ASSESSMENT OF PHYSICO-CHEMICAL CHARACTERISTICS OF LEACHATE CONTAMINATED LATERITIC SOIL

Asogwa, E.O.[1], Sabo, B.[2*], Agbonselobho, M.O.[1], Agbese, E.O.[1], Haruna, S.I.[3] and Mangey, J.A.[3]

[1]Civil Engineering Department, Federal University of Technology Minna, Nigeria.

[2] Modibbo Adama University Yola, Adamawa State, Nigeria.

[3]Water Resources and Environmental Engineering Department, Ahmadu Bello University Zaria, Nigeria.

***Corresponding email:** e.asogwa@futminna.edu.ng

ABSTRACT

This research studied the physico-chemical characteristics of leachate contaminated soil. Leachate is known as an important source of environmental pollution, more especially groundwater, pollution due to the presence of organic and inorganic substances, including heavy metals. Leachate is a major problem for municipal solid waste landfills and causes significant threat to surface water and groundwater. Leachate is generated by excess rainwater passing through the waste body. The pollutants from the waste material are transferred to the percolating water by the combination of physical, chemical and microbial processes. Leachate is characterized as water-based solution of four groups of pollutants; dissolved organic matter, heavy metals, inorganic macro components, and xenobiotic organic compounds. The physio and bio-chemical analysis: BOD, COD, pH, EC, total hardness, nitrite, chloride, calcium and heavy metals such as Pb, Fe, Zn, and Cu were determined. From the results obtained, pH increases with increase in percentage contamination, from pH of 5 at 0% contamination to 5.62 at 100% contamination and cation exchange capacity also increased from an initial value of 187.613mg/lat 0% to 200.575mg/l at 100% contamination. These results show that the dumpsite has slight effects on the adjacent stream and underlying soil. Therefore, the implementation of a properly designed leachate collection system to prevent future risk of continuous contamination of the underlying soil and groundwater is important.

Keywords: Leachate, Solid waste, Contamination, Lateritic Soil

1 INTRODUCTION

Water is the most abundant environmental resource on earth but its accessibility is based on quality and quantity, as well as space and time. It may be available in various forms and quantity but its use for various purposes is the subject of quality. About 70% of the human body and about 60-70% of plant cells is made up of water [1]. It is one of the determinants of human settlement, existence and activities on the earth. Its quantity is fixed but dynamic in formation and storage. Of all the environmental concerns that developing countries face, the lack of adequate, good quality water remains the most serious [2]. Once contaminated, groundwater may forever remain polluted without remedy or treatment. Water is one of the determinants of human earth system. Diseases may spring up through water pollution, especially groundwater contamination, and rapidly spread beyond human expectation because of its flow mechanism [3]. One of the major factors that make the earth habitable for humans is the presence of water. Forming the major component of plant and animal cells, it is the basis of life and therefore the development of water resources is an important component in the integrated development of any area. Open dumps as a method of waste disposal are the oldest and most common way of disposing solid wastes in most cities of developing nations [4]. One of the serious problems affiliated with the open dumps is the infiltration of the leachate into the surrounding environment, and consequent contamination of land and water [5]. Other research findings have shown that leachate and outflow percolation are the sources of groundwater and surface water pollution close to landfill sites [6, 7]. The quality of groundwater is based on the physical and chemical parameters due to weathering from source rocks and anthropogenic activities i.e. changes in nature made by human beings. The principal impact of the landfill leachate is the contamination of both the groundwater and surface water which has led to a number of studies over the years [8, 9].

2 MATERIALS AND METHODOLOGY

2.1 Study Area

Niger state has a total landmass of 76,363km2 with twenty- five local government Areas of which Bosso is one. Bosso Local Government area houses the study area and has a land mass of 1592km^2. The study area is physio graphically divided into alluvial plain, local valleys and undulating upland, followed by gentle hill slopes. The study area falls within the agro-climatic zone, between 720° 28'E to 730° 37'E Longitude and 200° 00'N to 200° 05'N Latitude. The area comes under a sub-tropical, semi-arid climate and rainfall of between 800mm to 1,100mm. The heaviest rainfall period is experienced from July through to September of each year. The temperature of the study area ranges between 27°C to 42°C [10], with the lowest and highest temperature months as December/January and March/April, respectively.

