Chemical Science International Journal

29(7): 18-27, 2020; Article no.CSIJ.52737
ISSN: 2456-706X
(Past name: American Chemical Science Journal, Past ISSN: 2249-0205)

Characterization of Leachate from Municipal Open Solid Waste in Makurdi, Benue State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author DNJ designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SEI and AWR managed the analyses of the study. Author UIA managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CSJI/2020/v29i730191
Editor(s):
(1) Dr. Pradip K. Bhowmik, University of Nevada Las Vegas, USA.
Reviewers:
(1) Irma Dervišević, University of Prishtina, Serbia.
(2) K. O. Ozegin, Ambrose Alli University, Nigeria.
(3) Rubén Fernando Gutiérrez-Hernández, Tecnológico Nacional de México and Instituto Tecnológico de Tapachula, México.
Complete Peer review History: http://www.sdiarticle4.com/review-history/52737

Received 02 November 2019
Accepted 07 January 2020
Published 16 September 2020

Original Research Article

ABSTRACT

The increase in the growth of population and urbanization in most state capitals has resulted in generation of large volumes of solid waste. Municipal solid waste is generated daily with an average of 0.5-1.5 Kg/daily per household. Municipal solid waste has become a health hazard in Nigeria, which is yet to be tackled properly by the government and local authority. The methods used for the analysis of leachate samples were adopted from American public health association (APHA, 2012). This study characterizes the physico-chemical properties of leachate from municipal open solid waste in Makurdi, Benue state, Nigeria. The results showed that the colour and smell were light brown and malodourous respectively while the mean pH, temperature, Total solids, Total volatile solids, Suspended solids, Total dissolved solids, COD, BOD_5, BOD_5/COD ratio, Pb, Ni, Co, Cr and Cd were 7.79±0.02, 35.28, 5993.0±33.0 mg/L, 228.0±8.5 mg/L, 887.0±6.5 mg/L, 12168.0±22.1 mg/L, 868.00±0.12 mg O_2/L, 373.000±0.002 mg O_2/L, 0.46, 0.461.000±0.0010, 0.0845.000±0.0004, 0.2045.000±0.0009, 0.5211.000±0.0011 and 0.1565.000±0.0010 respectively. The leachate sample contain high concentration of organic and inorganic constituents including toxic metal content higher than the NESREA standards limit for drinking water.

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Keywords: Open solid waste; leachate; organic and inorganic compounds.

1. INTRODUCTION

Nigeria is pestered by a myriad of environmental issues, of which a lack of proper solid waste management system is chief. The annual generation of municipal solid wastes (MSW) in Nigeria is 25 million tonnes. At present most of the solid waste is being disposed in an unscientific manner which causes an adverse impact on the environment and human health [1]. Municipal open solid waste is generally dumped in an open dump outside the houses, shopping centre, offices, streets along the road, or at some collection sites. Widespread water, air and land pollution is caused from these dumps because the dumping sites are not properly managed and have been planted with suitable plant species to help in quick degradation of solid waste by way of creating conducive environment for the growth of microorganism besides providing greenery. Appropriate post open dumping practices are also seldom performed causing perpetual problems of air, water and soil pollution. Despite the attempts at waste avoidance, reduction, reuse and recovery (recycling, composting and energy recovery), open dumpsites are still the principal focus for ultimate disposal of residual wastes and incineration residues world-wide [2]. The placement and compaction of municipal wastes in open site facilitates the development of facultative and anaerobic conditions that promotes biological decomposition of open dump solid wastes. Hence, leachates of diverse composition are produced, depending on site construction and operational practices, age of the open dump solid waste, climatic and hydrogeological conditions and surface water ingress into the solid waste. Leachates from these open solid waste dumps migrate vertically and laterally into the environment by direct discharge into water bodies serving many communities around and far away from the open dump sites. The open-dump solid waste leachate containing pollutants are introduced into the ecosystems without treatment. This has resulted in the release of obnoxious gases and toxic metals into the environment [3].

