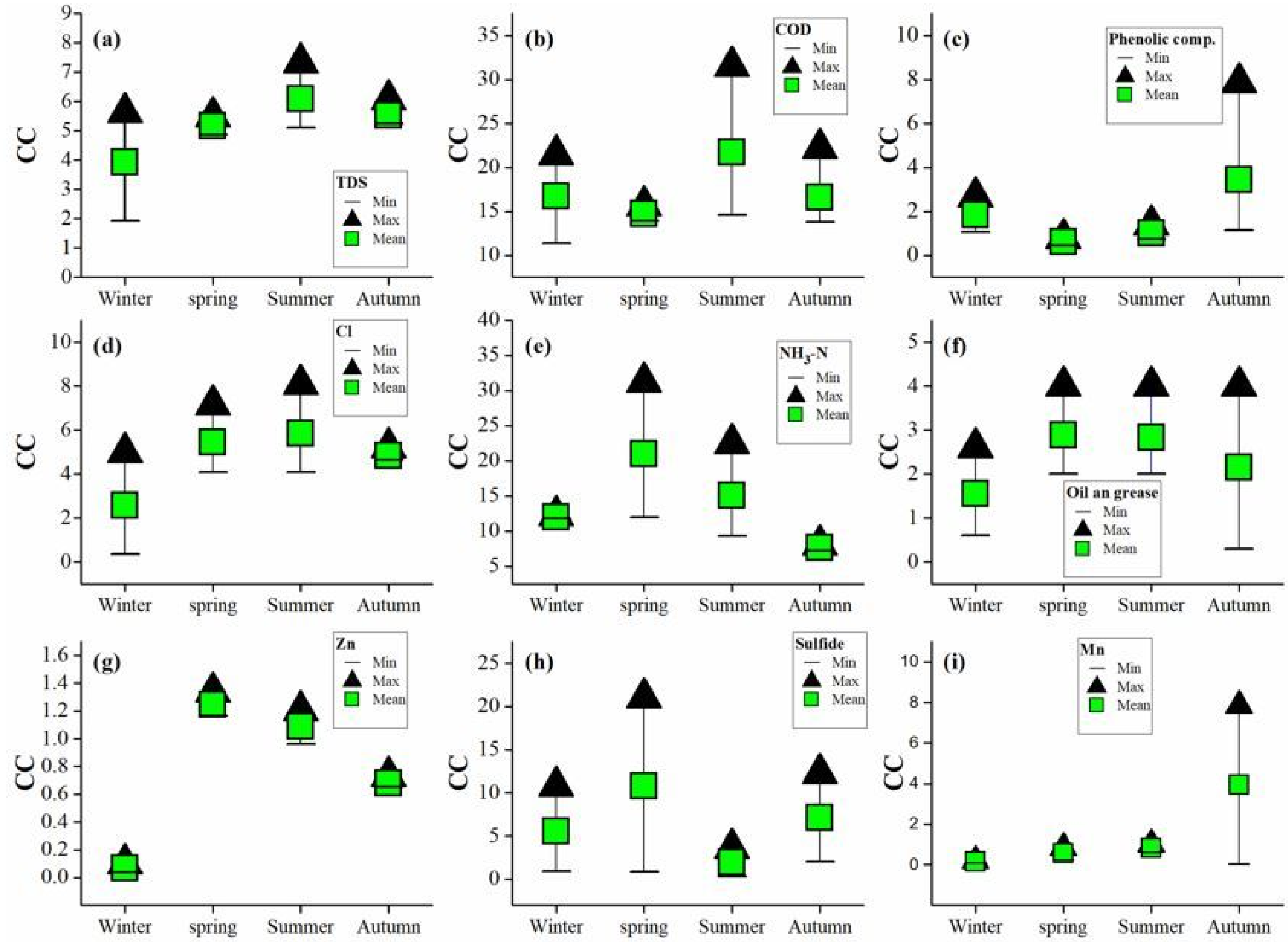

Figure 4

Evaluation of relative contamination level in Lakhodair landfill leachate composition

