

**STUDIES OF LEACHATE IN DUMPSITES IN ENUGU
METROPOLIS, ENUGU STATE**

BY

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TITLE PAGE

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ENUGU STATE**

APPROVAL PAGE

Madu, Onyinye Callista, a postgraduate student in the Department of Zoology and Environmental Biology, Faculty of Biological Sciences, University of Nigeria, Nsukka with registration number PG/M.Sc/16/82004 has satisfactorily completed the course and research work requirement for the award of Master of Science degree (M.Sc) in Zoology and Environmental Biology (Ecology and Environmental Biology). The work embodied in this project report is original and has not been submitted in part or in full for any other diploma or degree in this or any other university.

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DEDICATION

This project work is dedicated to Almighty God and my beloved husband, Chief Chukwuemeka Nwoye.

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I am grateful to God Almighty for his love, grace and protection in my life and for helping me through this work. I thank my supervisors Prof. G. E. Odo and Dr. C. I. Atama for their wonderful and fatherly guide in the course of this project. God bless both of you.

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ABSTRACT

A study of leachates in dumpsites in Enugu metropolis, Enugu State was undertaken from July, 2018 to January, 2019. The aim was to determine the leachate characteristics of the various dumpsites in Enugu. A total of 9 residential areas' major dumpsites (Emene, Abakpa, Trans-Ekulu, GRA, Gariki, Asata, New Haven, Uwani, and Achara Layout) were studied. Site selections along the vicinity of the dumpsite were areas where waters from the dumpsites drip to the ground. The collected leachate samples were taken to the laboratory in plastic bottles in an ice cooler, filtered through a 250 mm Whatman filter paper and then stored in polyethylene bottles and preserved in cold room at a temperature of 4 °C prior to the physicochemical and metallic analyses. The data obtained from the study were analyzed using SPSS for Windows version 20. From the result, the pH value of the dumpsites ranged from 6.77 – 7.66 in the wet season and 6.73 – 7.29 in the dry season. Seasonal differences in pH values were recorded in the dumpsites. Electrical conductivity of the dumpsites ranged from 12.22 – 437.33 in wet season and 26.00 – 457.33 in dry season respectively. Also, the total dissolved solids values for both seasons ranged from 53.44 – 1480.78 (wet season) and 78.89 – 1263.11 (dry season). The present study heavy metals evaluation showed significantly increased copper (wet season: 0.01 – 2.29; dry season: 0.00 – 2.54), manganese (wet season: 0.02 – 0.64; dry season: 0.12 – 4.54), lead (wet season: 0.00 – 0.02; dry season: 0.03 – 1.05), cadmium (wet season: 0.01 – 0.93; dry season: 0.11 – 2.31), chromium (wet season: 0.02 – 0.15; dry season: 0.04 – 0.84), arsenic (wet season: 0.01 – 2.17; dry season: 0.09 – 2.81), and nickel (wet season: 0.08 – 0.30; dry season: 0.13 – 0.92) levels during the dry season. The concentrations of the heavy metals in the wet season followed this sequence in decreasing order: Ar > Cd > Mn > Ni > Cu > Cr > Pb. Arsenic and chromium were highest in Uwani dumpsite, cadmium levels highest in New Haven, manganese levels highest in GRA, nickel was highest in Echara New Layout, copper was highest in Asata, and lead was highest in Abakpa dumpsites. The dry season sequence in decreasing order is as follows: Mn > Ar > Cu > Cd > Pb > Ni > Cr. The heavy metals highest values were recorded in Asata for manganese, Uwani for arsenic and nickel, Abakpa and Uwani for copper, Echara New Layout for cadmium and chromium, and New Haven for lead concentrations. Overall, the study showed that copper levels have strong positive correlations with manganese, lead, arsenic and nickel concentrations. Also, manganese correlated with lead, arsenic and nickel. Cadmium correlated with chromium, while arsenic correlated with nickel. All the metallic correlations were positively strong. Copper and manganese had negative correlations, but that of cadmium was positive. The results obtained in this study showed that the leachates generated from the dumpsites could have harmful impact on the groundwater quality in the study area. This suggested that the surface and groundwater of the study sites are unreliable for drinking purposes, with emphasis on the need to improve on waste management practices and construct properly an engineered leachate collecting system at dumpsites to curtail pollution of surface and/or groundwater. Other implications of the leachate and regimes were also discussed.

CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

The activities of human and animals at homes, industries and commercial centers may result in the generation of solid wastes. In order to keep the surroundings and environment clean and neat, solid wastes have to be disposed off. In developing countries, there is an increasing awareness to minimize the levels of pollutants discharged into the environment. Several methods of disposal are in existence among which is landfilling. About seventy percent (70%) of solid wastes disposal is by landfilling especially in the developing countries such as Nigeria (Dong *et al.*, 2009). This is because it offers the lowest cost and is most easily managed. 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 (Al-Sabahi *et al.*, 2009). Indecorous handling of solid waste has resulted in serious ecological, environmental and health complications (Salami *et al.*, 2014). The municipal solid waste has been a major environmental problem in many countries. The landfill is the most common technology used to dispose municipal solid residues in developing countries. Consequently, several policies, strategies, plans and methods have been developed in the field of municipal solid wastes management. These include waste reduction and waste recovery for reuse, recycling, composting and incineration for energy generation in addition to landfilling of final rejects (Narayana, 2009). Solid waste management is a serious problem in Nigeria, as most cities lack standard engineered landfills. Open landfills are the primary means of municipal solid waste disposal in many countries worldwide including Nigeria because they offer low economic costs and have capacity to accumulate large amounts of solid waste compared to other methods such as incineration (Mohajeri *et al.*, 2010; Tsarpali, 2012). The awakening to the polluting effects of leachate from these dumpsites on the environment as a whole has motivated a number

of studies (Adepelumi *et al.*, 2008; Ugwu and Nwosu, 2009; Aderemi *et al.*, 2011; Oyelami *et al.*, 2013). 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 (Oyelami *et al.*, 2013).

The accumulation of waste disposed in landfills has generated a waste water product known as leachate (Abu-Daibes *et al.*, 2013). Moreover, haphazard discharge of industrial and municipal effluent can result in environmental pollution with diverse heavy metal (Agamator and Agamator, 2010; Abu-Daibes *et al.*, 2013; Mpofil *et al.*, 2013). Disposal of solid wastes has been identified as one of the major threat to groundwater resources by the production of landfill leachate. Landfill leachate is the highly toxic fluid (liquid and gas) that is produced as a result of the decomposition of the solid waste by the action of bacteria, viruses and fungi and the presence of precipitation and rain water on the solid waste at the dumpsite (Popoola and Fakunle, 2016). Landfill leachate accumulates at the bottom of the dumps with the heavy metals and carbonic acids contaminants being released at the base of the landfill migrating downward and horizontally to the groundwater (Popoola and Fakunle, 2016). Landfill leachate may be categorized as a water-based solution of four groups of contaminants namely: dissolved organic matter, inorganic macro-components, heavy metals, and xenobiotic organic compounds (Maiti *et al.*, 2016). The most important potential environmental influences associated with landfill leachate are contamination of groundwater and surface water, where groundwater is a worldwide significant and valuable renewable resource for human life and economic growth (Maiti *et al.*, 2016). Leachate formation occurs when the percolating water dissolves the soluble components out of the solid material (Asibor *et al.*, 2016). This is generally heavily contaminated and consists of complex waste water that is very difficult to deal with (Mohajeri *et al.*, 2010). Further contaminants are added depending on the type of solid waste and biodegradation stage. In recent

times, dumpsites pose a major threat due to leachate emerging from solid waste disposal which is strongly influenced by the composition of the wastes, the volume of leachate generated and the location of the dumpsite from water bodies (Ohwoghere-Asuma and Aweto, 2013). This has turned into a major issue as it influences the environment, wellbeing of the individual concerned and social prosperity. Most attention over groundwater pollution has been placed round pollution associated with human activities such as haphazard dumping of wastes followed by the burning of the wastes (Bhalla *et al.*, 2012; Olukanni *et al.*, 2015; Olukanni *et al.*, 2016). The studies on leachate and groundwater characterization show a serious threat to the local aquifer (Jaskelevicius and Lynikien, 2009; Patil *et al.*, 2013). Singh *et al.* (2011) made analysis on samples of solid waste, leachate and groundwater and stated that groundwater pollution is as a result of leachate which is imperative over natural processes in the surroundings of the dumpsite. Sources of major concern to the pollution of groundwater such as domestic wastes, landfills, agricultural chemicals and so on, can generate various types of pollutants which include heavy metals, cyanides, bacteria, nitrogen species, chlorinated hydrocarbons phenols, and dissolved organic matter, inorganic macro-components, xenobiotic organic compounds among others (Yusof *et al.*, 2009). Many factors influence the leachate composition including the types of wastes deposited in the landfill, composition of wastes, moisture content, the particle size, the degree of compaction, the hydrology of the site, the climate, and age of the fill and other site specific conditions such as landfill design and type of liner used if any (Rafizul *et al.*, 2011). As a result, surface water, groundwater reservoirs and soil layers become vulnerable to pollution from the dumpsite. A number of incidences have been reported in the past where leachates have been implicated in the contamination of surrounding soil and groundwater aquifer or nearby surface water, while studies by Longe and Balogun (2010) as well as Ohwoghere-Asuma and Aweto (2013) have shown that leachates outflow and percolation are source of ground and

surface water pollution adjacent to landfill sites. Dumped soil wastes are exposed to precipitation from rain, melted snow or the waste itself. As the liquid flows through the dumpsite, salts, organic and inorganic compounds are transported in the leachates. Leachates can move as surface water or percolate through the underlying strata and have very high polluting potentials.

The most important impact of landfill leachate is the surface and groundwater contamination which has given rise to studies in recent years. The rate of contaminant migration depends on the physical, chemical and biological processes in the soil profile (Rapti-Caputo and Vaccaro, 2006). Soils behave as a natural sink for pollutants released from both natural and anthropogenic sources. The decomposition of organic matter in solid wastes changes the physicochemical properties of the soil thereby affecting the groundwater sources beneath by the process of leachate percolation. The assessment of soil pollution becomes more complicated as a result of the different sources of the pollutants and their variable distribution (Vandana Partha *et al.*, 2011). Pivato and Gaspari (2006) pointed out that the liquid municipal solid waste of landfill is rich in minerals, organic compounds, ammonia and other toxic elements that can be a source of great concern to the aquatic environments. Also, Ozkaya *et al.* (2006) indicated that the degree of toxicity of the liquid leachates may vary from one candidate to another sample and this difference was probably linked to the mobilization of contamination or pollution load carrying or installation of solid waste. Moreover, Olivero-Verbel *et al.* (2008) found that the landfill leachates contained high concentrations of cadmium, mercury, nickel, manganese, copper and lead where the toxicity of leachates depends on the concentration of such metals associated with organic matter. Groundwater pollution is principally due to the process of industrial development and urbanization that has gradually developed over time without any esteem for environmental significances. The impact of leachate on groundwater and other water resources has attracted a lot of care because of its devastating environmental significance. Leachate migration from

landfills to the environments poses a high risk to groundwater resource if not satisfactorily managed (Patil *et al.*, 2013). The growing generation and buildup of wastes produce serious environmental, economic, and social difficulties in both developed and developing countries (Dharmarathne and Gunatilake, 2013). Electronic goods, painting waste and used batteries, among other wastes when dumped with municipal solid wastes increase the heavy metals in dumpsites and dumping devoid of proper segregation of hazardous waste can further elevate toxic environmental effects (Maiti *et al.*, 2016). Environmental impact of land filling of municipal solid wastes can usually result from the run-off of the noxious compounds into surface water and groundwater which ultimately lead to water pollution as a result of percolation of leachate (Venkata-Ramaiah and Krishnaiah, 2014). Other research findings have shown that leachate and outflow percolation are the sources of groundwater and surface water pollution close to landfill sites (Olukanni *et al.*, 2014a; Olukanni *et al.*, 2014b). 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 factors which affect leachate generation include topography, climate, vegetation, landfill cover, dumpsite characteristics, type of waste and the solid waste management systems in practice (Parameswari *et al.*, 2012). Several controlling factors for the leachate contamination include: rainfall, leachate mode of transportation, redox controls, topography, influence of unlined irrigation canal, age of the municipal solid wastes dumping site, induced fracturing, surface and sub-surface flow dynamics (Kale *et al.*, 2010). The toxic and mobile levels of heavy metals present in soils do not only depend on the total concentrations but also on their specific chemical form, metal properties, binding state, soil properties such as pH, environmental factors and matter content (Osu and Okoro, 2011). Consequently, these heavy metals are absorbed by plants through their roots and eventually into the food chain of mammals feeding on plants for daily

survival. These heavy metals are regarded to be very environmentally unfriendly. Thus, random disposal of such unexamined wastes indicates imminent harm to livelihood (Ojiako *et al.*, 2012; Abu-Daibes *et al.*, 2013; Mpofil *et al.*, 2013; Turki and Bouzid, 2017). The rate of metal contamination in our soil environment results from the constant disposal of waste generated from industrial and municipal activities ranging from batteries, leads foils, glass, metallurgical process, inks, effluent of fertilizer companies. These metals from wastes are highly recalcitrant in nature with their presence in the soil not easily eliminate or degraded by soil organisms through metabolic processes (Nda-Umar *et al.*, 2012). The negative effect of heavy metals cannot be easily underestimated as it reduces the quality of soil. It has contending influence on the properties such as pH of the soil and eventually inhibiting the proliferation of microorganism due to high contamination overtime (Nwuche and Ugoji, 2008).