Makurdi the capital of Benue State is located along river Benue with coordinates as 7°43′50′N and 8°32′10′E at the elevation/altitude of 104 meters. Has an estimated population of over 500,000 as at 2007 [4]. The municipal open solid waste (MOSW) sites are randomly located behind old airforce quarters, Wurukum along Makurdi-Lafia road where the municipal authorities in Benue State, Benue State Environmental Sanitation Agency (BENSESA) subsequently convey these solid wastes and dumps. The sites feeds river Benue with the leachate generated from the open dump solid waste. Makurdi is currently experiencing the problem of municipal waste management, principally as a result of unplanned development, rural-urban migration and natural increase within the city [5].

More than 45 million tonnes/year of municipal solid waste is generated from the urban centres which are collected inefficiently, inadequately, transported and disposed unscientifically in open dumps [6]. The generation is expected to rise to 125 million tonnes/year by the year 2025 [7]. The MOSW composition varies from place to place and also bears a rather consistent correlation with the average standard of living [8]. Generally in Makurdi metropolis, MOSW is disposed of in open areas without taking proper precautions or operational controls. The everyday person on the street in Makurdi metropolis seems unaffected by the waste piles on dumpsites and its subsequent generation of leachate. Literature has attributed the lack of awareness and low perception of the populace as contributing factors of municipal solid waste management issues [9].

The realization of the polluting effects of open solid waste leachates on the environment has prompted a number of studies. These include studies on domestic wastes, leachate quality, as well as underground water quality. For treatment however, neutralisation, chemical treatment, gravel filtration, waste stabilisation pond and constructed wetlands, among other strategies are been investigated in order to develop a cost effective and sustainable method of treatment of toxic metals from leachates at the open dump site. These leachates cause surface and groundwater pollution which is of major concern as they exert harmful effect to environment and life forms by causing carcinogenicity, skin irritation, multi-organ failure, neurotoxicity etc.[10].

Leachate is the liquid residue resulting from the various chemical, physical and biological processes taking place within the open-dump solid waste. One of the major pollution problems caused by the Municipal open dump solid waste (MODSW) is leachate, which is generated as a consequence of precipitation, surface run-off and infiltration or intrusion of groundwater percolating through an open-dump solid waste, biochemical processes and the inherent water content of wastes themselves [11]. Open-dump solid waste leachate is generated by excess rainwater percolating through the waste layers in a dump. A combination of physical, chemical and microbial processes in the waste transfer pollutants from the waste material to the percolating water thereby causing water contamination [12]. After an open dump solid waste site is closed, the open site will continue to produce contaminated leachate and this process could last for 30-50 years [13]. Generally, leachate may contain large amounts of organic matter (biodegradable, but also refractory to biodegradation), as well as ammonia-nitrogen, heavy metals, chlorinated organic and inorganic salts, which are a great threat to the surrounding soil, groundwater and even surface water [14]. The compositions of leachate can be divided into four parts of pollutants: Organic matter, specific organic compounds, inorganic compounds and heavy metals [12]. The composition of open dump leachate, the amount generated and the extraction of potential pollutants from the waste depend upon several factors, including solid waste composition, degree of compaction, absorptive capacity of the waste and waste age. It also depends on seasonal weather variations, levels of precipitation, temperature, pH size, hydro-geological conditions in the vicinity of the waste site. A simplified water balancing equation takes all of these factors into account and allows designers to predict an amount of leachate that will be produced by the open dump site [15]:

$$L = P - R - \Delta SM - ET - \Delta MC. \qquad (1)$$

Where L = leachate production, P = precipitation, R = surface run-off, ΔSM = change in soil moisture, ET = actual evapotranspiration losses from a vegetated surface and ΔMC = change in the moisture content of the refuse components.

