International Scientific Organization
http://iscientific.org/
Chemistry International
www.bosaljournals.com/chemint/

Toxicological symptoms and leachates quality in Elelenwo, Rivers State, Nigeria

Godson Ndubuisi Iwuoha* **and Abiola Akinseye**

Department of Pure and Industrial Chemistry, Faculty of Science, University of Port Harcourt, Nigeria
*Corresponding author's E. mail: holygodson@yahoo.com

A R T I C L E I N F O

Article type:
Research article
Article history:
Received July 2018
Accepted December 2018
July 2019 Issue
Keywords:
Toxicity
Waste disposal
Leachates
Guidelines

A B S T R A C T

The toxicological symptoms prevalent and reported in Elelenwo area were taken into consideration and the leachates quality of its notable dumpsites was investigated for possible links. In situ measurements were made and standard procedures followed for analyses of lead, cadmium and nickel as well as other physicochemical load of the leachates. The results obtained were compared with various guidelines set by some notable regulatory bodies. The outcome showed more than 100 folds toxicity levels above the various benchmarks especially for lead, cadmium and nickel. These dumpsites as a result are environmental hotspots for pollution distribution to nearby surface waters, air and wastewaters bodies as well as the ground water. There is a strong link between reported toxicological symptoms among inhabitants of Elelenwo and Leachates toxicity from these dumpsites and there is emergency need for clean-up action by appropriate authorities.

Capsule Summary: Elelenwo dumpsites are environmental hotspots for spread of pollution to air, surface and ground water and there is a strong link between leachates toxicity and prevalent toxicological symptoms among Elelenwo's inhabitants.

Cite This Article As: G. N. Iwuoha and A. Akinseye. Toxicological symptoms and leachates quality in Elelenwo Rivers State, Nigeria. Chemistry International 5(3) (2019) 198-205. https://doi.org/10.5281/zenodo.2064343

INTRODUCTION

Municipal solid waste management in Nigeria is a serious environmental problem mainly due to the unfashionable, yet popular open waste dump method and incineration practiced by most waste disposal and management agency in the country(Aluko et al., 2003; Horsfall and Spiff, 2013). Despite ongoing enlightenment on the 5Rs of waste management namely; refuse, reduce, reuse, recycle and recovery, there has been uncontrolled multiplication in numbers and sizes of waste disposal sites and this is not unconnected with rapid urbanization, industrialization, population growth, rapid village-city migration of humans and other anthropogenic activities (Keenan et al., 2010; Bhalla et al., 2013; Aluko et al., 2013). Rivers state with its heavy rainfall almost all year round and many open waste dumps is a potential source of leachates, which are liquids produced from percolation or infiltration of liquids through wastes in any dumpsite or Landfill (Monroe, 2001; Speigh 1996; Keenan et al., 1984).Leachates quality vary from one dumpsite or landfill to another and this depends on the solid waste composition, precipitation, cover design, hydrogeology, age of landfill or dumpsite, Leachates interaction and among others, (Speigh, 1996; Henry, 1996, Bhalla et al., 2013; Igbanoi, et al., 2019). Most unfortunately, leachates contains so many harmful substances like heavy metals, organic compounds, soluble salts, particulates, suspended matters which can grossly compromise soil, surface water, ground water qualities, and further (bio)-accumulate and biotransform in the environment and food chain (Aliks, 1992; Adnan, 2010; Guptaa, 2009; Patil et al., 2012; Igbano et al., 2019).