The root cause of environmental pollution has been man's tendency to dilute and disperse wastes rather than to remove them at the source. With ever increasing population, urbanization and industrialization, the environment is considerably polluted even in the developing countries. Many dumpsites in urban areas have been converted into heavily polluted sites. In most cities in Nigeria, co-disposal of industrial, municipal, domestic and medical wastes in open and unsecured dumpsites and non sanitary landfills is a common practice. Wastes are haphazardly deposited as a result of which adjoining lands get enriched in salts and trace metals; thereby posing threat to the environment. Chemicals like phthalates, polyaromatic hydrocarbons and other organic micropollutants often found in leachates are assimilated by aquatic species, plants and passed through food chain and bioaccumulate in human on long term exposure. Exposure to multiple chemical combinations in occupational exposed populations and those residing near dumpsites has led to series of human health disorders such as organic dysfunction, reproductive, neurobehavioral and genetic disorders. However, since majority of the developing countries

depend on shallow groundwater wells and boreholes for their portable water need due to poor public water supply infrastructures; it is therefore expedient that a comprehensive study be carried out on the assessment of pollution levels from these dumpsites given that the consumption of groundwater from contaminated aquifers goes with health hazard implications.

1.1.1 Justification for the study

Waste management systems such as dumpsites and landfills reduce trash and garbage in urban areas of countries. Whereas dumpsites are solution to waste management in several countries, they are great source of environmental pollution besides climate change. Waste generation increases as the population grows and also as a country develops. Generated waste has to be disposed to minimize environmental impacts. Dumpsites and landfills emit gases such as methane and carbon dioxide, which are greenhouse gases (Shindell *et al.*, 2009; Akpofure, 2014). The alarming rate of domestic waste generation exploding population and increasing urbanization outweighs the approaches adopted by government on solid waste disposal (Adejobi and Oloruninbe, 2014). The poor disposal of solid waste is one of the major causes of bad quality environment in many cities and towns in Africa today. In recent times, urban centres in Africa have shown that the problem of solid waste management has become a major concern for authorities, state and federal government, environmentalist, planners and other related professionals alike (Chukwuemeka and Yusuff, 2015).

Dumpsites and landfills also contain leachates which are potential hazardous waste. Untreated leachate could impact on the environment and cause pollution to ground water (Kostova, 2006; Awaz, 2015). This is mainly because leachate may contain heavy metals such as lead, copper, zinc, nickel, chromium and cadmium, which are likely to be ground water contaminants if it seeps underground. Effects of these heavy metals to human health are known from previous studies (Aucott, 2008). Several studies have implicated leachates from dumpsites

and landfills as major contributor to surface and groundwater pollution both locally and globally. The works done in Chennai, India (Esakku *et al.*, 2005); Riyadh City, Saudi Arabia (Al-Wabel *et al.*, 2011); Cebu City, Philippines (Galarpe and Parilla, 2014); and Dhapa, India (Maiti *et al.*, 2016) evaluated heavy metals assessment and characterization of leachates of dumpsites. In Africa, Abd El-Salam and Abu-Zuid (2015) in Egypt assessed the impact of landfill leachate on groundwater quality. Notable works have been done in Nigeria on leachate studies.

In the Northern region, Buteh *et al.* (2013) studied the elemental composition of leachate in Bauchi Metropolis. The works by Adewuyi and Opasina (2010), Aiyesanmi and Imoisi (2011), Ojoawo *et al.* (2012), Sabejeje *et al.* (2014), Salami *et al.* (2015), Popoola and Fakunle (2016), and Olukanni *et al.* (2017) in Ibadan, Benin, Ogbomoso land, Ondo, Lagos, Ibadan, and Ota respectively are representative leachate studies in the Southwestern region. Further, from the South-South region, Asibor *et al.* (2016) carried out studies in Okwo, Delta State on leachate characterization and groundwater qualities assessment. Apart from the recent work by Michael (2017) in Onitsha, Anambra State on evaluation of leachate contamination index, there is dearth of published works on leachate studies in the South-East region.

Given the paucity of data on the dumpsites leachate physicochemical, metallic and microbiological composition in the South-East, the present study becomes both timely and worthwhile to obtain representative information for long-term monitoring program of leachates as well as surface and groundwater quality assessment. Hence, the need to quantify the levels of these heavy metals in leachate from the dumpsites in Enugu Metropolis to enable comprehensive awareness of the risks of the environmental and health impacts posed by the study area dumpsites to complement the existing studies. Furthermore, since the knowledge of leachate composition is essential to evaluate its pollution of a dumpsite, there is urgent need to study the

physicochemical composition and microbial load of the dumpsite leachate with the intent to propose its environmental risk reduction in Enugu Metropolis.

1.1.2 Significance of the study

The dumpsites contain domestic wastes, waste papers, scrap metals, vegetable wastes, and cans for different chemicals, plastic containers, old rags, vehicle tyres, scalpels and even human wastes. These pollutants get leached into groundwater through percolation especially when the sources of pollutants are haphazardly located close to water wells. Some of these wastes are hazardous and are bound to cause serious health problems if they enter domestic water supply.

This study of great importance therefore provides relevant information on the pollution potential of the dumpsites against the backdrop of groundwater contamination in the study region as needed to safeguard the current and future populations. Also, the report from this study would give insight and stimulate further studies on other dumpsites in the country vis-à-vis their physiochemical and heavy metals profiling, in other to advise the policy makers accordingly.

1.1.3 Objectives of the study

The general objective of the study was to determine the leachate characteristics of selected dumpsites in Enugu Metropolis.

The specific objectives of the study were to:

- i.** determine the physicochemical parameters of leachates from different dumpsites in Enugu Metropolis;
- ii.** evaluate the heavy metal composition of the leachates from various dumpsites in the study area;
- iii.** compare the monthly variations in the compositions of the study parameters of physicochemical and heavy metals of the different study locations, and

- iv.** determine the relationships that exist among the study parameters in relation to concentrations.

1.2 Literature Review

1.2.1 Leachates

Leachate is a liquid produced when wastes undergo decomposition, and when water (due to rainfall, surface drainage, groundwater, etc.) percolates through solid waste undergoing decomposition. As the water percolates downward, biological and chemical constituents of the waste leach into the solution. The percolating water may also mix with the liquid that is squeezed out of the waste due to the weight of the material. Thus, leachate is a liquid that contains dissolved and suspended materials that, if not properly controlled, may pass through the underlying soil and contaminate sources of drinking water, as well as surface water.

The composition of leachate depends on the stage of degradation and the type of wastes within the disposal facility. Leachate may contain dissolved or hanging substances connected with home and other wastes management of the dumpsite, and many by-products of chemical and natural reactions (Kostova, 2006). Leachates from municipal solid waste dumpsites have different pH values, organic and inorganic matter concentrations and moisture as a result of the biological activity occurring when the solid waste degrades. Leachate also may contain some hazardous components found in waste flow (Kostova, 2006). Organic contaminants of leachate are primarily soluble refuse components or decomposition products of biodegradable fractions of waste (Ogundiran and Afolabi, 2008).

Other environmental pollutants found in the leachate are mainly metal salts, which originate from different anionic and cationic constituents of leachates. Common heavy metals found in dumpsite leachates include zinc (Zn), copper (Cu), cadmium (Cd), lead (Pb), nickel (Ni) and chromium (Cr). Too little zinc (below 0.3 mg/kg/day) causes loss of appetite, decreased sense of taste and smell, sluggish healing of skin injury. Zinc shortage can cause birth abnormalities (Plum *et al.*, 2010). Too much zinc in the body can cause stomach cramps, skin

irritation, vomiting, nausea and anaemia. Very high levels of zinc can harm pancreas, cause arteriosclerosis and disturb the protein metabolism. Long exposure to zinc chloride can cause respiratory disorders. Presence of zinc negatively influences the activity of microorganisms and earthworms. This slows down breakdown of organic matter (Plum *et al.*, 2010). Long term contact with Cu can cause irritation of the nose, mouth and eyes and it causes headache, stomach aches, dizziness, vomiting and diarrhoea. Effects of copper are manifested at fairly low concentrations (Baun, 2004). Copper also negatively influences the activity of microorganisms. Copper absorption is depressed when zinc is given in high excess over copper (Plum *et al.*, 2010). Cadmium is one of the most poisonous elements which may be released to in the atmosphere. It is toxic to kidney, can cause bone demineralization as a result of renal dysfunction, and also cancer. Cd-contaminated food causes acute gastrointestinal effects. Low dosages of cadmium cause ovarian progesterone biosynthesis, while high dosages inhibit it (Godt *et al.*, 2006). Nickel also a heavy metal is deposited in kidneys, lungs, liver, heart and testes symptoms nickel poisoning include; headache, vertigo, nausea, vomiting, irritability and insomnia. Lead accumulates in bone, kidney and liver. It has gastrointestinal absorption of 10 % and biological half-life of about 20 years. Higher levels of lead reduce synthesis of haemoglobin and causes anaemia. It also affects nervous system and impairs renal system. Chromium can cause allergic reactions such as skin rash, nose irritations and nose bleeds, upset stomach and ulcers, weakened immune systems, kidney and liver damage and respiratory problems. Chromium ends up in air through coal combustion and in soils through waste disposal (Baun, 2004).

1.2.1.1 Collection system for leachates

A leachate collection system basically consists of a drainage layer of inert materials with high permeability of drainage pipes which have to collect the leachate and to discharge it out of

the dumping areas of collection and inspection shafts and of collection pipes (Abd El-Salam and Abu-Zuid, 2015). There are many components to a collection system including pumps, manholes, discharge lines and liquid level monitors. However, there are four main components that govern the overall efficiency of the system. These four elements are liners, filters, pumps and sumps. Natural and synthetic liners may be utilized as both a collection device and as a means for isolating leachate within the landfill to protect the soil and groundwater. The chief concern is the ability of a liner to maintain integrity and impermeability over the life of the landfill. Subsurface water monitoring, leachate collection and clay liners are commonly included in the design and construction of a water waste landfill.

To effectively serve the purpose of containing leachates in a landfill, a liner system must possess a number of physical properties. The liner must have tensile strength, flexibility, and elongation without failure. It is also important that the liner resist abrasion, puncture, and chemical degradation by leachate. Lastly, the liner must withstand temperature variation and be black (to resist UV light), easily installed and economical. The pipe dimension, type and layout must all be planned with the weight and pressure of waste, and transport vehicles in mind. The pipes are located on the floor of the cell. Above the network lies an enormous amount of weight and pressure. To support this, the pipes can either be flexible or rigid, but the joints to connect the pipes yield better results if the connections are flexible. An alternative to placing the collection system underneath the waste is to position the conduits in trenches or above grade (Mor *et al.*, 2006).

The collection pipe network of the leachate collection system drains, collects and transports leachate through the drainage layer to a collection sump where it is removed for treatment or disposal. The pipes also serve as drains within the drainage layer to minimize the mounding of leachate in the layer. These pipes are designed with cuts that are inclined at 120

degrees, preventing entry of solid particles. The further layer is used above the drainage layer in leachate collection (Tatsi and Zouboulis, 2002).

1.2.1.2 Characterization of leachates

Leachate contains soluble organic and inorganic compounds as well as suspended particles. Depending on weather, leachate flow can increase (during rainy season) or decrease (during dry/summer season). The landfill leachate discharge may lead to serious environmental problems. Leachate may percolate through landfill liners and subsoil, causing pollution of groundwater and surface water resources. A landfill is designed to protect the environment from harmful contamination by minimizing the migration of contaminants in leachates by providing appropriate liner. A characteristic of this wastewater is the change of some components with the change of biological conditions in landfills (Mor *et al.*, 2006).

Leachate also carries trace pollutants. These are found in low concentrations but they can be toxic, persistent, capable to bioaccumulate (Nyugen *et al.*, 2013). Among the different leachate pollutants, organic substances like ammonical nitrogen and heavy metal are of significant concern to the environment (Yusof *et al.*, 2009). These include heavy metals (e.g. benzene or arsenic) and organic pollutants (benzene trichloroethylene, and PCB's). All these factors make leachate difficult to manage.

Leachate from municipal solid waste landfills typically has high values for total dissolved solids and chemical oxygen demand, and a slightly low to moderately low pH. Municipal solid waste leachate contains hazardous constituents, such as volatile organic compounds and heavy metals pollution also can lead to ecological risk (Karbassi *et al.*, 2015).