The production of leachate also varies widely through the successive aerobic, acetogenic, methanogenic and stabilization stages. The degradation process of the waste in a dumps passes through different phases. The first phase which is normally short is characterized by the aerobic degradation of organic matter. When the oxygen is depleted, the degradation continues anaerobically. The anaerobic degradation process consists of two major fermentation phases, the acidogenic phase generating young, biodegradable leachate and the methanogenic phase, generating old, stabilised leachate [16]. During fermentation organic molecules are broken down into simpler substances in an energy yielding process. Some physico-chemical characteristics are typical for each phase whereas other parameters are not specifically phase dependant. Young leachate from the early acidogenic phase contains large amounts of readily biodegradable organic matter. The complex organic compounds are fermented anaerobically, yielding mainly soluble organic acids such as free volatile fatty acids (VFAs), amino acids, other low molecular weight compounds and gases like H_2 and CO_2 [17]. The concentration of VFAs can be quite significant, representing 95% of the TOC, leading to low pH (around 5). Typical COD values are 3,000-60,000 mg/l [13]. High ratio BOD_5/COD values of 0.5-0.7 indicate large amounts of biodegradable organic matter [18]. During this phase the metals are more soluble because of lower pH and the bonding with the VFAs, leading to relative high concentrations of Fe, Mn, Ni and Zn. Old leachate from the methanogenic phase is partially characterized by the lower concentration of VFAs. This is due to their conversion into CH_4 and CO_2 as gaseous end products during this second fermentation period. As the content of VFAs and other readily biodegradable organic compounds in the leachate decreases, the organic matter in the leachate becomes dominated by refractory compounds, such as humic like compounds and fulvic acid like substances [17]. Thus a low ratio BOD_5/COD, most often close to 0.1, is a characteristic value for stabilised leachates. The humic substances give a dark colour to stabilised leachates. The decrease of VFAs results in an increase in pH [18]. The concentration of metal ions is in general low due to the decreasing solubility of many metal ions with increasing pH. However, lead is an exception, since it forms very stable complexes with the humic acids [17]. Besides the effect of the shifting pH on metal-ions, there is the reduction of sulphate to sulphide during this phase, which increases the precipitation of metals ions.

In general, the strength of leachate decreases with time due to biological breakdown of organic compounds and precipitation of soluble elements such as toxic metals. Due to its biodegradable nature, the organic compounds decrease more rapidly than the inorganic compounds with increasing age of leachate production. Therefore the ratio of Total Volatile Solids to Total Fixed Solids (TVS/TFS) decreases with the age of the waste [2]. Three main groups of waste are classified as young (less than five years), intermediate (5-10 years), and old or stabilized are more than 10 years. Normally, young waste leachate (the acid-phase waste, <5 years) contain large amounts of biodegradable organic matter. More than 95% of the Dissolved Organic Carbon (DOC) consists of volatile fatty acids, and little of high molecular weight compounds. In mature waste (the methanogenic-phase waste), the organic fraction in the leachate becomes dominated by refractory compounds, and the DOC content consists of high molecular weight compounds [19]. According to the study of [20] the concentration of the organic substances and the ratio of BOD to COD are generally higher during the active stage of decomposition and decrease gradually due to leachate stabilization.

Toxic metals are some of the constituents of leachate which are introduced into the ecosystem causing a serious problem to ecological systems including aquatic system, microorganisms and also to human health [21]. These toxic metals are not biodegradable and they have a tendency to accumulate in biological system (vegetables, aquatic inhabitants), which are enriched by human beings through food chain [22]. Therefore these toxic metals are of great concern because they are being added to soil and water in increasing amounts [23]. Although, some are micro nutrients (Cu, Mn and Zn) which are required in small amounts for plant and animal life but may be harmful if taken up by plants or animals in large amounts, others (e.g. Cd) have no apparent biological function [24].

Most of the pollutants present in leachate possess a significant threat to both environment and public health as they contain xenobiotics and toxic metals which are non-biodegradable and persistent in the environment. There have been reports on the generation and characterization of municipal solid waste in Makurdi. However, there are a few reports on the contributions of leachate generated from municipal solid waste dumpsites to environmental pollution. This was the reason for conducting a study to determine the levels of some physico-chemical properties of leachate in open dump solid waste dumpsites to estimate the pollution effects and to suggest a sustainable cost effective and environment friendly method of treatment.