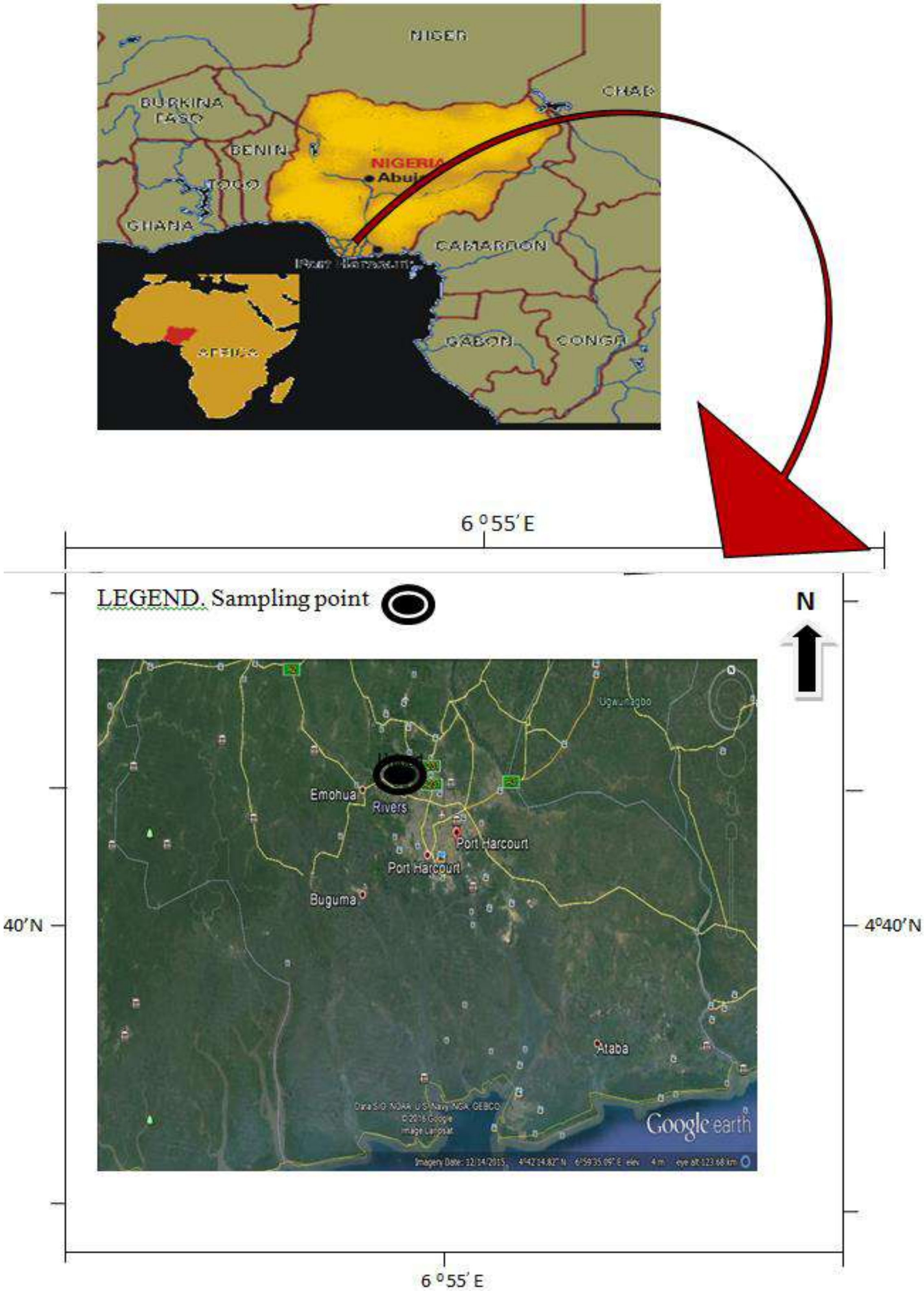

Fig. 1: Map of Port Harcourt, Nigeria indicating sampling point (Elelenwo) Google Earth (2018)

The health and environmental implications of heavy metals, soluble salts and pathogenic loading in leachates cannot be over emphasized and importantly leachates can leach into surface water and ground water. Both which could be sources of drinking and irrigation water for agriculture. Plants, aquatic species and soil micro-organisms accumulate these toxic substances (some which are non-biodegrable) with time and to the extent that the lower level of food chain becomes a real threat to life to animals and humans up the food chain. (Adnan, 2010; Adepegba, 2012; Iwuoha and Onojake, 2016; Igbanoi et al., 2019).Good quality drinking water is a gold standard for preventing diseases and improving quality of life. (Patil, et al, 2012). Recent United nation report puts the life expectancy in Nigeria just above 50 year and this could be linked to contaminated air, drinking water and food we eat (Patil et al., 2012, Iwuoha and Onojake, 2016).

Lack of data (existing and current) on leachates quality of the Elelenwo dump sites close to the Eleme woji river and well known Elelenwo dumpsites off East-West road and well reported increasing rate of Kidney failure, high blood pressure, reduced fertility and lung injury among residence of this area necessitate this research. The information derived could be of help to the people in authority, hence, the aim of the article is to investigate some physicochemical properties and heavy metals loading of the leachates at above dumpsites that could eventually pre-dispose people to the above toxicological symptoms.