1.2.1.3 Treatment of leachates

The knowledge of the quantity and composition of leachates usually gives an insight into appropriate, effective and sustainable treatment approach. An effective method for leachate

treatment is to recirculate the leachate back through the landfill. This is done to providing leachate treatment within the waste, increase waste settlement leading to more efficient use of land airspace, and to accelerate waste degradation. Recirculation does have potential issues with odours and other problems. Therefore if an operator wants to re-circulate leachate into the landfill, they must submit a plan that details the design, operation, monitoring and reporting that will be performed. This would also include contingency plans for events such as elevated leachate head, seeps, odours, equipment failure, slope instability and emergencies. Approval must be given prior to construction and commissioning. Therefore, physicochemical and biological methods of treatment are required to treat leachates before they are discharged into the environment at the dumpsite to either eliminate, or drastically reduce, the short term and long term detrimental effects on ecology, public health and the environment (Gupta *et al.*, 2015). Proper hazardous waste disposal must be employed if the entire contamination process is going to be successful. Protect our water supply and protect the public's health, it's good for all of us (Rowe *et al.*, 2012).

Activated carbon adsorption systems have also been used in the treatment of landfill leachates for the removal of dissolved organics; however, they are generally considered as one of the more expensive treatment options and often, must be combined with other treatment technologies to achieve desired results (Schiopu and Gavrilescu, 2010). The most common biological treatment is activated sludge, which is a suspended-growth process that uses aerobic microorganisms to biodegrade organic contaminants in the leachate. With conventional activated sludge treatment, the leachate is aerated in an open tank with diffusers or mechanical aerators. Since solid waste management becomes an essential issue and the leachate is considered as very hazardous, the landfill leachate needs to be treated accordingly to the standards before being discharged to the environment.

1.2.1.4 Management of leachates

The best way to control leachate is to prevent its generation. This includes managing surface and storm water flows, use of proper cover materials to prevent infiltration, and keeping high liquid content material out of the waste management facilities. If prevention and management is not enough, liner systems, removal systems and operational practices can also be implemented. Operators of the waste management facilities (WMF) are responsible for storage, treatment and handling of the leachate in accordance with the Waste Management Facilities Regulation and the permit or Environmental Act License.

1.2.2 Effects of leachate pollutants on human health

Water naturally contains small amounts of dissolved substances like zinc, calcium, magnesium and even impurities like silt, sand and microbial substances under normal circumstances. These quantities are considered safe for human use; however, when they exceed threshold limits, then the water is polluted. Metal ions and their complex exhibit a wide range of toxicity to organisms ranging from sub lethal to lethal, depending upon time of exposure and the ambient temperatures. For example, the heavy metals; Pb, As, Cd, Cr, Mn, Ni, and Hg are highly toxic even in low concentrations (Sangarika *et al.*, 2010). Cadmium and lead are some of the heavy metals that are hazardous to human health for example; long term exposure to lead can cause severe disruption of biosynthesis of hemoglobin and anemia, high blood pressure, damage to kidneys, miscarriages, brain damage, sperm damage in males and disruption of nervous system. Mercury can cause brain and kidney damage as well as interference with the nervous system, birth defects, miscarriages, and damage to DNA; while elevated manganese levels can disrupt the nervous system and regeneration of hemoglobin. When these pollutants are dumped haphazardly in landfills, the resulting leachate easily percolates into groundwater thus causing groundwater pollution. Leachate from ash landfills is likely to have elevated pH and to contain

more salts and metals than other leachate. Household batteries and fluorescent tubes make a small quantity of landfill wastes by volume but are a significant source of pollutants. More than 80% of mercury in solid wastes can in fact be traced to electronic substances, especially batteries (Michael, 2001). The other groundwater pollutants of concern are the pathogens and nutrients. Nitrogen limits the oxygen carrying capacity of red blood cells in infants causing a condition referred to as methemoglobinemia or blue baby syndrome (Osu and Okoro, 2011). Variation of groundwater quality is influenced by factors such as biological and physicochemical parameters. These parameters are influenced by geological and anthropogenic activities. Studies have shown that impact assessment of pollution sources of groundwater, have been receiving major attention both now and in the past. Sources of major concern to groundwater pollution include leachate from pit latrines, solid waste dumpsites, industrial effluents, domestic wastes, sea water intrusion, agricultural chemicals, and oil spillage. These sources can generate many types of pollutants including heavy metals, nitrogen species, chlorinated hydrocarbons phenols, cyanides, and bacteria among others.

1.2.3 Effects of dumpsites on environmental health

The term “open dump” is used to characterize a land disposal site where the indiscriminate deposit of solid waste takes place with either no or at best very limited measures to control the operation and to protect the surrounding environment. In addition, it is typical that no planning (such as location sensitivity) or engineering measures (such as a liner system) have been implemented prior to the delivery of waste. Sanitary landfill is an acceptable waste management method, with controlled emissions and limited health and environmental impacts, while open dumps are exactly the opposite. In between an open dump and a sanitary landfill there is a grey area usually named as “controlled dump” with varying levels of engineering and environmental controls. These vary from region to region and/or from nation to nation. The

decomposition of waste brings about the generation of gases, mainly a mixture of methane and carbon dioxide (about 50-50% in anaerobic conditions), which is called biogas. As methane is formed, it builds up pressure and then begins to move through the soil, following the path of least resistance. Often it moves sideways for a time before breaking through to the surface. Methane is lighter than air and is highly flammable. If it enters a closed building and the concentration builds up to about 5 to 15% in the air, a spark or a flame is likely to cause a serious explosion. Aside from being a flammable gas, methane released to the atmosphere greatly contributes to the depletion of the ozone layer and to climate change since it has approximately 21 times the global warming potential of carbon dioxide, over a 100 year period (EPA, 2012). Soil pollution is another environmental problem caused by dumpsites. Depending on the tendency of the contaminants, they end up either in water held in the soil or leached to the underground water. Contaminants like Cd, Cu, Ni, Pb and Zn can alter the soil chemistry and have an impact on the organisms and plants depending on the soil for nutrition. Many studies show evidence of serious hazards caused by open waste dumping ultimately affecting the plants' life cycles. Waste in open dumps often becomes a breeding ground for vermin, flies, and other potential carriers of communicable diseases. Open dumpsites without daily soil cover are also a source of odor, dust and litter. When open burning of solid waste is practiced (a usual practice to reduce volume), it could result in the emission of toxic substances to the air from the burning of plastics and other materials. The toxic fumes usually increase the concentration of air pollutants such as nitrogen oxides, sulfur oxides, heavy metals (mercury, lead, chromium, cadmium, etc.), dioxins and furans, and particulate matter.

1.2.3.1 Pollutants and health risks

I. Persistent organic pollutants

PoPs, such as dioxins and furans (PCdds and PCdFs) are persistent non-biodegradable organic compounds produced through uncontrolled burning of waste, natural generation of methane gas and low temperature burning of waste to recover metals. PoPs trigger a biological response in humans that results in neurological, immunologic and reproductive problems (White and Birnbaum, 2009). PoPs have been also considered responsible for respiratory disorders (Boadi and Kuitunen, 2005), and elevated cancer risk (Krajcovicova and Eschenroeder, 2007).

II. Heavy metals

Heavy metals can be found in dumpsite leachate, air and soil produced either from plastic burning or smelting of scrap metals and E-waste. Lead, mercury, cadmium and arsenic are the main heavy metals causing neurological impairments, anemia, kidney failure, immunosuppression, gastrointestinal and respiratory irritation, abnormalities of skeletal system, inflammation of liver, cancer of liver, cardiovascular diseases after chronic exposure (ISWA, 2015).

III. Volatile organic compounds (VoCs)

Volatile organic compounds are harmful to humans and also contribute to ground-level ozone pollution, also known as smog. Inhaling certain VoCs can lead to eye, nose, and throat irritation, headache, loss of coordination, nausea, and damage to liver, kidney, and central nervous system (EPA, 2014).

IV. Polynuclear aromatic hydrocarbons (PAHs)

The PAHs are a class of compounds composed of two or more aromatic rings and they are present in dumpsites (Nduka *et al.*, 2013). Hundreds of them have been identified and found as complex mixtures. They are generated by incomplete combustion, forest fire and volcanic

eruptions or by other anthropogenic sources such as industrial production, transportation and waste incineration. They are classified as environmentally hazardous organic compounds by European Community (EC) and United States Environmental Protection Agency (USEPA), and are included in the priority pollutant list. Several PAHs are known to be potential human carcinogens (ISWA, 2015).

V. Hydrogen sulfide (H₂S)

Hydrogen sulphide is a colorless, flammable gas with a characteristic odor of rotten eggs. It is produced in dumpsites when sulphate-bearing materials (such as gypsum and plasterboard) with high concentrations are mixed with biodegradable waste (ISWA, 2015). The composition of the waste material and the practices followed on site will determine the amount of H₂S produced. At low concentrations, H₂S may result in irritation to the mucous membranes of the eye and respiratory tract. Exposure to high concentrations results in depression of the central nervous system, loss of consciousness and respiratory paralysis (HPA, 2009a). Other health effects have been reported, although data on the effects in humans following repeated exposure are limited and difficult to interpret because of co-exposure to other chemicals.

VI. Particulates

Dumpsite activities produce both fine and coarse particulates, the make-up of which will depend on the activities undertaken on-site and the types of waste being handled. Exposure to particles that can enter the respiratory system is known to be associated with a range of adverse effects on health (ISWA, 2015). Particles of greater than 10 µm in diameter are unlikely to penetrate beyond the nose and larynx but, as the diameter of particles falls, the likelihood of their entering the lungs and being deposited in the airways increases. Particles of less than about 2.5 µm diameter are referred to as black carbon or 'fine' particles and are deposited relatively efficiently in the deeper parts of the lung – for example, in the alveolar spaces. Black carbon

consists of pure carbon in several linked forms. It is formed through the incomplete combustion of dumpsites bio-components. These particles may also have effects on health. People with pre-existing lung and heart disease, the elderly and children are particularly sensitive to particulate air pollution (ISWA, 2015). Dusts from dumpsites can become airborne and move off site through a number of mechanisms. The amount of dust lifted from the surface of the dumpsite is dependent upon the speed of the wind, the condition of the surface and the size of the dust particles. The distance travelled by dust emissions will depend on the particle size and on the wind speed and turbulence. Smaller dust particles will stay airborne for longer and disperse over a wider area. Strong and turbulent winds will also keep larger particles airborne for longer (ISWA, 2015).

VII. Odours

Odours are frequently a key issue for dumpsites, especially those receiving biodegradable waste (Fang *et al.*, 2012). Odours are typically associated with activities such as the handling of odorous wastes and the covering of biodegradable wastes or with the presence of trace components in gas or leachates. Odorous emissions are often accompanied by reports of ill-health from communities. Individuals may report a wide range of non-specific health symptoms, attributing these to odour exposure, including nausea, headaches, drowsiness, fatigue and respiratory problems. Health symptoms reported in association with odorous emissions can arise at olfactory detectable concentrations well below the levels associated with toxic effects or thresholds for mucous membrane irritation (ISWA, 2015). Individual responses to odors are highly variable and are influenced by many factors including sensitivity, age and prior exposure to the odour. Psychological and social factors, in addition to an individual's level of concern about the potential harm to their health, will also play an important role in an individual's response.

VIII. Leachate

Leachate releases by dumpsites are uncontrolled and surface and groundwater pollution should be considered as an almost certain consequence of the dumpsites operation. Taking into account that dumpsites are located without any proper procedures that take into consideration environmental vulnerability, it is not a surprise that serious surface and groundwater pollution is the rule in dumpsites (David and Oluyeye, 2014).

IX. Biogas

Biogas formation at dumpsites can result in explosion risks and several similar accidents have been reported, some of them with lethal consequences. Carbon dioxide and methane are the two major components of biogas (ISWA, 2015). The health effects of exposure to methane and carbon dioxide are well known. Both are colourless, odourless gases which act as asphyxiants. Carbon dioxide is non-flammable and, at low concentrations or low levels of exposure, it increases the depth and rate of respiration, blood pressure and pulse (HPA, 2010). At increasing concentrations, a depressive phase develops which can culminate in cardiorespiratory failure. Concentrations above 6% by volume can give rise to headache, dizziness, mental confusion, palpitations, increased blood pressure, difficulty breathing and central nervous system depression (ISWA, 2015). Humans cannot breathe air containing more than 10% carbon dioxide without losing consciousness. In contrast to carbon dioxide, methane is a flammable gas, which is explosive in air at concentrations between 5 and 15% by volume. Inhalation can cause nausea, vomiting, headache and loss of coordination. At very high concentrations it may cause coma and death due to respiratory arrest (HPA, 2009b). In addition, municipal waste usually includes limited quantities of harmful substances like chemicals (pesticides, garden products, batteries, bleach, paint, varnishes, cleaning products); biologicals (human waste, green waste, animal infestations, dead animal carcasses, animal waste, used needles/syringes, drugs etc.)

1.2.3.2 Wastes and health risks

Several population studies document that dumpsites can have serious effects on the health and wellbeing of the population (Guerriero and Cairns, 2009). A wide range of toxic substances can be released into the environment from uncontrolled waste disposal, for example, methane, carbon dioxide, benzene and cadmium. Many of these pollutants have been shown to be toxic for human health. The International Agency for Research on Cancer classifies exposure to cadmium and benzene as highly carcinogenic for humans (ISWA, 2015). In addition, dumpsites are likely to contain highly hazardous compounds resulting from industrial production, for example asbestos and lead. Previous epidemiological studies have found that two main health outcomes – cancer and congenital malformations – are statistically associated with waste exposure in dumpsites. The health impacts related to dumpsites are directly linked to the types of the different waste streams that are disposed off (ISWA, 2015). Different waste streams involve different health and safety risks. Dumpsites' on-site activities might increase or decrease the related health risks. Uncontrolled scavenging and open burning of waste, either for volume reduction or for metal recovery, are two of the most usual causes for increased health risks.