2.2 Materials

The materials used include Leachates Samples, Soil Sample, Sieves of Different Sizes, Incubator and Airtight Buckets. Plate 1 shows the samples of contaminated lateritic soil.

Plate 1. Samples of contaminated lateritic soil

2.3 Sample Collection

The Lateritic soil used for this study was collected from a borrow pit in Lapai-Gwari Road borrow pit, Gidan Kwano Minna, Niger State. The soil samples will be disturbed samples. The sample will be obtained from a depth not less than 1.5m to avoid organic top soil from mixing up with the sample. The soils were air dried and kept for 7 days for maturation and passed through 425 mm sieve before using the same for laboratory test. Municipal Solid Waste leachate (Samples L3) was collected from selected active non engineered landfill site in Gidan Kwano Minna, Niger State Nigeria. The leachate was scooped from sump, sieved and stored in a covered container placed in an incubator to avoid further reactions. The waste stream is mainly domestic and some percentage of commercial wastes. The site has no form of cover hence the wastes are exposed to direct sun and rainfall. About 300gm of soil samples was taken for each test and after addition of leachate contaminants the samples were placed in air tight buckets and kept for 14 days for maturing. After 14 days the buckets were opened and test was conducted. The soil specimens were saturated with various leachate concentration ratios in distilled water ranging from 0 to 100% at step concentration of 0, 25, 50, 75 and 100% with 14 days curing time.

2.4 Laboratory Test

2.4.1 pH, TDS and EC determination

Procedure

pH, Electrical Conductivity, TDS was analyzed using Hanna Multi parameter instrument HI 9812-5. The instrument was first calibrated and the reading was taking from the sample. The probe was rinsed twice before subsequent sample reading.

2.4.2 Dissolved oxygen /salinity

The dissolved oxygen was done using Extech heavy duty DO/Salinity/Temperature Meter Model 407510A.

2.4.3 BOD test procedure

The BOD test takes 5 days to complete and is performed using a dissolved oxygen test kit. The BOD level is determined by comparing the DO level of a water sample taken immediately with the DO level of a water sample that has been incubated in a dark location for 5 days. The difference between the two DO levels represents the amount of oxygen required for the decomposition of any organic material in the sample and is a good approximation of the BOD level.

3 RESULTS AND DISCUSSION

Table 1 presents the mean values of chemical composition of the lateritic soil used in the research work.

Table 1. Chemical Composition of the lateritic soil

Parameter	Percentage	Parameters	Percentage
PH	5	P_2O_5	0.47
EC		SO_3	0.42
Colour	Reddish Brown	CaO	0.31
SiO_2	28.27	Cl	0.26
Al_2O_3	18.04	Mno	0.20
Fe_2O_3	2.43	ZrO_2	0.15
K_2O	1.77	$P_2O_5Pr_6O_{11}$	
TiO_2		SrO	0.5311
MgO	1.10		

Table 2 presents the results for characterization (Physiochemical Parameters) of Leachate Samples used in the research.

Table 2. Leachate Characterization

Parameter	Concentration (mg/l)	WHO Standard	FMENV Criteria
pH	8.14	6-9	6-9
EC (µs/cm)	52800	5,000-10,000	5000
Ca (mg/l)	92.51	100-200	1000
Mg (mg/l)	104.67	50-100	2000
Cl (mg/l)	13720	1000	2000
PO4 (mg/l)	2.7	10-20	10
NO3 (mg/l)	15	100	100
BOD (mg/l)	8.8	50	50
COD (mg/l)	16.65	100	250
Cu (mg/l)	0.424	1	1
Fe (mg/l)	5.807	5	5
Zn (mg/l)	0.46	0.5	0.5
Mn (mg/l)	3.695	2	2
Pb (mg/l)	0.567	0.1	0.5

(Source: WHO- World Health Organization, FEMENV- Federal Ministry of Environment Nigeria)