MATERIAL AND METHODS

The study area is the Elelenwo dumpsites approximately located with the following geographical coordinates of Latitude 4^0 42'N and longitude 6^0 59'E in Port Harcourt metropolis of Rivers State, Nigeria. See figure 1 for map of study area. Leachates samples were collected along the dumpsite axis at different distances from the massive heaps namely 5 m, 10 m, 100 m at a depth sufficient to bring out the leachates during the rainy season (June, 2018) from randomly selected leachates drains at the site in well labeled three different clean bottles that were rinsed with the leachates prior to sample collection for determination of the following physicochemical parameters; Electrical conductivity, Total dissolved solids (TDS), Chemical Oxygen demand (COD), Biochemical Oxygen demand (BOD_5), pH, Sulphates, Lead, Cadmium and Nickel. Microsoft office excel 2007 was used to express the results obtained before the discussion. Standard method by Ademoroti (1996) was used for determination of total dissolved solids. The pH `and electrical conductivity of the leachates and surface water samples were done in-situ with a portable water test kit to obtain accurate results. The pH of values was obtained by using mettle Toledo portable pH standard buffers (4.0 and 7.00). The electrical conductivity meter was used to measure the resistance offered by the water samples between two platinized electrodes which has been standardized with 1412 μ/cm conductance observed with 0.01M KCl at a temperature of 25 ^{0}C.

The sulphate levels in the leachates and surface water were determined by the turbidimetric method. In this procedure concentration of the turbidity is calculated against known concentrations of 0.0148 g of anhydrous Na_2S0_4 that was diluted to 100ml with distilled water. Sodium Chloride in hydrochloric acid and glycerol in ethanol solution was added after which 0.3g of Barium chloride was used to produce turbidity. The solution was stirred and absorbance values were noted at 420nm using Genesis 10UV spectrophotometer. The Iodometric-Azide modification method was determining BOD over a 5 days period while the open reflux method was used for COD determination. For heavy metal measurements, leachates samples were prepared by acid digestion followed by filtration through Whatman No.44 filter paper. The filtrate were used to analyze for the various metals using a flame atomic absorption spectrophotometer which has been standardized with known concentration of the heavy metals solution and applying the suitable hallow cathode lamp and resonance wavelength of each heavy metal.

RESULTS AND DISCUSSION

The concentration in mg/L of Lead, Cadmium and Nickel are expressed in Table 1, which also contains three different regulatory standard or guidelines for drinking water with their respective maximum levels approved as at 2011 for the respective parameters. The regulatory bodies are; Australiasian Bottled Water Institute (ABWI) model code (2011), World Health Organization (WHO, 2009; 2011) and CODEX Standard for National Mineral Waters (2011).The loading of Lead in Leachates at the two sites are above of their maximum regulatory limits. At site 1, we have 1.370 mg/L and at site 2, we have 1.942 mg/L. the concentration is higher at site 2 relative to site 1 by a factor of 1.4. The mean value of the two sites (1.656 mg/L) is 166 times higher than both the WHO and CODEX maximum targets and 331 times higher than the ABWI (2011) limits.

The simple implication of this permutation is lead intoxication of the leachates which will eventually find its way to the underground water and the Eleme Wogi River as well. Noteworthy is the fact that there is no centralized body treatment and distribution system in the region. What is popular is the bore-hole water that is only filtered and subsequently used directly for domestic and drinking purposes. The result is not surprising in view of the nature of the dumpsites which includes, used tires, dead car's engines, used lubricating oil, grease, dead car batteries, discarded animal parts, foodstuff, industrial discharges, electronic components, paper etc, which are often incinerated periodically. The high levels of lead in the leachates might have resulted in toxicological symptoms that are now well reported and linked to the increasing and disturbing rates of organ failure mainly kidney, memory and learning difficulty, miscarried pregnancies, anemia, high blood pressure, and behavioral problems among the youths of this area. The high concentration of lead in rivers and boreholes in Niger-delta is well reported by Mgbemena and Obodo (2015). In similar way, cadmium at these sites has concentrations in the leachates that are disturbing. The value in the Leachates at site 1 is 0.028 mg/L, while at site 2, it was 0.053 mg/L.