I. Municipal wastes

Organic wastes in dumpsites are biodegraded and thus they create conditions favorable for the survival and growth of microbial pathogens (ISWA, 2015). These conditions can be further enhanced if the waste is disposed of with pathogens from human body fluids such as faeces, urine, blood and sputum. All are present in typical municipal waste through nappies, sanitary pads and the general discards from vomiting and human secretions. Organic wastes also provide a food source for carriers of enteric pathogens such as rodents, insects, birds and larger wild mammals. Subsequently, the diffuse airborne emissions from biologically and chemically decomposing municipal solid wastes at dumpsites are clearly a health risk (ISWA, 2015).

Decomposition of organic fraction in dumpsites results in the generation of gases and contributes to leachate formation. While in modern sanitary landfills all those emissions are eliminated or under complete control (due to the use of advanced environmental protection measures like liners, top covers, biogas and leachate management system, continuous monitoring), in dumpsites those emissions are uncontrolled and they are actually associated with serious health hazards (ISWA, 2015).

II. Hazardous wastes

Hazardous wastes in dumpsites are a real threat for the lives of the workers and the nearby residents. WHO has estimated that environmental exposure contributes to 19% of cancer incidence worldwide (Vineis and Xun, 2009). Additionally, a WHO Global Health risks report looked at five environmental exposures (unsafe water, sanitation and hygiene; urban outdoor air pollution; indoor smoke from solid fuels; lead exposure; and climate change), and estimated they account for nearly 10% of deaths and disease burden globally and around one quarter of deaths and disease burden in children under the age of five (ISWA, 2015). Hazardous wastes are by-products of human activities that could cause substantial harm to human health or the environment if improperly managed. As an example, the United States Environmental Protection Agency (USEPA) classifies liquid, solid, and gaseous discarded materials and emissions as hazardous if they are poisonous (toxic), flammable, corrosive, or chemically reactive at levels above specified safety thresholds (ISWA, 2015). The term hazardous waste generally refers to potentially dangerous or polluting chemical compounds, other potentially hazardous industrial, military, agricultural, and municipal byproducts, including biological contaminants (Vineis and Xun, 2009). Chemical manufacturing, primary metal production, metal fabrication, and petroleum processing are some of the most usual industrial hazardous waste generators. However, businesses of all sizes generate dangerous chemicals. Obsolete pesticides, stored in

leaking drums or torn bags, can directly or indirectly affect the health of anyone who comes into contact with them (ISWA, 2015). During heavy rains, leaked pesticides can seep into the ground and contaminate the groundwater. Poisoning can occur through direct contact with the product, inhalation of vapours, drinking of contaminated water, or eating of contaminated food. Other hazards may include the possibility of fire and contamination as a result of inadequate disposal such as burning or burying. Chemical residues discharged into the sewage system may have adverse effects on the operation of biological sewage treatment plants or toxic effects on the natural ecosystems of receiving waters (ISWA, 2015). Asbestos is another common hazardous waste, directly linked with serious health impacts. Asbestos refers to a family of fibrous minerals found all over world. When the fibers break off and become airborne, they can create a health risk if inhaled. Asbestos exposure is associated with certain types of lung cancer, and long-term occupational exposure can also cause the lung disease asbestosis. In the past, asbestos was used in many household products and building materials because of its heat- resistant and structural properties. As a result, building renovation and demolition projects produce much of the asbestos waste found today.

The largest shares of these dumpsites are in Africa and in eastern European and northern Asian countries (ISWA, 2015). Dust from dumpsites may contain metals and human pathogens that come into contact with this pollution through contaminated groundwater and soil, or direct contact with the waste site. Children often are seen playing in and around dumpsites, introducing direct exposure with hazardous waste through dermal contact, inhalation of dust or accidental ingestion. Informal neighborhoods are often built on top of previous dumpsites where the soil, groundwater and nearby surface waters are contaminated, indirectly exposing the local population to leached pollutants. A notable issue with dumpsites in the developing world is the presence of scavengers – workers and their families at dumpsites who make their living by

recovering economically valuable materials in the waste (ISWA, 2015). In such situations, people come into direct contact with the hazardous waste. The health impacts of these pollutants include lung cancer, neurological problems and cardiovascular disease.

III. Health-care wastes

Health-care wastes are usually found in almost all the dumpsites in the developing world (ISWA, 2015). Health-care facilities, microbiological research laboratories, diagnostic laboratories, pharmaceutical firms and funeral homes have always generated a wide variety of waste components that have the potential of transmitting infectious agents to humans. These include discarded materials or equipment from the diagnosis, treatment and prevention of disease, assessment of health status or identification purposes, that have been in contact with blood and its derivatives, tissues, tissue fluids or excreta, or wastes from infection wards. Typical elements of the health-care wastes are the following: cultures and stocks of infectious agents generated in research or clinical laboratories; wastes from the production of biologicals including vaccines, antigens and antitoxins, and sera; pathological waste, including tissues, organs, and body parts; body fluids that are removed during surgery, autopsy, or other medical procedures; specimens of body fluids (ISWA, 2015).

Blood and blood products including discarded liquid human blood; discarded blood components (e.g., serum and plasma); containers with free flowing blood or blood components. Items or materials contaminated with blood or blood products. Sharps from health care, research, clinical laboratories and blood banks, including but not limited to: needles and syringes, scalpel blades, and broken or unbroken glassware, which were in contact with blood or blood derivatives. Animal waste including carcasses, body parts, body fluids, blood originating from animals from veterinary clinics or research institutes. The hazardous components of HCW pose physical, chemical, radiological and/or microbiological risks to the public and those involved in

their handling, treatment and disposal (ISWA, 2015). In most cases, the concentration of hazardous chemicals present in HCW is generally too low to be considered an occupational problem or a danger to the public. Physical injuries caused by discarded sharps are a more significant risk associated with HCW and may directly contribute to the transmission of microbial infectious agents. In addition, health risks may be generated through the release of toxic pollutants during dumpsite open burning or accidental fires (ISWA, 2015).

The most common and most investigated cause of the microbiological risks associated with HCW is injuries due to needles. Other sharps wastes presenting similar risks include glass and plastic ware employed in clinical and anatomic laboratories, blood collection systems for obtaining specimens, and scalpel blades from surgical procedures. These sharps may all have been in contact with microbial pathogens. More importantly, sharps can cause percutaneous injuries and thereby create an opening for infectious agents to enter the body. The latter is one of the five essential elements in the acquisition of microbial infections (ISWA, 2015). Most exposures to biological hazards from health-care wastes occur when workers or informal recyclers are trying to recover useful elements like metals. Workers may be exposed to blood and body fluids from leaking containers as well as airborne pathogens as the waste enters the dumpsite. Health-care waste components may also create microbiological risks as a source of infectious aerosols, i.e. droplets of less than 1-3 microns in diameter, which contain etiologic agents of human and animal diseases.

Human and animal tissues, organs, and body parts have also been reported in scientific literature as sources of infectious aerosols (ISWA, 2015). Finally, animal bedding materials, which have been saturated with body fluids, blood and excrement, can generate aerosols, which are a potential microbiological risk. Blood and blood products, as well as various types of body fluids may be capable of transmitting pathogens when brought into direct contact with the

mucosal lining of the mouth and nose, the eyes, and areas of the skin containing cuts and abrasions.

It should be also noted that many of the chemicals and pharmaceuticals used in health-care establishments are hazardous (toxic, genotoxic, corrosive, flammable, reactive, explosive, shock-sensitive). These substances are commonly present in small quantities in health-care waste; larger quantities may be found when unwanted or outdated chemicals and pharmaceuticals are disposed off (ISWA, 2015). They may cause intoxication, either by acute or by chronic exposure, and injuries, including burns. Intoxication can result from absorption of a chemical or pharmaceutical through the skin or the mucous membranes, or from inhalation or ingestion. Injuries to the skin, the eyes, or the mucous membranes of the airways can be caused by contact with flammable, corrosive, or reactive chemicals (e.g. formaldehyde and other volatile substances). The most common injuries are burns. Disinfectants are particularly important members of this group: they are used in large quantities and are often corrosive (ISWA, 2015). It should also be noted that reactive chemicals might form highly toxic secondary compounds.

IV. E-waste

The term E-waste describes waste electronic goods, such as computers, televisions and cell phones, while waste electronic and electrical equipments (WEEE) also includes traditionally non-electronic goods such as washing machines, dishwashers, refrigerators and ovens (ISWA, 2015). Computers and mobile telephones are disproportionately abundant because of their short lifespan. Components of electrical and electronic equipment such as batteries, circuit boards, plastic casings, cathode-ray tubes, activated glass, and lead capacitors are also classified as E-waste. E-waste is chemically and physically distinct from other forms of municipal or industrial waste; it contains both valuable and hazardous materials that require special handling and

recycling methods to avoid environmental contamination and detrimental effects on human health (ISWA, 2015).

Recycling can recover reusable components and base materials, especially Cu and precious metals. However, due to lack of facilities, high labour costs, and tough environmental regulations, rich countries have only recently begun to recycle E-waste as EPR systems have been implemented in Europe and elsewhere. Instead, E-waste has been either landfilled, or exported from rich countries to poor countries, where it may be recycled using primitive techniques and little regard for worker safety or environmental protection. The chemical composition of E-waste varies depending on the age and type of the discarded item (ISWA, 2015). However, most E-waste is composed of a mixture of metals, particularly Cu, Al, and Fe, attached to, covered with, or mixed with various types of plastics and ceramics. Heavy WEEE items, such as washing machines and refrigerators, which are mostly composed of steel, may contain fewer potential environmental contaminants than lighter E-waste items, such as laptop computers, which may contain high concentrations of flame-retardants and heavy metals. Virtually all E-waste contains some valuable components or base materials, especially Cu (ISWA, 2015). These are environmentally important, because they provide an incentive for recycling, which occurs predominantly in poor countries, and may result in a human health risk or environmental pollution. Platinum group metals are included in electrical contact materials due to their high chemical stability and conductivity of electricity. The precious metal concentrations in printed circuit boards are more than tenfold higher than commercially mined minerals (Betts, 2008).

The concentrations of environmental contaminants found in E-waste depend on the type of item that is discarded and the time when that item was produced. Some contaminants, such as heavy metals, are used in the manufacture of electronic goods, while others, such as polycyclic

aromatic hydrocarbons (PAHs) are generated by the low-temperature combustion of E-waste. The burning of insulated wire, which typically occurs in open iron barrels, generates 100 times more dioxins than burning domestic waste (Gullett *et al.*, 2007). Although recycling may remove some contaminants, large amounts may still end up concentrated in landfills or E-waste recycling centers, where they may adversely affect human health or the environment. Polybrominated diphenyl ethers (Pbdes) are flame-retardants that are mixed into plastics and components. There are no chemical bonds between the Pbdes and the plastics and therefore they may leach from the surface of e-waste components into the environment (Deng *et al.*, 2007). Pbdes are lipophilic, resulting in their bioaccumulation in organisms and biomagnification in food chains. Pbdes have endocrine disrupting properties (Tseng *et al.*, 2008). Obsolete refrigerators, freezers and air conditioning units contain ozone-depleting chlorofluorocarbons (CFCs). These gases may escape from items disposed in landfills. Dust is a significant environmental media that can provide information about the level, distribution, and fate of contaminants present in the surface environment. As an example, recent studies have demonstrated elevated body loadings of heavy metals and persistent toxic substances in children (Bi *et al.*, 2007) and E-waste workers, respectively, at Guiyu, China. E-waste pollutants are released as a mixture, and the effects of exposure to a specific compound or element cannot be considered in isolation.

However, a more complex understanding of the interactions between the chemical components of E-waste is needed. Exposure to E-waste is a complex process in which many routes and sources of exposure, different lengths of exposure time, and possible inhibitory, synergistic, or additive effects of many chemical exposures are all important variables. Exposure to E-waste is a unique variable in itself and the exposures implicated should be considered as a whole. Sources of exposure to E-waste can be classified into three sectors: informal recycling, formal recycling, and exposure to hazardous E-waste compounds remaining in the environment

(i.e., environmental exposure). Exposure routes can vary dependent on the substance and the informal recycling process.

Generally, exposure to the hazardous components of E-waste is most likely to arise through inhalation, ingestion, and dermal contact. In addition to direct occupational (formal or informal) exposure, people can come into contact with E-waste materials, and associated pollutants, through contact with contaminated soil, dust, air, water, and through food sources, including meat. Children, fetuses, pregnant women, elderly people, people with disabilities, workers in the informal E-waste recycling sector, and other vulnerable populations face additional exposure risks. Children are a particularly sensitive group because of additional routes of exposure (e.g., breastfeeding and placental exposures), high-risk behaviors (e.g., hand-to-mouth activities in early years and high risk-taking behaviors in adolescence), and their changing physiology (e.g., high intakes of air, water, and food, and low rates of toxin elimination). The children of E-waste recycling workers also face take-home contamination from their parents' clothes and skin and direct high-level exposure if recycling is taking place in their homes (ISWA, 2015).