2. MATERIALS AND METHODS

The materials used in this study include reagents. The reagents/chemicals were supplied by May and Baker Limited Dagenham England which are of analytical grade and were used without further purification. Distilled-deionized water was used for their preparation and dilution of all solutions. Concentrated H_2SO_4, $CuSO_4$, $KMnO_4$, sodium oxalate ($Na_2C_2O_4$), Manganese sulphate, alkali-iodide, $Na_2S_2O_3$, NaOH, HCl and NaCl. The apparati used include; volumetric flasks, evaporating dish, filter paper, beakers, conical flasks, sieve, mortar and pestle while the instruments used were oven, thermostat water bath, digital Jenway pH meter (Model 3310), digital weighing balance, thermo-meter, Atomic Absorption Spectrophotometer. All the glassware used in the present study is Borosil grade. They were cleaned by soaking them in a detergent solution first and then in nitric acid (10%) for 48 hours. These were then rinsed with distilled deionized water prior to use.

2.1 Sampling Sites

The leachate sample were collected randomly from four different non-engineered sites within the same area as shown on Fig. 1. The old dump sites are located behind old air force quarters near on the bank of river Benue which has been continuously used for solid waste disposal for over 15 years.

Four leachate samples for the study were collected from four tube wells dug into the dumpsites to a dept of 1.6m to collect effluent from the waste mass during raining season in September, 3014. Since the dumpsite was not equipped with a leachates collector, the leachates collected at the base of the dumpsites was sampled randomly from four different locations. A 500 cm^3 beaker tied by a rope and a weight attached to the end of the beaker by lowering to surbmerge below the leachate and transferred to the 2 L glass bottle that has been washed with detergent and rinsed out thrice with distilled water. The collected MODSW leachate from the different points were mixed thoroughly to make a composite sample in a clean labeled bottle, covered, transported to the laboratory and kept at room temperature [25,26].

2.2 Methods

The composite sample was analysed for its physico-chemical parameters according to