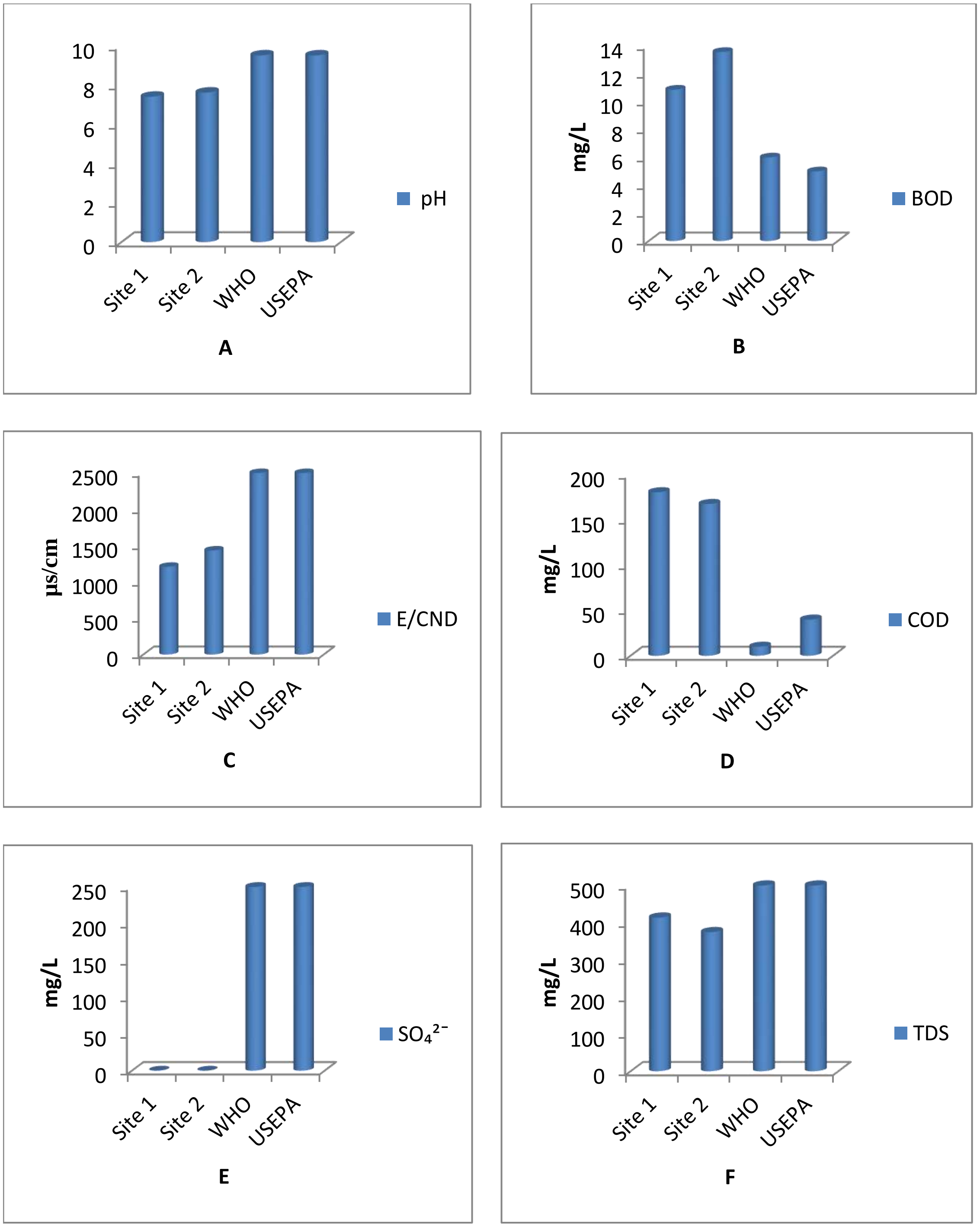

Fig. 2: Physicochemical parameters' concentrations of leachates in the two sites and their comparative match with the respective regulatory bodies' maximum acceptable limit by world health organization (WHO, 2009) and Unites States Environmental Protection Agency (USEPA, 2009).

The values were above the maximum acceptable levels of any of the regulatory body. The leachates mean concentration for the two sites is 0.0405 mg/L, is 1.35 times higher than WHO and CODEX maximum values, while it is 8.1 times higher than ABWI maximum value. No wonder that toxicological symptoms of Cadmium toxicity are common among Elelenwo inhabitants, the symptoms includes cancer, kidney damage and hypertension. The levels of Nickel in the leachates for the two sites by far exceed maximum regulatory targets of 0.1 mg/L, 0.07 mg/L and 0.02 mg/L for ABWI, WHO and CODEX respectively. The implication is that underground water, nearby surface

Table 1: Concentration (mg/L) of selected heavy metals at two sites in Elelenwo dump sites with three different regulatory standards