People living in E-waste recycling towns or working in E-waste recycling had evidence of greater DNA damage than did those living in control towns. Although the toxicology of many E-waste components is well characterized, some newer materials, such as gallium and indium arsenides found in newer semiconductors, are less well understood. Their incorporation into nanomaterials may increase bioavailability in unanticipated ways. Developing children and fetuses may be particularly vulnerable to toxins found in E-waste, and early epidemiological studies near informal E-waste recycling sites indicate potential developmental neurotoxicity (ISWA, 2015). Understanding the hazards of E-waste, the impacts of its disposal, and the

dangers of informal or careless recycling will help reduce or prevent disease outcomes associated with exposure to E-waste components.

V. Burning wastes

Open burning of waste is a usual practice in many dumpsites, as a means to reduce the waste volume. The practice of open burning results in many harmful public health and environmental effects. Worldwide scientific research has conclusively demonstrated that burning of waste at dumpsites produces air toxins. Typically, burning occurs at low temperatures (250 °C to 700 °C) in oxygen-starved conditions (ISWA, 2015). Hydrocarbons, chlorinated materials and pesticide compounds under these conditions produce a wide range of toxic gases harmful to the environment and public health. These gases contain dioxins/ furans, volatile organic compounds, particulate matter (Pm), hydrogen chloride (HCl), carbon monoxide (CO) and oxides of sulfur and nitrogen and liberate metals including antimony, arsenic, barium, beryllium, cadmium, chromium, lead, manganese, mercury, phosphorus and titanium. The United States Environmental Protection Agency estimates that uncontrolled mixed garbage burning is a larger source of dioxins than coal combustion, ferrous metal smelting, and hazardous waste incineration or bleached pulp mill operations (ISWA, 2015). The burning of waste produces two types of ash, bottom and fly ash. Fly ash is made of light particles which is carried out by combustion gas and is laden with toxic metals, dioxin/ furan and other products of incomplete combustion which can travel thousands of kilometers before they drop out where they enter into the human food chain. One of the most harmful pollutants released during open burning is dioxin. Dioxin is a known carcinogen and is associated with birth defects. Dioxin can be inhaled directly or deposited on soil, water and crops where it becomes part of the food chain.

Formaldehyde is released when pressed wood products, paints, coatings, siding, urea-formaldehyde foam, and fiberglass insulation are burned. Exposure to formaldehyde can result in

watery eyes, a burning sensation in the eyes and throat, nausea, difficulty in breathing (i.e., coughing, chest tightness, wheezing), and skin rashes. Prolonged exposure to formaldehyde may cause cancer. Burning of plastics, or polyvinyl chloride (PVCs), can produce hydrogen chloride gas, or hydrochloric acid, which can cause fluid buildup in the lungs and possible ulceration of the respiratory tract (ISWA, 2015). The visible smoke from burning is composed of tiny particles (particulates), which contain toxic pollutants. If inhaled, these microscopic particles can reach deep into the lungs and remain there for months or even years. Breathing particulates increases the chances of respiratory infection, can trigger asthma attacks, and causes other problems such as coughing, wheezing, chest pain, and shortness of breath. Black carbon is a very usual output of open burning practices. Besides being the second-greatest contributor to global warming after carbon dioxide, black carbon also poses risks to human health, including cardiovascular disease, respiratory disease and premature death (ISWA, 2015). Carbon monoxide is generated from the incomplete combustion of waste. Carbon monoxide is a colorless, odorless gas that prevents oxygen from being absorbed by the blood and lungs. It is especially dangerous when inhaled by young children with immature lungs, the elderly, and people with chronic heart conditions or lung diseases.

Of particular health concern are tyre fires. Tyres are composed of natural rubber from rubber trees, synthetic rubber made from petrochemical feedstock, carbon black, extender oils, and steel wire, up to 17 heavy metals, other petrochemicals and chlorine (ISWA, 2015). A coal and tyre chlorine content comparison showed that tyres might contain as much as 2 to 5 times the chlorine level of typical western coal. Tyre fires burn for a long time allowing the buildup of the by-products of combustion around surrounding areas. Burning tyres are known to emit dioxins and benzene derivatives, which have been linked with reproductive impairment and cancer in humans. Tyre fires releases a dark, thick smoke that contains carbon monoxide, sulphur dioxide

and products of butadiene and styrene. Further, tyre fires can be extremely difficult to contain and extinguish and therefore burn and smolder for a long period of time. Even after they are extinguished, tyre fires can flare up again weeks, even months later. This can cause a build-up of the by-products of combustion in confined areas such as surrounding homes, which creates an additional health hazard (ISWA, 2015).

1.2.3.3 Occupation and health risks

Occupational health risks in dumpsites concern both workers and informal recyclers. In solid waste management, occupational health risks can be minimized by making waste technologies more contained, reducing contaminant emissions, changing working methods, use of protective clothing, and keeping the public and residents a safe distance away from operations. For example, risk of respiratory infection or allergic response to organic dust can be greatly reduced if transfer stations, composting and recycling process systems are enclosed or ventilated and if workers wear respiratory masks (UNEP, 2006). Because of inadequate understanding of the magnitude of the problem and poor financial resources, the risks are still largely unmanaged in most developing countries (Boadi and Kuitunen, 2005). In principle, workers and informal recyclers are exposed to the health and safety risks. Exposure to waste dumpsites is likely to give rise to significantly increased risks of chronic respiratory illness. Small quantities of biological material are present in most wastes, giving rise to a potential for exposure to bioaerosols (Mugo *et al.*, 2015).

Disposal of organic-rich wastes, including untreated municipal solid wastes, greatly increases the potential for bioaerosol emissions. All of them have indicated a higher prevalence of work-related dermatological, neuromuscular, respiratory, hearing, gastrointestinal symptoms, and injuries among landfill workers than among the control group participants. Furthermore, specific symptoms like nasal stuffiness were positively correlated with the handling of wood

products, machine oil, greases, and lubricants; job tasks that required the use of manual or power tools also were positively correlated with backaches and aching joints. The occupational safety of waste scavengers, particularly at dumpsites, is very poor and unfortunately in many cases they concern children too (ISWA, 2015). Waste scavenging commences already during the unloading of lorries. The sight is not uncommon of young men climbing on the waste being unloaded from the lorry with the trailer still raised in the tipping position. Often, there are machines present at the site to spread (and compact) the waste. Waste scavengers search through high piles of waste in the close proximity of machines. There is a constant potential for injury from slips, trips and falls. As scavengers hardly ever use any protective clothing such as boots, gloves and masks, they often get cut by sharp objects like needles and broken glass, as well as bitten by dogs and rats. In addition to the safety issues mentioned, there are frequent incidents of violence as well.

Dizziness, asthma, coughing, skin diseases, arthritis and urinary tract and kidney infections, on the other hand, could be occupational illnesses, linked to the conditions in which the work is carried out, where there is smoke from the burning of waste, there are no sanitary facilities, and water consumption is low, despite direct exposure to solar radiation and high temperatures (ISWA, 2015). The most common types of risks and accidents are related to injuries caused by some material, blows and getting hit by trucks, as well as skin infections. There are many more risks associated with the work than the interviewed people mentioned. It seems that because they work in such extreme conditions, they only manage to recognize the most common and visible risks and accidents (ISWA, 2015).

CHAPTER TWO

MATERIALS AND METHODS

2.1 Study Area

The study area is Enugu Metropolis. This covers three Local Government Areas: Enugu East, Enugu North and Enugu South (Bostic, 2009). Nine major residential areas in the metropolis which include Emene, Abakpa, Trans-Ekulu, GRA, Gariki, Asata, New Haven, Uwani, and Achara Layout were the study locations – a representation of the three Local Government Areas of Enugu Metropolis. Enugu State is in the South East geopolitical zone of Nigeria. It is located between 6° 30'N of Equator and 7° 30'E of Latitude. It shares border with the following states: Abia and Imo to the South; Ebonyi to the East; Benue to the North-East; Kogi to the North-West; and Anambra to the West. Enugu State covers an area of 7, 161km² (2, 765 sq mi) and ranks 29th out of the 36 states of Nigeria in terms of land area. The location of Enugu State falls in the tropical rain forest zone with a derived savannah. Hence, has a tropical savanna humid climate which is at its peak between March and November with a mean daily temperature of 26.7 °C (80.1 °F).

The average annual rainfall in Enugu is around 2, 000 mm (79 in), which arrives intermittently and becomes very heavy during the rainy season. All the solid wastes generated from the Metropolis are usually deposited at the major dumpsites. Open dumping is the method of disposal in practice which generates leachates leading to soil pollution (Okafor and Onwuka, 2013). The solid wastes generated include paper waste, human hair waste, packaging waste, glass, plastic bags, leaves from plants, branches from trees, aluminium cans, PVC pipes and condemned water closets. At the sites, the dumping and burning of solid waste persist and the dumpsites are not well drained, and are selected for study due to their age (duration of presence) and anthropogenic activities.

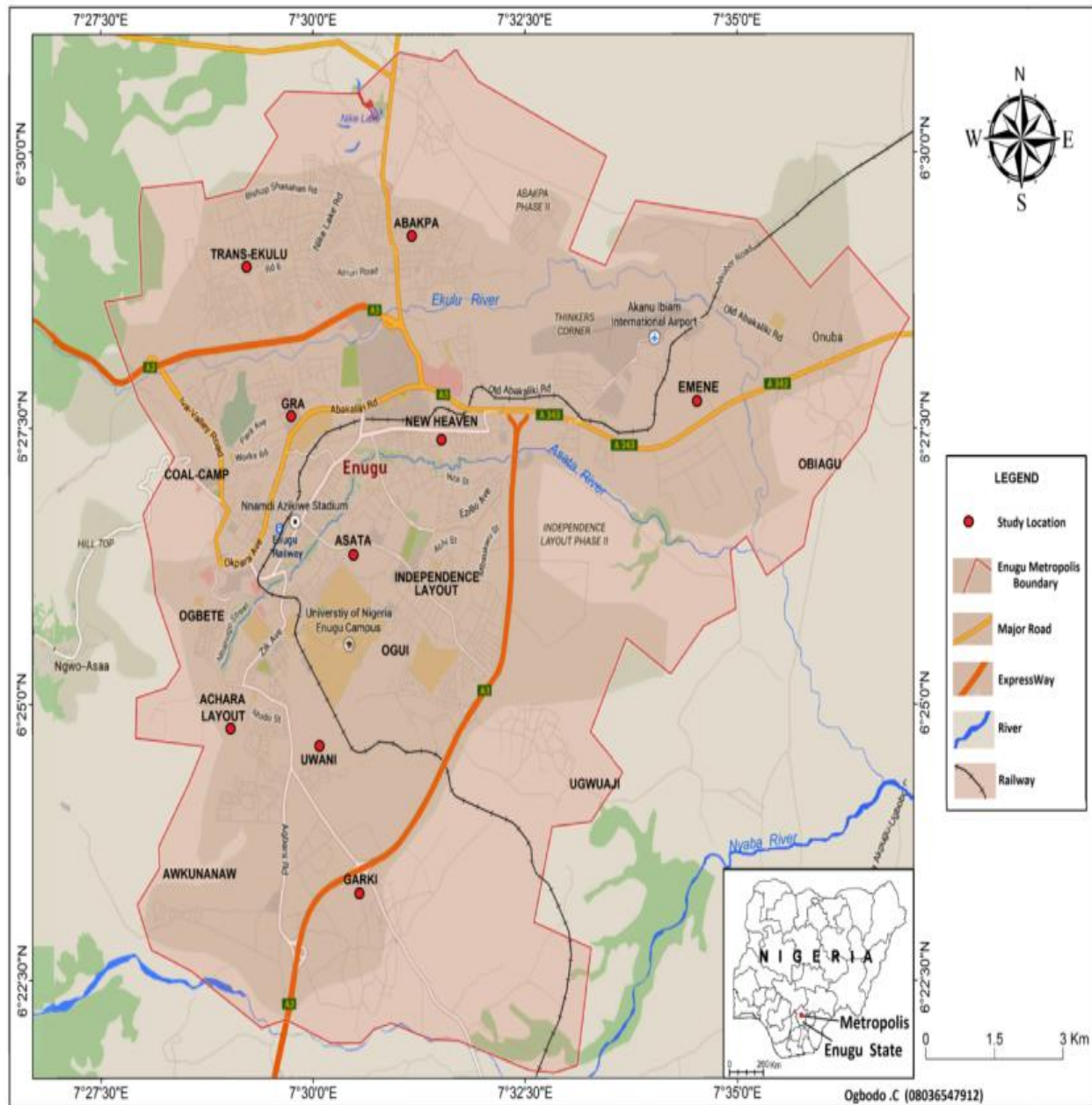


Figure 1: Enugu Metropolis Showing the Study Locations

Source: GIS Laboratory Unit, Department of Geography, University of Nigeria, Nsukka (2018).