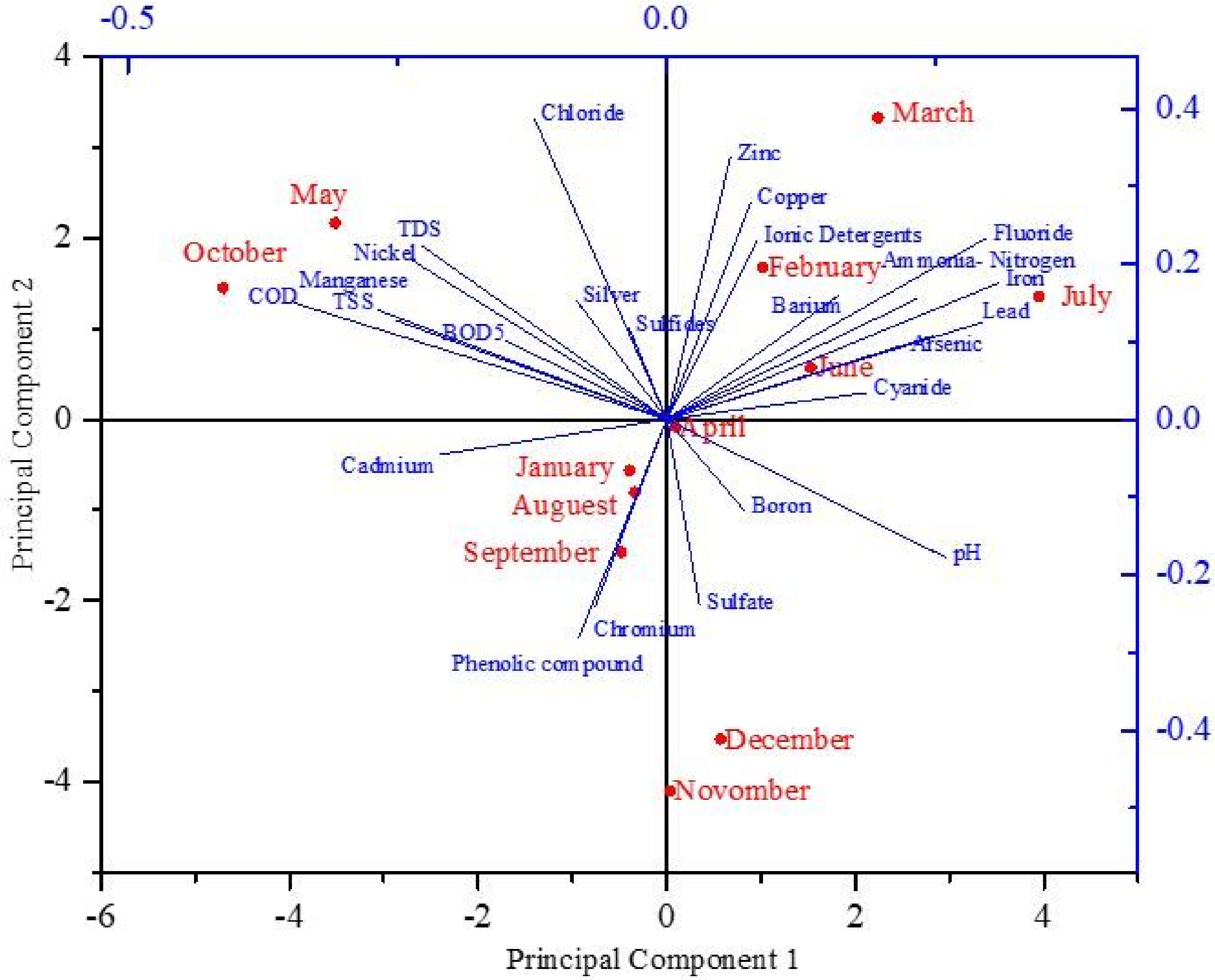

Figure 5

Rotated varimax component matrices of factor analysis for Lakhodair landfill leachates