S/N	Parameters	Site 1	Site 2	*ABWI	*WHO	*CODEX
1	Pb	1.370	1.942	0.005	0.01	0.01
2	Cd	0.028	0.053	0.005	0.003	0.003
3	Ni	2.063	2.068	0.100	0.02	0.02

* = Food Standard Australia New Zealand (FSANZ), (2012).

water and the food chain are exposed to nickel toxicity. Toxicological symptom of Nickel toxicity include; low sperm count , Eczema, acute lung injury and headaches. The toxicity levels of Nickel in the leachates cannot be unconnected to above toxicological symptoms. The leachates mean nickel value of 2.0655 mg/L is 21 times higher than the ABWI maximum value, 30 times higher than WHO (2011) maximum value and 103 times higher than the CODEX maximum value for drinking water. The toxic levels of Nickel in leachates as seen in our report are consistent with other reports for leachates and waste water in Niger delta (Iwuoha and onojake, 2016; lgbanoi et al., 2019).

The pH of leachates in site 1 and 2 is 7.40 and 7.61 respectively. Both are within the range of acceptable limit by WHO and USEPA, i.e. 6.5-9.5. Note the upper limit of 9.5 was used in the figure 2a. The above pH values show carbonate-bicarbonate equilibrium shifting towards formation of more bicarbonate. No wonder, the carbonate levels recorded in the two sites are very low i.e 0.57 mg/L and 0.64 mg/L for sites 1 and 2 respectively. The pH value has a strong link with electrical conductance and total alkalinity. The electrical conductivity is an important parameter for water quality control (Igbanoi et al., 2019), the values in the two sites are respectively 1210 µs/cm and 1435 µs/cm for sites 1 and 2 respectively. These values even though below the benchmark of 2500 µs/cm indicate some remarkable ionic activity which could be linked to relatively high values of total dissolved solids and very high Chemical oxygen demands and Biochemical oxygen demands. Figure 2c shows leachates Electrical conductivity values for site 1 and 2 compared with WHO and USEPA values.

The high BOD_5 values for two sites i.e. 10.86 mg/L and 13.56 mg/L for site 1 and 2 showed that there is presence of decomposing or decomposed organic material in substantial quantity. It is an indicator of high microbial activity because the results exceeded the maximum acceptable values by WHO and USEPA i.e. 6 mg/L and 5 mg/L respectively. High BOD_5 values is linked to high COD values and indicates low dissolved oxygen content of the leachates. This also suggests that with heavy rains nearby river will be polluted or contaminated. The odour and aesthetic quality of the dump vicinity would be compromised. Figure 2b and 2d indicated the BOD_5 and COD levels in the leachates in the two sides in comparison with their respectively regularly bodies' maximum acceptable limit respectively. For COD values in the leachates, we have 180.48 mg/L and 167.54 mg/L for site 1 and 2 respectively, while the WHO and USEPA maximum acceptable value are 10 mg/L and 40 mg/L respectively. Anaerobic decomposition of the dump site gives rise to the production of alcohol, methane and foul smelling hydrogen sulphide. The sulphide reacts with available dissolved oxygen to form sulphate leading to further depletion of dissolved oxygen. The presence of Fe^{2+} ion formed from various iron scraps in the dump lead to its oxidation, hence, the high COD level in the leachates. Increasing COD values in the leachates further depletes dissolved Oxygen in the leachates and making the dumpsite serious environmental concern to nearby water bodies and underground water quality.

The low value of sulphate in the leachates in the two sites i.e. 0.041 mg/L and 0.022 mg/L compared to the WHO and USEPA maximum acceptable limit of 250 mg/L indicate other stabilizing factors in the dumpsite that reverses the formation of sulphate ion. The high pH value of 7.4 and 7.61 collaborates this, as the non-acidic nature of the leachates. Figure 2e shows the comparison of sulphate levels against WHO and USEPA maximum limit. The total dissolved solid (TDS) in the two sites are below the maximum acceptable limit of 500 mg/L, however, the loading in the two sites, i.e., 414 mg/L and 375 mg/L for site 1 and 2 respectively shows that the dumpsite have high microbial activity on the biodegradable organic matter load of the dumpsite. There are also relatively high chemical transformations to form salts that are water soluble. Figure 2f shows the leachates' TDS levels in the two sites compared to the regulatory body maximum limit. Results revealed that the leachates in Elelenwo dumpsites, Rivers State, Nigeria are polluted, and under the current scenario of increasing water sheds pollution (Abbas et al., 2018; Ali et al., 2019; Barbosa Segundo et al., 2019; Camaño Silvestrini et al., 2019; Čelić et al., 2019; Chu et al., 2019; Costa et al., 2019; Fiorentino et al., 2019; Iqbal, 2016; Iqbal et al., 2019; Joshi and Gogate, 2019; Li et al., 2019; Ma et al., 2019; Majdinasab and Yuan, 2019; Nzediegwu et al., 2019; Poblete et al., 2019; Qi et al., 2019; Wang et al., 2019a; Wang et al., 2019b; Yang et al., 2019; Zhang et al., 2019), there is need to monitor water bodies' quality regularly and adopt the efficient methods to treat the wastewater