3.1 Effect of Leachate Contaminated Lateritic Soil on pH

It is observed from Figure 1 that the pH of lateritic soil increases with leachate concentration. The probable reason for this behaviour may be due to high concentration of monovalent and divalent cation contained in the leachate. pH determination of soil is important as excessive acidity or alkalinity can be detrimental. It is reported by [11, 12] that under high rainfall conditions cation especially Ca^{2+} leach, while under low rainfall conditions Ca^{2+} and other cations are not easily leached. The results of pH of the natural soil samples indicate that the soil is acidic. The experimental data indicates that the pH value of the natural lateritic soil samples is 5. The acidic nature of the soil is dependent on two factors. Leaching of appreciable amounts of exchangeable bases from the soils due to high precipitation (1100 mm annually) is one of the factors. While decomposition of organic matter, which leads to the formation of organic and inorganic acid (e.g. Carbonic acid – H_2CO_3) which renders the soil acidic is the second factor. The experimental data of soil pH as a function of leachate added is presented in Figure 1. The concentration of each constituent of leachate is presented in Table 2. The leachate also contained chloride and sulphate anions. As a result of negative charge developed by the clay particles, ions are absorbed on the surface. Any process that encourages presence of high levels of exchangeable base such as calcium, magnesium, potassium and sodium will reduce acidity and increase alkalinity. Hence pH of the lateritic soil in Figure 1 increases as the leachate concentration increase and this is similar to the findings of [13].

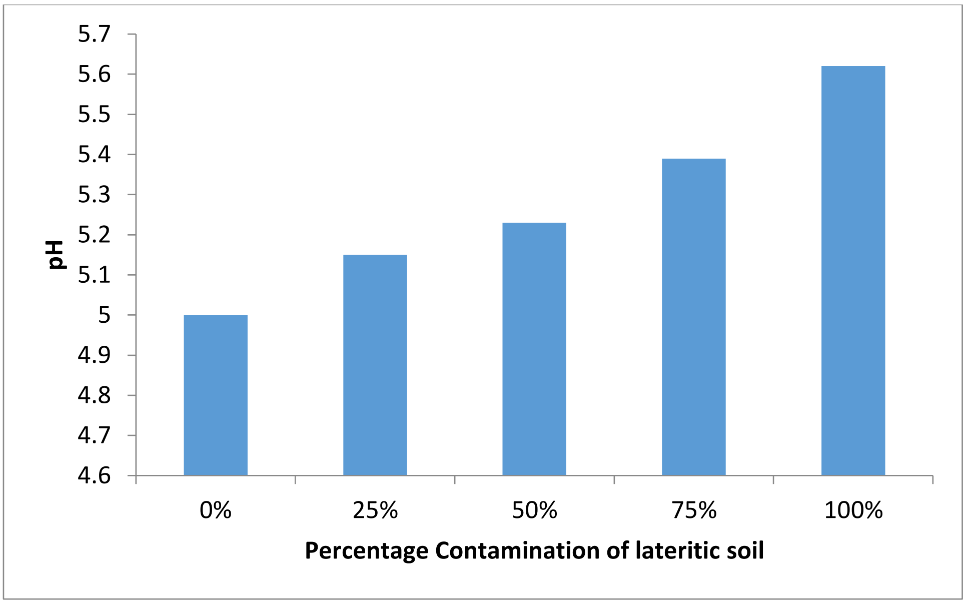

Figure 1. Variation of pH with percentage Lateritic soil contamination

3.2 Effect of Leachate on cation exchange capacity of Lateritic soil

Ion exchange is the most important of all processes occurring in the soil. The capacity of the soil to absorb and exchange ions varies greatly with the amount of clay. Exchange of ions takes place due to isomorphous substitution. Results of CEC determinations is shown in Figure 2. From the results, it can be deduced that CEC has increased from an initial value of 187.613mg/l to 200.5758mg/l. While the increase in cation exchange capacity of soil is interesting as reported by [11] attributed the following reason: It concludes that the increase in cation exchange capacity of soil is attributed due to rise in pH. The acquisition of extra negative charge with a rise in pH is mainly due to two reasons: First, the development of negative charge is due to the dissociation of hydrogen of SiOH groups present at the edges of the tetrahedral layers, and the surface of the clay is left with the negative charge of the oxygen ions according to the reaction.

$$\mathrm{SiOH} = Si\mathrm{O}^- + \mathrm{H}^+ \tag{1}$$

This type of negative charge is pH dependent charge. The amount of dissociation increases with increasing pH and resulting in an increase in the cation exchange capacity. Some researchers also reported the changes in CEC to be pH dependent, and this arises from exposed – SOH and AlOH sites.