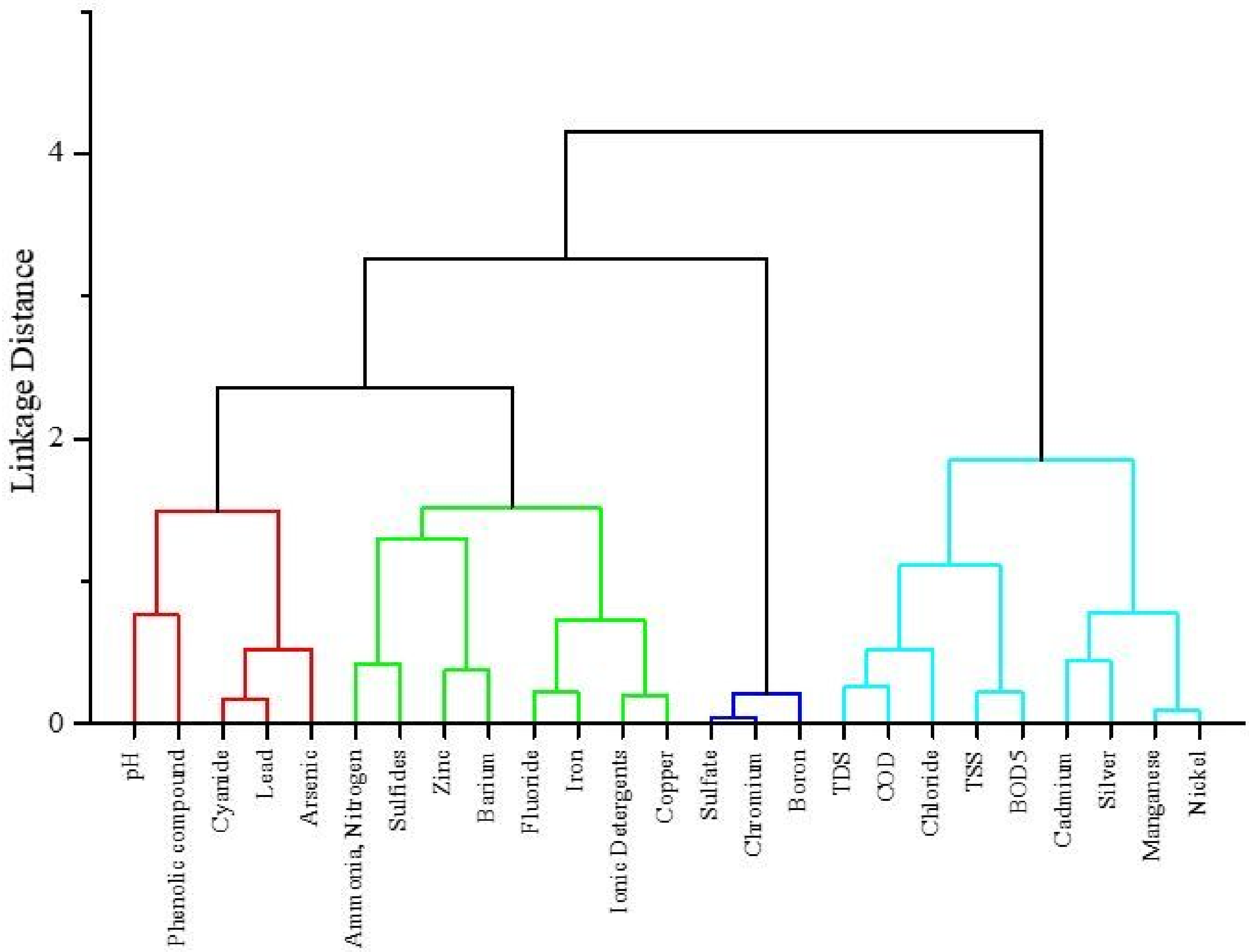

Figure 6

Exploration of clustering similarities in the physiochemical and trace elements of the Lakhodair landfill composition

Supplementary Files

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