2.2 Study Design

Purposive sampling design was adopted for this study. Samples were obtained from nine (9) different study locations of the study area. At each study location, three major dumpsites were selectively sampled. Samples were also collected from borehole in GRA. The study duration was from July 2018 to January 2019, and samples were collected at monthly intervals. Since the dumpsites are not equipped with leachate collector system, leachates were sampled from the four extremes of dumpsites using treated bottles after which the samples were properly mixed into homogenous sample in plastic containers for each Local Government representative dumpsites. The samples were properly labeled and stored in the refrigerator. Prior to analysis, the samples were allowed to return to room temperature, after which the determination of leachate parameters was carried out. All the parameters were measured according to the standard methods at the Research Laboratory of Energy Center, University of Nigeria, Nsukka.

2.3 Sample Sites and Sampling Procedure

A total of nine dumpsites were sampled in the study area. For each of the dumpsite, four sampling sites were selected by purposive sampling. Site selections along the vicinity of the dumpsites were areas where waters from the dumpsites drip to the ground. Samples containers of 1-litre plastic bottles were washed with detergent or soaked in 10% nitric acid and rinsed with de-ionized or distilled water to avoid contamination and allowed to dry before use. The bottles were rinsed twice with leachate sample water prior to collection as well. Rinsing with sample waters served as precautionary measure taken to avoid any interference that may arise from using contaminated samples containers. The collected leachate samples were taken to the laboratory in plastic bottles in an ice cooler, filtered through a 250 mm Whatman filter paper and then stored in polyethylene bottles and preserved in cold room at a temperature of 4 °C prior to the physicochemical and metallic analyses.

2.4 Samples Examination

2.4.1 Physicochemical analysis

The physicochemical parameters of hydrogen ion concentration (pH), temperature (T), total dissolved solids (TDS), and electrical conductivity (EC) were determined using standard procedures (APHA, 2005).

I. Hydrogen-ion Concentration (pH)

The pH value of leachate was determined using the electrometric method. The pH was measured in the laboratory using the Hanna pH meter (Hi-1922 model) according to APHA (2005). The meter was calibrated with pH buffer solution of 4.0, 7.0. After calibration, the electrode was removed from the pH 7 buffer solution and was rinsed severally with distilled water and blotted with soft tissue. It was then inserted into each of the samples (the electrode was rinsed with distilled water after each dipping) with the pH knob switched on. The readings were taken when the digital display becomes stable. At the end of the test, the electrode was rinsed again and stored immersed in distilled water.

II. Total dissolved solids

The TDS of leachate was measured and calculated in the laboratory using the gravimetric method. A Whatman filter paper No. 1 (15cm) was oven dried and a 250 ml conical flask was placed in an oven at 180 °C for 3 hours. Both were allowed to cool in a desiccator and then weighed. Exactly 100 ml of leachate sample was filtered through the filter paper into the conical flask. Thereafter, the leachate was evaporated to dryness on a hot plate (gently to avoid spouting) and the filter paper was placed in the oven set at 180 °C until a constant weight was obtained for the paper and flask separately. The total dissolved solids for the samples were then calculated using the formula:

Weight of empty conical flask = X g

Weight of flask + residue = Y g

Weight of residue (TDS) = (Y – X) g

Then TDS (mg/L) = (Y – X) × 1000 × 10 (APHA, 2005).

III. Electrical conductivity (EC)

The conductivity of leachate samples was determined in the laboratory using the Hanna 911 conductivity meter which was standardized with 0.01N potassium chloride (KCl) solution (APHA, 2005). Each sample of 100 ml volume was measured into a beaker and its conductivity by placing the meter probe directly into the sample (the probe was rinsed with distilled water after each placement). The readings were taken from the display on the meter and values were recorded in micro Siemens per centimeter ($\mu\text{S}/\text{cm}$) (APHA, 2005). At the end of conductivity determination, the instrument was turned off and the probe was rinsed with distilled water and stored in air dry.

IV. Temperature

The leachate temperature of each site was measured *in situ* in degree Celsius ($^{\circ}\text{C}$) using laboratory thermometer calibrated from 0 – 100 $^{\circ}\text{C}$. On each sampling day, the thermometer was dipped in water for about 5 minutes at a depth of 5 cm. Temperature was recorded as soon as the reading stabilized.

2.4.2 Metallic analysis

The heavy metals analysis for lead, cadmium, chromium, copper, nickel, arsenic and manganese were done in accordance with standard procedure and guidelines (APHA, 2005) and were analyzed using an atomic absorption spectrophotometer (AAS) (Buck Scientific, VGP 210 Model).

I. Lead (Pb)

Leachate sample (25 cm^3) was pipetted into a 250 cm^3 volumetric flask, dilute with about 25 cm^3 of distilled water and 3 drops of the indicator solution (xylenol orange) was added and then observe. If the solution turned red, 1 ml dilute nitric acid (0.5M) and add cautiously and stir until the solutions acquire a yellow colour. A pinch of hexamine (hexamethylenetriamine) powder was added until the colour becomes intensely red. This was to ensure that the solution has attained a pH of 6. The solution was titrated with standard EDTA solution (0.05M) until the colour changes to lemon-yellow and the concentration of the lead ion was calculated.

II. Cadmium (Cd)

Leachate sample (25 cm^3) was pipetted and dilute with distilled water (50 cm^3) and 3 drops of the indicator solution (xylenol orange) was added followed by a drop of dilute H_2SO_4 (0.05M) and the solution turn to yellow. A pinch of hexamine was added and shaken vigorously until the colour turn deep red. The solution was then titrated with EDTA solution (0.05M) slowly near the end point to a colour change from red to yellow and the concentration of cadmium was calculated.

III. Chromium (Cr)

Leachate sample (25 cm^3) was pipetted into 250 cm^3 conical flask and dilute with distilled water (25 cm^3). Xylenol orange indicator (3 drops) was added to obtain yellow solution. A pinch of powdered hexamine was added and the solution became red. The resulting solution was titrated with EDTA solution (0.05M) and the colour was observed. The concentration of chromium was then calculated.

IV. Copper (Cu)

Leachate sample (25 cm^3) was pipetted into 250 cm^3 conical flask and was diluted with distilled water (50 cm^3) followed by the addition of three drops of xylenol orange indicator, and

then observe the colour solution. A pinch of hexamine powder was added and then observed the colour change. The solution was then titrated with EDTA solution (0.05M) and then observed the colour of the end point and the concentration of copper were calculated.

2.5 Statistical Analysis

The data obtained from the study was analyzed using Statistical Package for Social Sciences (SPSS) for Windows version 20. The mean differences were tested using One-way Analysis of Variance (ANOVA) and separated using Duncan Multiple Range Test (DMRT). Pearson correlation coefficient (r) and Principal Component Analysis (PCA) were used to test the relationships that exist among the study parameters. Probability values (P -value) of $P < 0.05$ would be regarded significant.

CHAPTER THREE

RESULTS

3.1 Mean Variations of the Physicochemical and Metallic Parameters of Leachates of Dumpsites in Enugu Metropolis

The monthly variations of the physicochemical and metallic parameters in the various dumpsites of Enugu Metropolis are presented on Tables 1 – 10. In Emene dumpsite, monthly variations of the physicochemical and metallic parameters showed that the pH values were significantly ($p < 0.05$) higher in July, August and September than in the rest of the months, whereas the least was observed in January. The temperature recorded in the dry season months were higher ($p < 0.05$) than the wet season months. The electrical conductivity, total dissolved solids, copper, manganese, lead, chromium, arsenic and nickel were higher in January than in the other months. However, whereas the metallic parameters were significantly so ($p < 0.05$), the physicochemical higher components recorded in January were more or less insignificant ($p \geq 0.05$). The concentrations of cadmium were insignificantly ($p \geq 0.05$) higher in November than the rest of the months (Table 1).

Table 1: Monthly variation of the physicochemical and metallic parameters of Emene dumpsite

Parameters	Months					
	July	August	September	November	December	January
pH	7.67±0.07 ^c	7.63±0.03 ^c	7.67±0.03 ^c	7.07±0.03 ^a	7.33±0.13 ^b	7.03±0.07 ^a
T (°C)	26.00±0.00 ^b	25.30±0.00 ^b	24.00±0.05 ^a	27.00±0.04 ^c	27.20±0.03 ^c	28.30±0.03 ^c
EC (µS/cm)	238.00±7.02 ^a	233.33±6.57 ^a	235.33±5.33 ^a	293.00±21.52 ^b	268.00±15.53 ^{ab}	299.33±8.51 ^b
TDS (ppm)	99.00±7.00 ^a	95.33±7.42 ^a	96.67±6.67 ^a	117.00±10.41 ^{ab}	102.33±4.10 ^a	136.33±7.31 ^b
Cu (mg/l)	0.02±0.01 ^a	0.01±0.01 ^a	0.02±0.01 ^a	0.11±0.04 ^b	0.02±0.00 ^a	7.41±0.05 ^c
Mn (mg/l)	0.03±0.01 ^a	0.03±0.01 ^a	0.03±0.00 ^a	0.10±0.07 ^a	0.09±0.07 ^a	10.13±0.04 ^b
Pb (mg/l)	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.08±0.06 ^a	0.07±0.07 ^a	1.32±0.10 ^b
Cd (mg/l)	0.24±0.03 ^a	0.24±0.03 ^a	0.27±0.00 ^{ab}	0.45±0.09 ^b	0.26±0.01 ^{ab}	0.35±0.11 ^{ab}
Cr (mg/l)	0.02±0.01 ^a	0.02±0.01 ^a	0.03±0.00 ^{ab}	0.06±0.01 ^b	0.03±0.01 ^{ab}	0.11±0.02 ^c
Ar (mg/l)	1.42±0.33 ^a	1.11±0.32 ^a	1.13±0.31 ^a	1.79±0.07 ^a	1.79±0.06 ^a	4.10±0.05 ^b
Ni (mg/l)	0.14±0.00 ^a	0.14±0.00 ^a	0.14±0.00 ^a	0.19±0.05 ^a	0.13±0.01 ^a	2.05±0.03 ^b

All values expressed as mean ± standard error of mean, with superscript based on Duncan's multiple comparison.

Different letters indicated significant difference ($p < 0.05$) in mean values among different months across rows.

pH: Hydrogen Ion Concentration; **T:** Temperature; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **Cu:** Copper; **Mn:** Manganese; **Pb:** Lead; **Cd:** Cadmium; **Cr:** Chromium; **Ar:** Arsenic; **Ni:** Nickel.

Table 2 shows the monthly variations of the physicochemical and metallic parameters in Abakpa dumpsite. There were no differences in the physicochemical parameters, as they did not vary significantly ($p \geq 0.05$). Although higher values were observed for pH in August, while electrical conductivity and total dissolved solids were both highest in November. The temperature recorded in the dry season months were higher ($p < 0.05$) than the wet season months. The concentrations of copper, manganese, lead, arsenic and nickel were significantly ($p < 0.05$) higher in January than the rest of the months. The concentrations of cadmium were insignificantly ($p \geq 0.05$) higher in September than the rest of the months (Table 2).

Table 2: Monthly variation of the physicochemical and metallic parameters of Abakpa dumpsite

Parameters	Months					
	July	August	September	November	December	January
pH	7.37±0.09 ^{bc}	7.47±0.07 ^c	7.37±0.03 ^{bc}	7.13±0.03 ^b	7.37±0.09 ^{bc}	6.73±0.12 ^a
T (°C)	26.00±0.00 ^b	24.30±0.00 ^a	24.00±0.05 ^a	27.00±0.04 ^c	28.20±0.03 ^c	28.30±0.03 ^c
EC (µS/cm)	296.00±1.15 ^{ab}	282.67±13.33 ^a	287.67±4.91 ^{ab}	311.00±12.17 ^b	294.00±1.15 ^{ab}	305.67±4.91 ^{ab}
TDS (ppm)	103.67±3.71 ^a	96.33±7.36 ^a	102.67±4.41 ^a	144.67±22.26 ^b	109.33±5.55 ^a	126.00±7.55 ^{ab}
Cu (mg/l)	0.02±0.00 ^a	0.01±0.00 ^a	0.02±0.00 ^a	0.13±0.05 ^b	0.02±0.01 ^a	7.46±0.04 ^c
Mn (mg/l)	0.02±0.00 ^a	0.02±0.00 ^a	0.04±0.01 ^a	0.26±0.19 ^b	0.05±0.03 ^a	11.16±0.04 ^c
Pb (mg/l)	0.01±0.00 ^a	0.01±0.01 ^a	0.02±0.00 ^a	0.06±0.06 ^a	0.06±0.05 ^a	0.89±0.04 ^b
Cd (mg/l)	0.23±0.01 ^a	0.20±0.05 ^a	0.34±0.05 ^{ab}	0.30±0.13 ^a	0.24±0.02 ^a	0.18±0.03 ^a
Cr (mg/l)	0.03±0.00 ^a	0.02±0.01 ^a	0.04±0.00 ^{ab}	0.04±0.01 ^a	0.03±0.01 ^a	0.05±0.01 ^a
Ar (mg/l)	1.72±0.00 ^{bc}	0.14±0.02 ^a	1.61±0.08 ^b	1.75±0.03 ^c	1.75±0.03 ^c	3.91±0.01 ^d
Ni (mg/l)	0.12±0.00 ^a	0.12±0.00 ^a	0.11±0.01 ^a	0.18±0.06 ^a	0.13±0.01 ^a	1.16±0.03 ^b

All values expressed as mean ± standard error of mean, with superscript based on Duncan's multiple comparison.