At higher pH, silica and alumina present in the soil dissolve and form non crystalline compounds of silicates and aluminates. These non-crystalline compounds acquire a negative charge and contribute to CEC as reported also by [14].

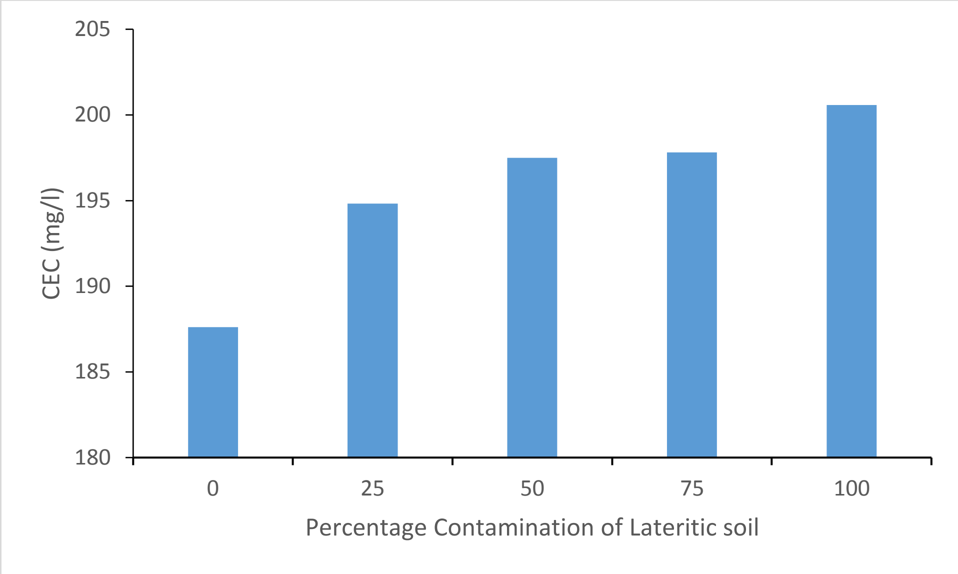

Figure 2. Variation of CEC with percentage contamination of lateritic soil

3.3 Effect of leachate contamination on the EC and COD of the lateritic soil

From Figures 3 and 4 it is observed that; Chemical Oxygen Demand (COD) of the lateritic soil decreases with increase in the Percentage contamination of the lateritic soil while electrical conductivity (EC) of the soil increases progressively with increase in leachate concentration except at 75%. This is mainly due to leachate characteristics rather than the chemical characteristics of soil. The adsorption of chemical constituents of leachate on the surface of the lateritic soil influences the chemical characteristics of the soil.