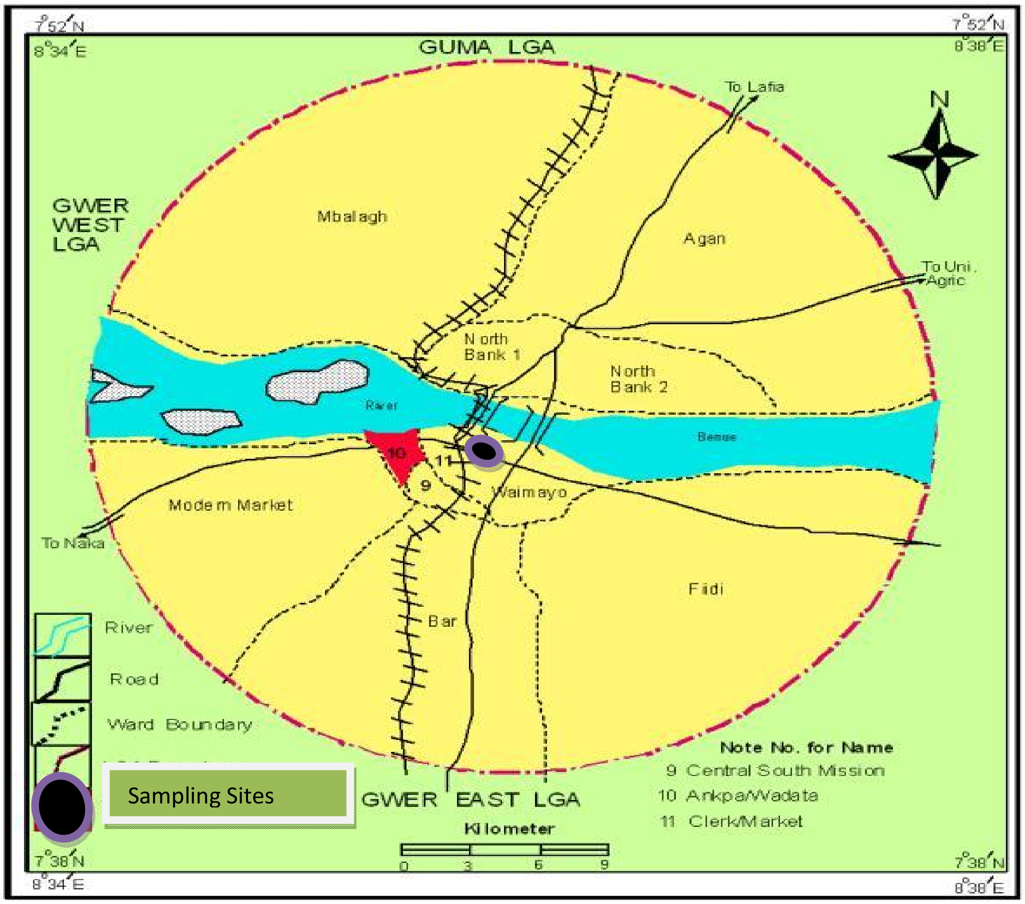

Fig. 1. Map of Sampling Stations on Dump Sites [Source:Ministry of Lands and Survey, Makurdi, 2015]

Standard methods for examination of water and wastewater specified by American Public Health Association (APHA) [27].

The determination of colour was carried out using Lovibond Tintometer APHA, [27]. The pH of the leachate sample was measured using a portable digital Jenway pH meter (Model 3310) equipped with glass electrode, A multipurpose Jenway portable combined TDS/conductivity meter (4510 model) was used to determine the temperature of the leachate,. The total solids, volatile solids, total suspended solids of the samples were determined by a method described by APHA, [27]. Total dissolved solids were determined by using standard methods by AOAC [28], the COD was determined according to the method reported by APHA, [27] and the BOD_5 was determined using Winkler method. In the determination of heavy metal in the leachate sample atomic absorption spectrophotometer was used.

3. RESULTS AND DISCUSSION

The levels of the mean values of physico-chemical parameters of municipal open solid waste leachate are presented in Table 1. From the results of this study, the colour of leachate samples were light brown with a malodorous smell, mainly due to the presence of organic acids, which come from the decomposition of organic matter which is in agreement with the study reported by [29], [30] and [31] reported that leachate are often yellowish, palebrown or dark-brown in colour due to the dissolved and particulate organic matter. Stabilized leachate contains high levels of organic substances such as humic and fluvic compounds, which can be indicated by leachate brown colour [32, 33].

The mean pH value of the leachate sample was 7.79 which is within the NESREA [34] standards of 6.5 -8.5.The result is consistent with those published by [35] with a pH value of 7.81 and

7.83 of leachate from Cipayung landfill. Higher pH values in the range of 8.3-9.10 were reported from the stabilized leachate of semi-aerobic landfill [32]. The pH value indicated high alkalinity this may lead to the disruption of biological process as a result of pH imbalance which may result to consequent pollution of the surrounding environments. This could be because organism capable of degrading organic matter mostly works maximally at pH 7. [36] carried out an analysis on the physico-chemical characterization and pollution index determination of leachates from Warri waste dumpsite, Southern Nigeria reported a pH range of 7.78-8.55. Generally, the pH of a stabilized leachate is higher than that of a young leachate [37]. The pH of young leachate is less than 6.5 while old dumpsite leachate has pH higher than 7.5 [38]. Initial low pH is due to high concentration of volatile fatty acids and varied according to the age of the dumpsites [39].

Total Solids (TS) mean value of leachate samples of the dump sites obtained was 593±33.0 mg/L. The TS value obtained from this work was slightly higher than the NESREA [34] standard limit of 500 mg/L indicating that the leachate might be contain tiny suspended solid from organic matter. The TS value was lower than the value (32966.66 mg/L) reported by Mudo et al. [40]. Brice et al. [41] reported values of TS (103.29 mg/L) lower than the value obtain in this study when they carried out a study on the chemical composition of leachates derived from various fractions of domestic refuse.