(Caicedo et al., 2019; Hernández-Chover et al., 2018; Mohammadzadeh Pakdel and Peighambardoust, 2018; Salgot and Folch, 2018; Yu et al., 2019).

CONCLUSIONS

There is need to harmonize guidelines by the various regulatory bodies on the maximum accepted limit for the various water and wastewater indices and these indices should be based more on toxicological and microbiological loading in water and wastewaters. Based on the results and discussions on this research, the government of Nigeria should not only declare a state of emergency on drinking water quality but also establish well equipped laboratories that will continue to monitor leachates threat to water quality. The toxicological symptoms exhibited by the Elelenwo inhabitants could be directly linked to the toxicity posed by lead, cadmium and nickel in the leachates of this dumps. The dumps in Elelenwo area is off course one of the major sources of environmental pollution especially to air, surface water and groundwater. Every step should be taken to reduce the noted toxicological symptoms reported in this area by properly and effective designing waste disposal management in this area.

REFERENCES

Abbas, M., Adil, M., Ehtisham-ul-Haque, S., Munir, B., Yameen, M., Ghaffar, A., Shar, G.A., Tahir, M.A., Iqbal, M., 2018. Vibrio fischeri bioluminescence inhibition assay for ecotoxicity assessment: A review. Science of the Total Environment 626, 1295-1309.

Ademoroti, C.M.A., 1996. Standard methods of water and effluent analysis. Foludex press ltd, Ibadan, Nigeria 40-71.

Adepegba, O., 2012. Leachates Recirculation Practise and views. Retrieved from https:// leachate.co.uk/main/leachate-management/.

Adie, G.U., Osibanjo, O., 2007. The impact of effluent of Bodija abattoir on the physical-chemical parameter of Oshunkaye stream in Ibadan City, Nigeria. African Journal of Biotechnology 6, 1806-1811.

Adnan, Amin, Taufeeq, Ahmed, Malik, Ehsanullah, Irfanullah,Muhammad, Masror, Khatak And Muhammad, Ayaz, Khan, 2010. Evaluation of industrial and city effluent quality using physicochemical and biological parameters.Electronic Journal of Environmental, Agricultural and Food Chemistry 9(5), 931-939.

Ali, I., Peng, C., Khan, Z.M., Naz, I., Sultan, M., Ali, M., Abbasi, I.A., Islam, T., Ye, T., 2019. Overview of microbes based fabricated biogenic nanoparticles for water and wastewater treatment. Journal of Environmental Management 230, 128-150.

Aliks, K.O., 1992. Environmental Analysis 560, 159-165.

Aluko,O.O., Sridhar, M., Oluwander, P.A., 2013. Characterization of leachates from a municipal solid waste landfill site. Journal of Environmental Health Research 2, 345-355.

Australasian Bottled Water Institute (ABWI), model code. Application A1043.

Barbosa Segundo, I.D., Silva, T.F.C.V., Moreira, F.C., Silva, G.V., Boaventura, R.A.R., Vilar, V.J.P., 2019. Sulphur compounds removal from an industrial landfill leachate by catalytic oxidation and chemical precipitation: From a hazardous effluent to a value-added product. Science of the Total Environment 655, 1249-1260.

Bhalla, B., Saini, M.S., Jha, M.K., 2013. Effect of age and seasonal variation on leachate characteristics of municipal solid waste landfill. International Journal of Research in Engineering and Technology, 2 223-232

Caicedo, C., Rosenwinkel, K.H., Exner, M., Verstraete, W., Suchenwirth, R., Hartemann, P., Nogueira, R., 2019. Legionella occurrence in municipal and industrial wastewater treatment plants and risks of reclaimed wastewater reuse: Review. Water Research 149, 21-34.