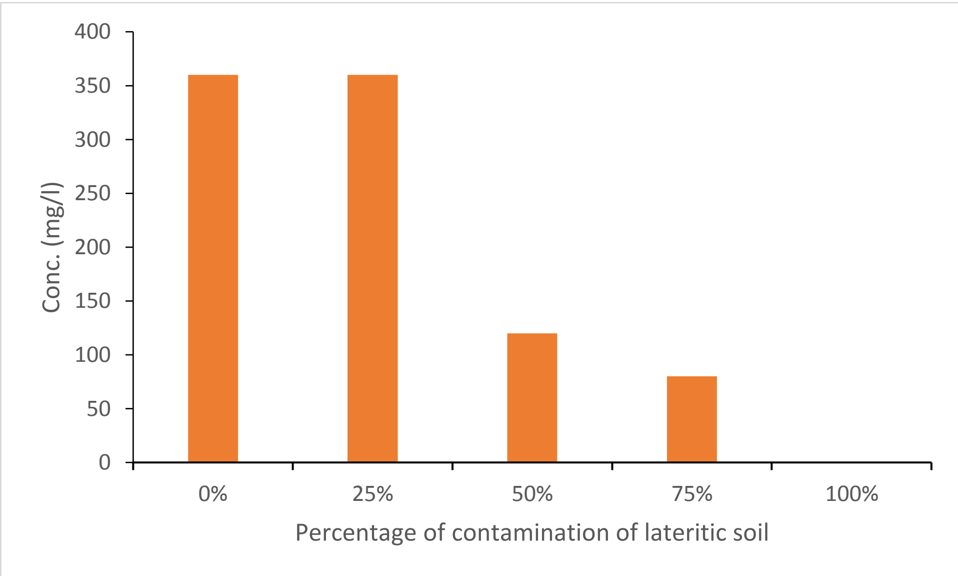

Figure 3. Characteristic pattern of COD at varying leachate contamination of lateritic soil

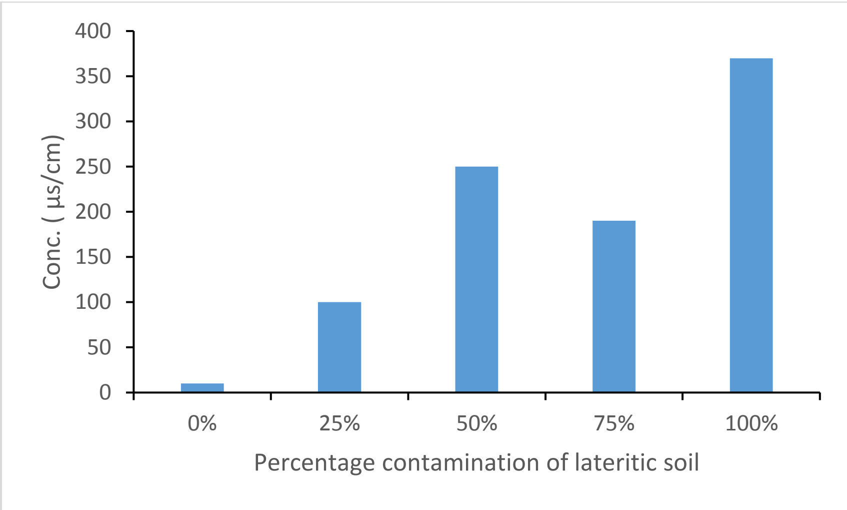

Figure 4. Characteristic pattern of EC at varying contamination of lateritic soil

Figure 5 shows the Characteristic pattern of PO_4 and NO_3 at varying contamination of lateritic soil while Figure 6 shows the Characteristic pattern of DO and BOD Percentage contamination of lateritic soil.

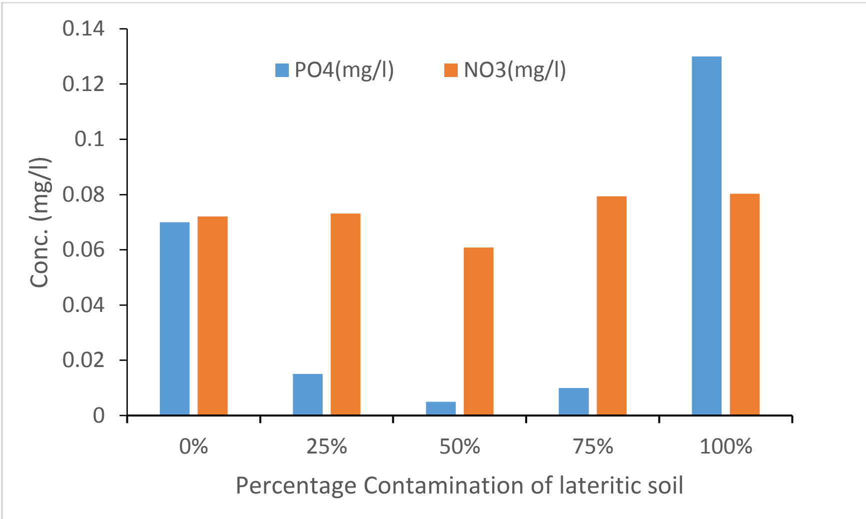

Figure 5. Characteristic pattern of PO_4 and NO_3 at varying contamination of lateritic soil