Different letters indicated significant difference ($p < 0.05$) in mean values among different months across rows.

pH: Hydrogen Ion Concentration; **T:** Temperature; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **Cu:** Copper; **Mn:** Manganese; **Pb:** Lead; **Cd:** Cadmium; **Cr:** Chromium; **Ar:** Arsenic; **Ni:** Nickel.

Table 3 shows the monthly variations of the physicochemical and metallic parameters in Trans-Ekulu dumpsite. The pH value was insignificantly ($p \geq 0.05$) higher in August, while higher values of both electrical conductivity and total dissolved solids were recorded in November than the rest of the months, although were observed to be non-significant ($p \geq 0.05$). The temperature recorded in the dry season months were higher ($p < 0.05$) than the wet season months. The concentrations of copper, manganese, arsenic, and nickel were significantly ($p < 0.05$) higher in January than the rest of the months. The lead, cadmium, and chromium did not show any significant ($p \geq 0.05$) variations in the monthly mean values when compared with the month with the highest value. Lead, cadmium, and chromium were highest in January, November, December and July (Table 3).

Table 3: Monthly variation of the physicochemical and metallic parameters of Trans-Ekulu dumpsite

Parameters	Months					
	July	August	September	November	December	January
pH	7.10±0.06 ^b	7.33±0.03 ^b	7.20±0.10 ^b	7.07±0.09 ^b	7.07±0.07 ^b	6.27±0.33 ^a
T (°C)	26.00±0.00 ^b	23.30±0.00 ^a	24.00±0.05 ^a	28.00±0.04 ^c	28.20±0.03 ^c	28.30±0.03 ^c
EC (µS/cm)	312.67±2.03 ^{ab}	281.67±3.18 ^a	317.33±23.73 ^{ab}	360.00±50.00 ^b	310.33±1.33 ^{ab}	302.00±4.73 ^{ab}
TDS (ppm)	126.67±2.91 ^a	102.67±4.41 ^a	124.67±8.42 ^a	135.00±21.39 ^a	128.33±1.86 ^a	135.00±14.05 ^a
Cu (mg/l)	0.15±0.00 ^c	0.06±0.04 ^{ab}	0.15±0.00 ^c	0.03±0.00 ^a	0.11±0.04 ^{bc}	7.29±0.02 ^d
Mn (mg/l)	0.04±0.00 ^a	0.25±0.21 ^a	0.51±0.24 ^a	0.14±0.11 ^a	0.14±0.10 ^a	11.40±0.02 ^b
Pb (mg/l)	0.01±0.00 ^a	0.01±0.00 ^a	0.01±0.00 ^a	0.32±0.05 ^b	0.14±0.13 ^a	0.46±0.02 ^b
Cd (mg/l)	0.54±0.01 ^{ab}	0.31±0.08 ^{ab}	0.27±0.14 ^{ab}	0.59±0.02 ^b	0.57±0.03 ^{ab}	0.24±0.19 ^a
Cr (mg/l)	0.05±0.01 ^a	0.05±0.00 ^a	0.05±0.02 ^a	0.04±0.02 ^a	0.06±0.01 ^a	0.04±0.02 ^a
Ar (mg/l)	1.71±0.01 ^b	1.06±0.07 ^a	1.70±0.03 ^b	1.83±0.09 ^b	1.73±0.03 ^b	3.69±0.02 ^c
Ni (mg/l)	0.25±0.05 ^b	0.09±0.01 ^a	0.10±0.02 ^a	0.25±0.05 ^b	0.32±0.02 ^b	0.48±0.07 ^c

All values expressed as mean ± standard error of mean, with superscript based on Duncan's multiple comparison. Different letters indicated significant difference ($p < 0.05$) in mean values among different months across rows.

pH: Hydrogen Ion Concentration; **T:** Temperature; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **Cu:** Copper; **Mn:** Manganese; **Pb:** Lead; **Cd:** Cadmium; **Cr:** Chromium; **Ar:** Arsenic; **Ni:** Nickel.

Table 4 shows the monthly variations of the physicochemical and metallic parameters in GRA dumpsite. The pH value was insignificantly ($p \geq 0.05$) higher in August, while higher values of electrical conductivity and total dissolved solids were recorded in September and January respectively than the rest of the months, although were observed to be non-significant ($p \geq 0.05$). The temperature recorded in the dry season months were higher ($p < 0.05$) than the wet season months. The concentration of copper, manganese, lead, arsenic and nickel were significantly ($p < 0.05$) higher in January than the rest of the months. The cadmium and chromium did not show any significant ($p \geq 0.05$) variations in the monthly mean values when compared with the month with the highest value. Cadmium and chromium concentrations were highest in November (Table 4).

Table 4: Monthly variation of the physicochemical and metallic parameters of GRA dumpsite

Parameters	Months					
	July	August	September	November	December	January
pH	7.13±0.03 ^{bc}	7.37±0.07 ^c	7.10±0.10 ^b	7.33±0.03 ^{bc}	7.17±0.03 ^{bc}	5.80±0.12 ^a
T (°C)	24.00±0.00 ^a	25.30±0.00 ^b	24.00±0.05 ^a	28.50±0.04 ^c	28.50±0.03 ^c	28.00±0.03 ^c
EC (µS/cm)	463.67±1.86 ^b	383.67±12.25 ^a	464.67±0.67 ^b	447.00±5.69 ^b	462.33±1.86 ^b	462.67±1.86 ^b
TDS (ppm)	183.33±3.48 ^b	127.33±6.33 ^a	192.67±4.67 ^b	144.00±23.50 ^a	184.67±4.63 ^b	214.00±13.11 ^b
Cu (mg/l)	0.22±0.00 ^b	0.14±0.00 ^b	0.22±0.00 ^b	0.04±0.02 ^a	0.15±0.07 ^b	7.28±0.02 ^c
Mn (mg/l)	0.57±0.11 ^b	0.72±0.06 ^b	0.83±0.02 ^b	0.08±0.01 ^a	0.38±0.19 ^{ab}	11.61±0.21 ^c
Pb (mg/l)	0.01±0.00 ^a	0.01±0.00 ^a	0.00±0.00 ^a	0.02±0.02 ^a	0.02±0.02 ^a	0.59±0.05 ^b
Cd (mg/l)	0.11±0.02 ^a	0.14±0.07 ^a	0.09±0.00 ^a	0.15±0.01 ^a	0.13±0.01 ^a	0.07±0.01 ^a
Cr (mg/l)	0.02±0.00 ^a	0.03±0.01 ^a	0.03±0.00 ^a	0.11±0.04 ^a	0.07±0.05 ^a	0.02±0.00 ^a
Ar (mg/l)	1.86±0.15 ^b	0.03±0.00 ^a	1.75±0.02 ^b	1.80±0.06 ^b	1.90±0.14 ^b	3.60±0.02 ^c
Ni (mg/l)	0.17±0.03 ^a	0.07±0.01 ^a	0.12±0.00 ^a	0.19±0.01 ^a	0.19±0.01 ^a	0.40±0.14 ^b

All values expressed as mean ± standard error of mean, with superscript based on Duncan's multiple comparison.

Different letters indicated significant difference ($p < 0.05$) in mean values among different months across rows.

pH: Hydrogen Ion Concentration; **T:** Temperature; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **Cu:** Copper; **Mn:** Manganese; **Pb:** Lead; **Cd:** Cadmium; **Cr:** Chromium; **Ar:** Arsenic; **Ni:** Nickel.

Table 5 shows the monthly variations of the physicochemical and metallic parameters in Gariki dumpsite. The pH value was insignificantly ($p \geq 0.05$) higher in August, while both electrical conductivity and total dissolved solids showed significantly ($p < 0.05$) higher mean values in January than in the rest of the months. The temperature recorded in the dry season months were higher ($p < 0.05$) than the wet season months. The concentration of copper, manganese, lead, arsenic and nickel were significantly ($p < 0.05$) higher in January than the rest of the months, whereas chromium concentration was significantly ($p < 0.05$) higher in November. The cadmium concentration did not show any significant ($p \geq 0.05$) variations in the monthly mean values when compared with the month with the highest value. Cadmium was highest in December (Table 5).

Table 5: Monthly variation of the physicochemical and metallic parameters of Gariki dumpsite

Parameters	Months					
	July	August	September	November	December	January
pH	7.23±0.12 ^{bc}	7.47±0.67 ^c	7.33±0.03 ^c	6.93±0.18 ^b	7.23±0.07 ^{bc}	6.03±0.09 ^a
T (°C)	26.00±0.00 ^b	26.30±0.00 ^b	25.00±0.05 ^a	27.00±0.04 ^c	27.50±0.03 ^c	28.00±0.03 ^c
EC (µS/cm)	441.33±1.45 ^b	339.67±22.15 ^a	441.33±1.33 ^b	443.33±9.60 ^b	342.00±59.07 ^a	585.67±3.71 ^c
TDS (ppm)	119.67±0.88 ^a	107.67±3.33 ^a	123.00±1.00 ^a	139.00±18.56 ^a	122.00±16.26 ^a	233.00±16.04 ^b
Cu (mg/l)	0.14±0.00 ^a	0.10±0.04 ^a	0.14±0.01 ^a	0.06±0.04 ^a	0.06±0.04 ^a	7.40±0.09 ^b
Mn (mg/l)	0.70±0.02 ^b	0.02±0.00 ^a	0.69±0.02 ^b	0.10±0.01 ^a	0.27±0.20 ^a	11.74±0.18 ^c
Pb (mg/l)	0.01±0.00 ^a	0.02±0.01 ^a	0.01±0.00 ^a	0.11±0.01 ^b	0.04±0.04 ^a	1.05±0.03 ^c
Cd (mg/l)	0.15±0.01 ^a	0.15±0.06 ^a	0.17±0.02 ^a	0.18±0.02 ^a	0.23±0.05 ^a	0.20±0.01 ^a
Cr (mg/l)	0.03±0.01 ^a	0.07±0.00 ^a	0.02±0.01 ^a	0.28±0.02 ^b	0.12±0.07 ^a	0.06±0.00 ^a
Ar (mg/l)	1.76±0.04 ^a	1.70±0.02 ^a	1.67±0.00 ^a	1.62±0.16 ^a	1.34±0.25 ^a	3.47±0.13 ^b
Ni (mg/l)	0.20±0.00 ^b	0.08±0.04 ^a	0.16±0.04 ^{ab}	0.15±0.02 ^{ab}	0.11±0.01 ^{ab}	0.65±0.03 ^c

All values expressed as mean ± standard error of mean, with superscript based on Duncan's multiple comparison.

Different letters indicated significant difference ($p < 0.05$) in mean values among different months across rows.

pH: Hydrogen Ion Concentration; **T:** Temperature; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **Cu:** Copper; **Mn:** Manganese; **Pb:** Lead; **Cd:** Cadmium; **Cr:** Chromium; **Ar:** Arsenic; **Ni:** Nickel.

Table 6 shows the monthly variations of the physicochemical and metallic parameters in Asata dumpsite. The pH values recorded in August and December were significantly ($p < 0.05$) higher than the values in the rest of the months. The temperature recorded in the dry season months were higher ($p < 0.05$) than the wet season months. The electrical conductivity showed that values recorded in August and December were much lower statistically ($p < 0.05$) than values observed in the rest of the months. Also, the total dissolved solids showed significantly ($p < 0.05$) lower mean value in August than in the rest of the months. The electrical conductivity and total dissolved solids were both highest in January. The concentration of copper, manganese, lead, arsenic and nickel were significantly ($p < 0.05$) higher in January than the rest of the months. The cadmium concentration did not show any significant ($p \geq 0.05$) variations in the monthly mean values when compared with the month with the highest value. Chromium concentrations in December and January were significantly ($p < 0.05$) higher than in the rest of the months. The levels of cadmium and chromium were highest in September and December respectively (Table 6).