The mean value of the suspended solids (SS) in the leachate sample of the dump sites was 887.0±6.5. The SS value in this study is lower than the value (2215.0 ±27.01) mg/L reported by [42] from an assessment of heavy metals in leachate of an unlined landfill in the Sultanate of Oman. Typical SS values of 200-2000 and 100-400 mg/l were recorded for the new (less than two years) and mature open dumpsites (more than 10 years), respectively [9]. The high value of the suspended solid indicates the presence of suspended organic matters material and the site is still undergoing biodegradation.

Total Dissolved Solids (TDS) comprises mainly of inorganic and dissolved organics. The amount of TDS reflects the extent of mineralization and a higher TDS concentration can change the physical and chemical characteristics of the receiving water [43]. TDS is one of the parameters taken into consideration for licensing discharge of landfill leachate in many countries such as in UK [44]. TDS values of the leachate sample of the dumpsite was 12168.0±22.1 mg/L higher than the NESREA [34] standard of 2000 mg/L. Indicating that the leachate has undergone mineralization process and has a very high tendency to change the physical and chemical characteristics of the receiving water. The value obtained in this study is within the range

Table 1. Mean values of physico-chemical parameters of municipal open solid waste Leachate

Parameters	Values	NESREA standard
pH	7.79±0.02	6.5-8.5
Colour	Light brown	-
Smell	Malodourous	-
Temperature ^{o}C	35.28	35.00
Total solids (mg/L)	5993.0±33.0	500.00
Total volatile solids (mg/L)	228.0±8.5	-
Suspended solids (mg/L)	887.0±6.5	-
Total dissolved solids (mg/L)	12168.00±22.1	500
COD (mg O_2/L)	868.00±0.12	30.00
BOD_5 (mg O_2/L)	373.000±0.002	6.00
BOD_5/COD ratio	0.43	0.40
Heavy metals (mg/L)		
Lead (Pb)	0.461.000±0.0010	0.1
Nickel (Ni)	0.0845.000±0.0004	0.01
Cobalt (Co)	0.2045.000±0.0009	0.05
Chromium (Cr)	0.5211.000±0.0011	0.20
Cadmium (Cd)	0.1565.000±0.0010	0.01

NESREA: National Environmental Standards and Regulations Enforcement Agency of those reported by [45] and [46] who reported values ranging from 70.7- 4,985.2 mg/L and 581-1,960 mg/L respectively. The biochemical oxygen demand (BOD) is the measure of biodegradable organic mass of leachate and that indicates the maturity of the landfill which typically decreases with time [47]. In this study, the mean BOD values for the leachate were 373±0.002 mg/L. The measured BOD values were considerably higher than the NESREA [34] standard limit of 6.00 mg/L. BOD value varies according to age of dumpsite. For new dumpsites, BOD values were 2000-30000 mg/L; for mature dumpsites, BOD value varies from 100-200 mg/L [9]. The values obtained from this study were in stark contrast to the values reported by [46] who reported values in the range of 798- 1,396 mg/L. The high BOD concentration may be as a result of a mixture of matured and new organic residues contained in the dumpsite.

The chemical oxygen demand (COD) represents the amount of oxygen required to completely oxidize the organic waste constituents chemically to inorganic end products. The mean COD value for the leachate sample was 868.00±0.12 mg/l which is higher than the NESREA [34] standard limit of less than 30 mg/L. Higher COD values of 4662 mg/L have been reported by [48] from leachate in Kolkata, India. For stabilized leachates, COD generally ranges between 5,000 - 20,000 mg/L. [46] reported a COD value of 113.9 mg/L. However, lower COD values in the range of 63.27-73.77 mg/L have been obtained by [40] from the city of Guaratingueta - SP, Brazil.COD value obtained in this work indicates the presence of a high amount of putrescible organic matter in the waste [49,50].