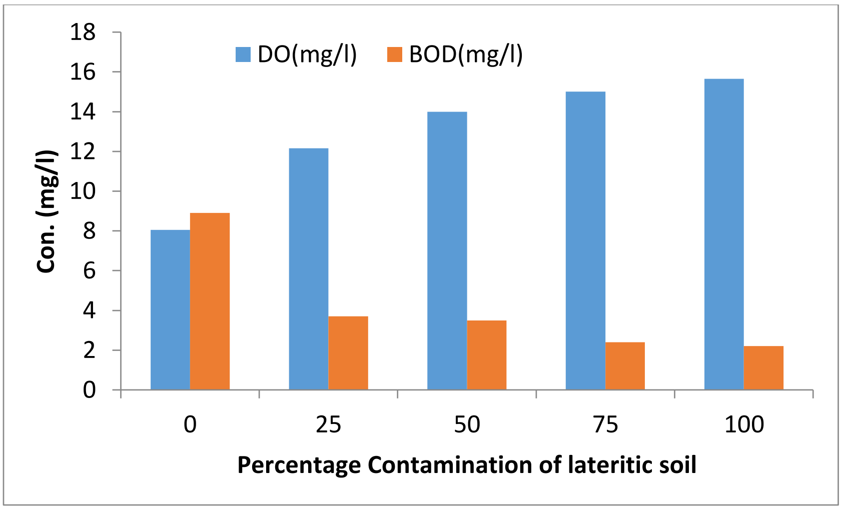

Figure 6. Characteristic pattern of DO and BOD Percentage contamination of lateritic soil

3.4 Effect of leachate contamination on other physico-chemical parameters

It can be deduced from fig. 5 that the value of PO_4 decreases progressively from 0 to 50% and increases progressively from 50 to 100%. The highest value (0.13mg/l) of PO_4 is recorded at 100% and the least value (0.005mg/l) occurred at 50%. Also, the value of NO_3 increased from 0 to 25% and decreased from 25 to 50% and finally increased progressively from 50 to 100%. The highest value (0.080mg/l) of NO_3 is recorded at 100% and the least value (0.060mg/l) is recorded at 50% contamination of the lateritic soil. The value of the dissolved oxygen increases as the contamination of the lateritic soil progresses, this can be seen in Figure 6. The highest value of the dissolved oxygen (15.65mg/l) occurred at 100% while the least value (8.05mg/l) occurred at 0% contamination respectively. The value of the biochemical oxygen demand (BOD) decreased progressively from 0% to 100% which is similar to the findings of [15]. The highest value (8.9mg/l) of BOD occurred at 0% and the least value (2.2mg/l) occurred at 100%. The variations on the values of the parameters are mainly due to leachate characteristics.

4 CONCLUSIONS

Based on the findings of this research the following conclusions can therefore be drawn: Cation exchange capacity increases from an initial value of 187.613 mg/l to 200.575 mg/l, pH also increased from 5 at 0% contamination to 5.62 at 100% contamination. Electrical Conductivity and Dissolved Oxygen increases while Biological Oxygen Demand and Chemical Oxygen Demand decreases respectively with increase in leachate concentration. The heavy metals Pb, Cu, Zn, Fe increases progressively from 0% to 100% as the contamination of the lateritic soil increases. There is variation in the physico-chemical characteristics of some parameters like PO_4, NO_3 which can be attributed to the leachate characteristics.