Camaño Silvestrini, N.E., Maine, M.A., Hadad, H.R., Nocetti, E., Campagnoli, M.A., 2019. Effect of feeding strategy on the performance of a pilot scale vertical flow wetland for the treatment of landfill leachate. Science of the Total Environment 648, 542-549.

Čelić, M., Gros, M., Farré, M., Barceló, D., Petrović, M., 2019. Pharmaceuticals as chemical markers of wastewater contamination in the vulnerable area of the Ebro Delta (Spain). Science of the Total Environment 652, 952-963.

Chu, Z., Fan, X., Wang, W., Huang, W.-C., 2019. Quantitative evaluation of heavy metals' pollution hazards and estimation of heavy metals' environmental costs in leachate during food waste composting. Waste Management 84, 119-128.

CODEX Standard for Natural minerial water, 2011. CODEX STAN 108-1981.

Costa, A.M., Alfaia, R.G.d.S.M., Campos, J.C., 2019. Landfill leachate treatment in Brazil–An overview. Journal of Environmental Management 232, 110-116.

Fiorentino, A., Di Cesare, A., Eckert, E.M., Rizzo, L., Fontaneto, D., Yang, Y., Corno, G., 2019. Impact of industrial wastewater on the dynamics of antibiotic resistance genes in a full-scale urban wastewater treatment plant. Science of the Total Environment 646, 1204-1210.

Food Standard Australia New Zealand (FSANZ), 2012. Chemical guidelines/standard for drinking water (at approval) - Application A1043.

Gupta, D.P., Sunita, Sahara J.P., 2009. Physiochemical analysis of ground water of selected area of Kaithal India, Researcher 1(2), 1-5.

Henry, G., 1996. Solid Waste landfill. Environmental Sciences and Engineering, 56, 334-410.

Hernández-Chover, V., Bellver-Domingo, Á., Hernández-Sancho, F., 2018. Efficiency of wastewater treatment facilities: The influence of scale economies. Journal of Environmental Management 228, 77-84.

Horsfall, M., Spiff, A.I., 2013. Principles of Environmental pollution, and toxicology and waste management, Onyoma Research Publications 16-17.

Igbanoi, F.J., Ihunda, I. E.,Iwuoha G.N., 2019. Leachates and physicochemical characteristics of Rumuodumaya dumpsites, Niger-Delta, Nigeria. Chemistry International 5(2), 126-131.

Iqbal, M., 2016. *Vicia faba* bioassay for environmental toxicity monitoring: a review. Chemosphere 144, 785-802.

Iqbal, M., Abbas, M., Nisar, J., Nazir, A., 2019. Bioassays based on higher plants as excellent dosimeters for ecotoxicity monitoring: A review Chemistry International 5, 1-80.

Iskandar, M.B., 2010. The effectiveness of biofilter as a treatment for domestic wastewater. University Malaysia Pahang (thesis).

Issaias, I., 2000. Environmental impact of urbanisation on water resources; A case study of Nairobi dam. Imperial college of science, technology and medicine (University of London), 100.

Iwuoha, G.N., Onojake, M.C., 2016. Bioaccumulation of heavy metal in crustaceans from Oron river channel, Osung area Oron-City Akwa Ibom State, Nigeria. Journal of Chemical Society of Nigeria 41, (1) 33-36.

Joshi, S.M., Gogate, P.R., 2019. Treatment of landfill leachate using different configurations of ultrasonic reactors combined with advanced oxidation processes. Separation and Purification Technology 211, 10-18.

Kahara, N.S., 2002. Characterizing anthropogenic source of pollution for tropical urban river management. A proposed case study of the Nairobi river basin, Nairobi, Kenya.

Karanth, K.R., 1987. Groundwater assessment development and management Tata McGraw Hill publishing company ltd., New Delhi, 725-726.

Keenan J.D., Steiner, R.L., Fungaroli, A.A., 1984. Landfill leachates treatment. Water Pollution Conter Federation. 56(1), 27-33.

Keenan, T.F., Prentic, I.C., Canadell, J.G., Williams, C.A., Hang, W., Raupach, M. and Collatz, G.J., 2010. Recent pause in the growth rate of atmospheric CO_2 due to enhancedterrestrial carbon uptake. Journal of Nature Communication 2, 2-7.

Kitchaka, K., 2001. Assessment of the river water quality and in respect to pollution, Nairobi basin, Nairobi.

Kumar, N., Sinha, D., 2010. Drinking water quality management through correlation studies among various physicochemical parameters: A case study. International Journal of Environmental Sciences 1, 253-259.