In general, the BOD_5/COD ratio describes the degree of biodegradation and gives information on the age of a dumpsite. High ratio of BOD_5/COD values of 0.5-0.7 indicate large amount of of biodegradable organic matter. During the early stage of decomposition of organic matter, the ratio of BOD_5/COD was reported to be less than 0.1 [51]. This calculated BOD_5/COD value of 0.43 is slightly greater than the NESREA [36] standard of 0.40 and lower than the value reported by [11] which was calculated to be 0.16. The calculated ratio of 0.43 is similar to those obtained by previous researchers with 0.47, 0.39. 0.41, 0.45 and 0.52 reported by [45] respectively. [46] reported BOD_5/COD ratio of 1.476, 0.54, 0.46 and 0.54 in their study of four dumpsites in Lagos, Nigeria. The value obtained in this work shows that the organic matter in the leachate is readily biodegradable and has a high degree of organic matter which can be attributed to the fact that the study site is active and open, being fed with waste on a daily basis. The mean lead content from this study was 0.461.000±0.001 mg/L which exceeded the National Environmental Standards, Regulations and Enforcement Agency (NESREA) [34] acceptable limit of 0.1 mg/L. The value is higher than 0.0865 mg/L for leachates from Warri waste dumpsite, southern Nigeria reported by [45]. The value of the lead content in this study is also higher than the value of 0.049 mg/L of lead content leached from the landfill in the city of Meknes, Morocco were reported by [52]. Also, Longe and Enekwechi [53] reported Pb content within a range of 0.01-0.4 mg/L from leachate. The high quantity of Pb content is attributed to the availability of Pb related wastes such as paper, cardboard, batteries, paints, pipes and photography processing chemicals in the dump site [56]. The chromium mean content of leachate in this study was 0.5211.000±0.0011 mg/L which exceeded the NESREA [34] standard with a mean of 0.02 mg/L. [54] reported a value of Cr content of (0.338 mg/L) from the landfill in the city of Meknes, Morocco while [45] reported a range of values from 0.262 – 1.618 mg/l in Ogbomosho which is within the value obtained from this work. The presence of Cr in the leachate sample may have originated from Chromium related waste such as pigments from photographic materials, paints, dyes, wood preservatives in the dumpsite. The mean cadmium content of the leachate in this study was 0.1565±0.0010 mg/L which is higher than the NESREA [34] standard of 0.01 mg/L. Samson et al. [11] reported Cd content from five dumpsite leachates in Ogbomosho not exceeding 0.01 mg/L which is in agreement with the results reported by Abdel et al. [55] in Dhapa, Kolkata, India. The mean value obtained from this work indicate that the dumpsite contain agricultural waste and residues from agrochemicals.

Nickel mean value for the leachate was 0.0845±0.0004 mg/L higher than NESREA [34] standard of 0.01 mg/L. Most of the report presented by other researchers showed higher Ni content in leachate for example [11] reported a value of 0.20 mg/L. [56] reported a value of 0.03±0.02 mg/L and [54] presented a value of 0.223 mg/L. The present of nickel indicate that the dumpsite contains plastic material. Cobalt mean value obtained from this study was 0.2045±0.0009 mg/L which is higher than the value reported by [55] from four dumpsites of

0.525 mg/L, 0.074mg/L, ND and ND. The concentration of heavy metals in leachate is generally higher at earlier stages because of higher metal solubility as a result of low pH caused by production of organic acids. As a result of decreased pH at later stages, a decrease in metal solubility occurs resulting in rapid decrease in concentration of heavy metals except lead because lead is known to produce very heavy complex with humic acids [17].

4. CONCLUSION

At present most of the solid waste is being disposed in an unscientific manner thereby generating leachate is one of the major causes of environmental problems of surface and subsurface water. The results showed that the leachate samples contain high concentration of organic and inorganic constituents including toxic metal content higher than the NESREA standards limit for drinking water. In view of the above, we, recommend that NESREA and state environmental and sanitation agencies should partner to upgrade the Nigeria metropolis refuse dumpsite into well engineered sanitary landfill and Phytoremediation technique should be used in combination with other physico-chemical methods which prove to be viable and economical in keeping the environment safe.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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