REFERENCES

1. Smith, B. and Edger, E. (2006). Environmental science: A study of interrelationships (10th ed.). *New York: McGraw-Hill Higher Education*, 514p.
2. Markandiya, A. (2004). Water quality issues in developing countries. *World Bank and University of Bath. Contribution to a volume on essays in environment and development*, pp. 1-34.
3. Afolayan, O.S., Ogundele, F.O. and Omotayo, A. (2012). Comparative analysis of the effect of closed and operational landfills in groundwater quality in Solous, Lagos, Nigeria. *Journal of Applied Technology in Environmental Sanitation*, vol. 2, no. 1, pp. 67-76.
4. AlSabahi, E., Rahim, S.A. and Zuhairi, W.W. (2009). The Characteristics of Leachate and Groundwater Pollution at Municipal Solid Waste Landfill of IBB City, Yemen. *American Journal of Environmental Sciences*, vol. 5, no. 3, pp. 256-266.
5. Oyelami, A., Aladejana, J. and Agbede, O. (2013). Assessment of the impact of open waste dumpsites on groundwater quality: a case study of the Onibu-Eja dumpsite, southwestern Nigeria. *Procedia Earth and Planetary Science*, vol. 7, pp. 648-651.
6. Adepelumi, A.A., Ako, B.D., Ajayi, T.R., Afolabi, O. and Ometoso, E.J. (2008). Delineation of saltwater intrusion. *Environ Geol*., vol. 56, pp. 927-933.
7. Jaskelevicius, B. and Lynikien, V. (2009) Investigation of Influence of Lapes Landfill Leachate on Ground and Surface Water Pollution with Heavy Metals. *Journal of Environmental Engineering and Landscape Management,* vol. 17, no. 3, pp. 131-139.
8. Saarela, J. (2003). Pilot investigations of surface parts of three closed landfills and factors. *Environmental Monitoring Assess*, vol. 84, pp. 183-192.
9. Kamon, M., Ying, C. and Katsumi, T. (1996). Effect of acid rain on lime and cement stabilized soils. *Japanese Geotechnical Society*, vol. 36, no. 4, pp. 91-96.

10. Musa, J.J., Adwumi, J.K. and Ohu, J.O. (2013). Comparing Developed Runoff Coefficient for some selected Soils of Gidan Kwano with Existing values. *International Journal of Basic and Applied Science*, vol. 1, pp. 473-469.

11. Mathew, P.K. and Rao, S.N. (1997). Influence of cations on compressibility behavior of a marine clay. *Journal of Geotechnical Engineering*, vol. 123, no. 11, pp. 1071-1073.

12. Diganta, G. and Bibeka, N.C. (2013). Chemical Characteristics of Leachate Contaminated Lateritic Soil. *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 2, issue 4, pp. 6-7.

13. Ravishankar, R. and Madhuri, B.M. (2004). Characterization of the MSW leachate at Mangalore dump yard. *NITK Research Bulletin*, vol. 14, no. 1, pp. 20-25.

14. Diganta, G. and Bibeka, N.C. (2013). Chemical Characteristics of Leachate Contaminated Lateritic Soil. *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 2, issue 4, pp. 7-8.

15. Sozan, W.R., Dler, M.S.S. and Khsraw, A.R. (2022). Physicochemical Characterization and Evaluation of Seasonal Variations of Landfill Leachate and Groundwater Quality around Tanjaro Open Dump Area of Sulaymaniyah City, Kurdistan, Iraq. *Hindawi Journal of Chemistry,* vol. 2022, pp. 1-6.

APPENDIX

Physico - Chemical Characteristics of Leachate Contaminated Lateritic Soil

% Leachate	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	Fe mg/L	CU mg/L	Cl mg/L	Ph mg/L	EC µS/cm	DO mg/L	BOD mg/L	COD mg/L	PO4 3- mg/L	NO3- ppm	Pb mg/L	Zn mg/L	CEC mg/L
0	150.6245	13.81188	13.03546	10.14108	0	0	24.78134	5	10	8.05	8.9	360	0.07	0.07205	0	0	187.6129
25	151.1241	14.25743	11.91489	10.3386	5.0656	0.356	29.73761	5.15	100	12.15	3.7	360	0.005	0.0733	0.397	0.376	194.8296
50	151.6236	14.72772	13.39007	10.37246	5.1875	0.389	41.10787	5.23	250	14	3.5	120	0.005	0.06085	0.409	0.391	197.4904
75	151.3739	14.8011	13.73759	10.40068	5.2563	0.412	66.4723	5.39	280	15	2.4	80	0.01	0.07955	0.428	0.401	197.8106
100	155.2456	14.8124	12.34043	10.40632	5.45	0.431	28.27988	5.62	370	15.65	2.2	0	0.01	0.0801	0.476	0.414	200.5758