Li, L., Fu, X., Ai, J., Zhou, H., Zhang, W., Wang, D., Liu, Z., 2019. Process parameters study and organic evolution of old landfill leachate treatment using photo-Fenton-like systems: Cu^{2+} vs Fe^{2+} as catalysts. Separation and Purification Technology 211, 972-982.

Ma, C., Yuan, P., Jia, S., Liu, Y., Zhang, X., Hou, S., Zhang, H., He, Z., 2019. Catalytic micro-ozonation by Fe_3O_4 nanoparticles @ cow-dung ash for advanced treatment of biologically pre-treated leachate. Waste Management 83, 23-32.

Majdinasab, A., Yuan, Q., 2019. Microwave synthesis of zeolites from waste glass cullet using landfill leachate as a novel alternative solvent. Materials Chemistry and Physics 223, 613-622.

Mgbemena, N.M., Obodo, G.A., 2015. Bioaccumulation of heavy metals in some fish samples from Oguta Lake, Imo State, Nigeria. Journal of Chemical Society of Nigeria, 40(2), 89-91.

Mohammadzadeh Pakdel, P., Peighambardoust, S.J., 2018. Review on recent progress in chitosan-based hydrogels for wastewater treatment application. Carbohydrate Polymers 201, 264-279.

Monroe, M., 2001. Textbook on landfill leachates treatment: VSEP offers a Revolutionary Solution. Retrieved from www.vsep.com/company/articles/2.html.

Nzediegwu, C., Prasher, S., Elsayed, E., Dhiman, J., Mawof, A., Patel, R., 2019. Effect of biochar on heavy metal accumulation in potatoes from wastewater irrigation. Journal of Environmental Management 232, 153-164.

Olago, O., Aketch, A., 2000. Pollution assessment in river basin pollution assessment report of the Nairobi river basin; Africa water network, pp. 106.

Patil, P.N., Sawant, D.V., Deshmukh, R.N., 2012. Physico-chemical parameters for testing of water-A review. International Journal of Environmental Sciences 3(3), 1194-1207.

Poblete, R., Oller, I., Maldonado, M.I., Cortes, E., 2019. Improved landfill leachate quality using ozone, UV solar radiation, hydrogen peroxide, persulfate and adsorption processes. Journal of Environmental Management 232, 45-51.

Qi, C., Yu, G., Zhong, M., Peng, G., Huang, J., Wang, B., 2019. Organophosphate flame retardants in leachates from six municipal landfills across China. Chemosphere 218, 836-844.

Salgot, M., Folch, M., 2018. Wastewater treatment and water reuse. Current Opinion in Environmental Science and Health 2, 64-74.

Speight, J.P., 1996. Uncertainty Resources Exploitation. United States environmental protection agency. 816-F-09-004.

Wang, D., Hou, H., Hu, J., Xu, J., Huang, L., Hu, S., Liang, S., Xiao, K., Liu, B., Yang, J., 2019a. A bio-electro-Fenton system with a facile anti-biofouling air cathode for efficient degradation of landfill leachate. Chemosphere 215, 173-181.

Wang, W.-L., Cai, Y.-Z., Hu, H.-Y., Chen, J., Wang, J., Xue, G., Wu, Q.-Y., 2019b. Advanced treatment of bio-treated dyeing and finishing wastewater using ozone-biological activated carbon: A study on the synergistic effects. Chemical Engineering Journal 359, 168-175.

World Health Organisation (WHO), 2011. Guideline for drinking-water quality. Table A3.3 Guideline values for chemicals that are of health significance in drinking-water.

World Health Organisation (WHO), Geneva, 2009. Guideline for drinking-water quality (electronic resource), 3rd edition incorporating 1st and 2nd agenda, Vol. 1, Recommendations.

Yang, X., Meng, L., Meng, F., 2019. Combination of self-organizing map and parallel factor analysis to characterize the evolution of fluorescent dissolved organic matter in a full-scale landfill leachate treatment plant. Science of the Total Environment 654, 1187-1195.

Yu, Y., Zou, Z., Wang, S., 2019. Statistical regression modeling for energy consumption in wastewater treatment. Journal of Environmental Sciences 75, 201-208.

Zhang, F., Peng, Y., Wang, S., Wang, Z., Jiang, H., 2019. Efficient step-feed partial nitrification, simultaneous Anammox and denitrification (SPNAD) equipped with real-time control parameters treating raw mature landfill leachate. Journal of Hazardous Materials 364, 163-172.