Table 6: Monthly variation of the physicochemical and metallic parameters of Asata dumpsite

Parameters	Months					
	July	August	September	November	December	January
pH	6.70±0.06 ^b	7.07±0.03 ^c	6.53±0.03 ^a	6.77±0.03 ^b	6.93±0.03 ^c	6.73±0.09 ^b
T (°C)	25.00±0.00 ^b	25.30±0.00 ^b	24.00±0.05 ^a	29.00±0.04 ^c	28.20±0.03 ^c	28.50±0.03 ^c
EC (µS/cm)	270.00±1.15 ^c	156.00±2.00 ^a	266.33±0.33 ^c	266.33±4.70 ^c	241.00±12.29 ^b	278.33±9.53 ^c
TDS (ppm)	128.00±2.65 ^b	102.67±1.67 ^a	127.33±1.33 ^b	127.67±2.96 ^b	126.00±4.62 ^b	132.00±3.06 ^b
Cu (mg/l)	0.38±0.01 ^b	0.10±0.00 ^a	0.40±0.02 ^b	0.05±0.02 ^a	0.01±0.01 ^a	7.42±0.20 ^c
Mn (mg/l)	0.19±0.00 ^a	0.17±0.00 ^a	0.19±0.00 ^a	0.79±0.30 ^b	0.74±0.33 ^{ab}	12.10±0.05 ^c
Pb (mg/l)	0.01±0.01 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.37±0.01 ^b	0.30±0.04 ^b	1.30±0.13 ^c
Cd (mg/l)	0.29±0.09 ^a	0.22±0.00 ^a	0.46±0.01 ^a	0.35±0.09 ^a	0.38±0.13 ^a	0.35±0.11 ^a
Cr (mg/l)	0.05±0.01 ^a	0.04±0.00 ^a	0.05±0.00 ^a	0.06±0.01 ^a	0.15±0.03 ^b	0.12±0.01 ^b
Ar (mg/l)	1.40±0.05 ^a	1.33±0.00 ^a	1.35±0.04 ^a	1.43±0.01 ^a	1.65±0.28 ^a	3.54±0.26 ^b
Ni (mg/l)	0.16±0.01 ^b	0.07±0.04 ^a	0.14±0.01 ^{ab}	0.17±0.00 ^b	0.11±0.03 ^{ab}	1.07±0.01 ^c

All values expressed as mean ± standard error of mean, with superscript based on Duncan's multiple comparison. Different letters indicated significant difference ($p < 0.05$) in mean values among different months across rows.

pH: Hydrogen Ion Concentration; **T:** Temperature; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **Cu:** Copper; **Mn:** Manganese; **Pb:** Lead; **Cd:** Cadmium; **Cr:** Chromium; **Ar:** Arsenic; **Ni:** Nickel.

Table 7 shows the monthly variations of the physicochemical and metallic parameters in New Haven dumpsite. From the result, it was observed that both the pH and the electrical conductivity recorded in January were significantly ($p < 0.05$) higher than those in the rest of the months, but the total dissolved solids recorded in January showed much lower ($p < 0.05$) value than those recorded in the rest of the months. The temperature recorded in the dry season months were higher ($p < 0.05$) than the wet season months. The concentrations of copper, manganese, arsenic and nickel were significantly ($p < 0.05$) higher in January than the rest of the months. The lead concentrations in November and December were significantly ($p < 0.05$) higher than the rest of the months. Whereas the cadmium concentration had lower ($p < 0.05$) values in August and January, the chromium concentration was lower ($p < 0.05$) in September and January. The levels of lead and cadmium were highest in December, while chromium was highest in November (Table 7).

Table 7: Monthly variation of the physicochemical and metallic parameters of New Haven dumpsite

Parameters	Months					
	July	August	September	November	December	January
pH	7.00±0.06 ^a	7.13±0.03 ^a	7.07±0.07 ^a	6.87±0.03 ^a	6.97±0.07 ^a	7.60±0.21 ^b
T (°C)	26.00±0.00 ^b	23.30±0.00 ^b	25.00±0.05 ^b	27.00±0.04 ^c	28.20±0.03 ^c	28.30±0.03 ^c
EC (µS/cm)	19.00±0.58 ^a	25.33±0.67 ^a	20.67±0.67 ^a	19.33±1.33 ^a	21.00±1.53 ^a	37.67±6.89 ^b
TDS (ppm)	1914.33±12.57 ^c	601.33±0.67 ^b	1926.67±6.67 ^c	1917.00±7.77 ^c	1813.67±92.27 ^c	58.67±2.33 ^a
Cu (mg/l)	0.24±0.00 ^b	0.02±0.00 ^a	0.26±0.00 ^b	0.01±0.00 ^a	0.04±0.02 ^a	7.18±0.13 ^c
Mn (mg/l)	0.31±0.03 ^b	0.21±0.00 ^a	0.25±0.01 ^{ab}	0.16±0.04 ^b	0.31±0.03 ^b	12.04±0.03 ^c
Pb (mg/l)	0.02±0.01 ^a	0.00±0.00 ^a	0.00±0.00 ^a	1.11±0.00 ^c	1.13±0.00 ^c	0.93±0.02 ^b
Cd (mg/l)	1.34±0.01 ^b	0.11±0.00 ^a	1.34±0.00 ^b	1.33±0.07 ^b	1.37±0.04 ^b	0.13±0.01 ^a
Cr (mg/l)	0.15±0.01 ^c	0.10±0.01 ^b	0.04±0.01 ^a	0.19±0.00 ^d	0.16±0.01 ^{cd}	0.05±0.02 ^a
Ar (mg/l)	2.18±0.01 ^b	0.10±0.01 ^a	2.21±0.01 ^b	2.29±0.09 ^b	2.20±0.03 ^b	3.46±0.17 ^c
Ni (mg/l)	0.08±0.01 ^a	0.08±0.01 ^a	0.07±0.00 ^a	0.06±0.00 ^a	0.08±0.01 ^a	1.20±0.03 ^b

All values expressed as mean ± standard error of mean, with superscript based on Duncan's multiple comparison. Different letters indicated significant difference ($p < 0.05$) in mean values among different months across rows.

pH: Hydrogen Ion Concentration; **T:** Temperature; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **Cu:** Copper; **Mn:** Manganese; **Pb:** Lead; **Cd:** Cadmium; **Cr:** Chromium; **Ar:** Arsenic; **Ni:** Nickel.

Table 8 shows the monthly variations of the physicochemical and metallic parameters in Uwani dumpsite. The pH value and total dissolved solids recorded in August and January respectively were significantly ($p < 0.05$) lower than the rest of the months. The temperature recorded in the dry season months were higher ($p < 0.05$) than the wet season months. The electrical conductivity was significantly ($p < 0.05$) higher in January than values recorded in the other months. The concentration of copper, manganese, lead, arsenic and nickel were significantly ($p < 0.05$) higher in January than the rest of the months. The cadmium and chromium concentrations in November were significantly ($p < 0.05$) higher than the rest of the months. The levels of pH and total dissolved solids were highest in November and September respectively (Table 8).

Table 8: Monthly variation of the physicochemical and metallic parameters of Uwani dumpsite

Parameters	Months					
	July	August	September	November	December	January
pH	7.17±0.67 ^b	6.93±0.03 ^a	7.30±0.10 ^b	7.37±0.07 ^b	7.27±0.07 ^b	7.23±0.09 ^b
T (°C)	26.00±0.00 ^b	25.30±0.00 ^b	24.30±0.05 ^a	27.00±0.04 ^c	27.20±0.03 ^c	28.30±0.03 ^c
EC (µS/cm)	10.00±0.58 ^{ab}	17.33±0.67 ^b	9.33±1.33 ^a	13.33±1.33 ^{ab}	13.67±1.86 ^{ab}	100.00±4.93 ^c
TDS (ppm)	942.00±5.20 ^d	256.67±1.67 ^b	943.67±2.67 ^d	943.33±23.33 ^d	870.00±5.77 ^c	88.00±4.58 ^a
Cu (mg/l)	0.01±0.00 ^a	0.00±0.00 ^a	0.01±0.00 ^a	0.02±0.00 ^a	0.02±0.01 ^a	7.59±0.05 ^b
Mn (mg/l)	0.34±0.01 ^b	0.12±0.00 ^a	0.37±0.04 ^b	1.15±0.03 ^c	1.08±0.03 ^c	4.04±0.04 ^d
Pb (mg/l)	0.01±0.00 ^a	0.00±0.00 ^a	0.01±0.00 ^a	0.17±0.00 ^b	0.09±0.05 ^{ab}	1.48±0.06 ^c
Cd (mg/l)	0.21±0.01 ^b	0.12±0.00 ^a	0.25±0.03 ^b	2.85±0.04 ^d	2.75±0.04 ^c	0.25±0.01 ^b
Cr (mg/l)	0.23±0.00 ^{ab}	0.18±0.01 ^{ab}	0.03±0.01 ^a	0.27±0.03 ^c	0.13±0.06 ^b	0.17±0.04 ^{ab}
Ar (mg/l)	2.12±0.02 ^a	2.20±0.01 ^{ab}	2.18±0.02 ^{ab}	2.24±0.02 ^b	2.16±0.05 ^{ab}	4.04±0.04 ^c
Ni (mg/l)	0.21±0.00 ^{bc}	0.04±0.01 ^a	0.24±0.03 ^c	0.21±0.00 ^{bc}	0.13±0.04 ^{ab}	2.43±0.05 ^d

All values expressed as mean ± standard error of mean, with superscript based on Duncan's multiple comparison.

Different letters indicated significant difference ($p < 0.05$) in mean values among different months across rows.

pH: Hydrogen Ion Concentration; **T:** Temperature; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **Cu:** Copper; **Mn:** Manganese; **Pb:** Lead; **Cd:** Cadmium; **Cr:** Chromium; **Ar:** Arsenic; **Ni:** Nickel.

Table 9 shows the monthly variations of the physicochemical and metallic parameters in Achara Layout dumpsite. The result showed that the pH values recorded in August and September were significantly ($p < 0.05$) higher than those in the rest of the months. The temperature recorded in the dry season months were higher ($p < 0.05$) than the wet season months. The electrical conductivity in the months of July, August and September were higher ($p < 0.05$) than those of November, December and January. The total dissolved solids were significantly ($p < 0.05$) higher in July than in the rest of the months. The dumpsite has highest values of pH and electrical conductivity in September. The concentrations of copper and manganese were significantly ($p < 0.05$) higher in November than the rest of the months. The lead, cadmium, chromium and arsenic concentrations in November, December and January were significantly ($p < 0.05$) higher than those recorded in July, August and September. The concentration of nickel was significantly ($p < 0.05$) lower in August than the rest of the months. Nickel's level was highest in the month of November (Table 9).

Table 9: Monthly variation of the physicochemical and metallic parameters of Achara Layout dumpsite

Parameters	Months					
	July	August	September	November	December	January
pH	7.30±0.21 ^{bc}	7.47±0.07 ^c	7.57±0.07 ^c	6.73±0.07 ^a	6.97±0.07 ^{ab}	7.03±0.07 ^{ab}
T (°C)	26.10±0.00 ^b	25.10±0.00 ^b	24.50±0.05 ^a	28.20±0.04 ^c	27.20±0.03 ^c	28.40±0.03 ^c
EC (µS/cm)	116.00±2.08 ^b	114.00±0.58 ^b	117.67±1.67 ^b	103.33±1.67 ^a	108.33±1.45 ^a	106.67±2.96 ^a
TDS (ppm)	1060.67±3.93 ^e	80.33±4.10 ^a	1045.67±4.67 ^d	141.67±0.67 ^c	128.67±2.96 ^b	126.67±3.18 ^b
Cu (mg/l)	0.02±0.00 ^b	0.02±0.00 ^b	0.02±0.00 ^b	0.04±0.00 ^c	0.02±0.01 ^{ab}	0.01±0.00 ^a
Mn (mg/l)	0.12±0.02 ^{ab}	0.05±0.03 ^a	0.17±0.00 ^b	0.39±0.02 ^c	0.23±0.06 ^b	0.16±0.04 ^{ab}
Pb (mg/l)	0.00±0.00 ^a	0.00±0.00 ^a	0.01±0.00 ^a	0.16±0.03 ^c	0.13±0.01 ^c	0.08±0.02 ^b
Cd (mg/l)	0.21±0.00 ^a	0.20±0.01 ^a	0.25±0.04 ^a	2.40±0.04 ^c	2.31±0.05 ^{bc}	2.22±0.07 ^b
Cr (mg/l)	0.14±0.03 ^a	0.15±0.02 ^a	0.01±0.00 ^a	0.91±0.02 ^b	0.81±0.13 ^b	0.78±0.11 ^b
Ar (mg/l)	0.02±0.00 ^a	0.01±0.00 ^a	0.02±0.00 ^a	0.23±0.01 ^b	0.25±0.04 ^b	0.25±0.09 ^b
Ni (mg/l)	0.47±0.00 ^b	0.01±0.01 ^a	0.42±0.01 ^b	0.55±0.03 ^c	0.49±0.03 ^{bc}	0.45±0.03 ^b

All values expressed as mean ± standard error of mean, with superscript based on Duncan's multiple comparison. Different letters indicated significant difference ($p < 0.05$) in mean values among different months across rows.

pH: Hydrogen Ion Concentration; **T:** Temperature; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **Cu:** Copper; **Mn:** Manganese; **Pb:** Lead; **Cd:** Cadmium; **Cr:** Chromium; **Ar:** Arsenic; **Ni:** Nickel.

Table 10 shows the monthly variations of the physicochemical and metallic parameters in Borehole GRA dumpsite. There were no significant ($p \geq 0.05$) differences in the pH values observed in the months. The temperature recorded in the dry season months were higher ($p < 0.05$) than the wet season months. The electrical conductivity and total dissolved solids recorded significant ($p < 0.05$) differences in their monthly variations with January being highest. The concentrations of lead, cadmium, chromium, arsenic and nickel were significantly ($p < 0.05$) higher in January than the rest of the months. Similarly, manganese levels recorded in November and January were significantly ($p < 0.05$) higher than those in the rest of the months. The concentration of copper did not significantly ($p \geq 0.05$) vary in the months. However, copper was highest in August (Table 10).

Table 10: Monthly variation of the physicochemical and metallic parameters of Borehole GRA dumpsite

Parameters	Months					
	July	August	September	November	December	January
pH	7.43±0.03 ^b	7.07±0.09 ^{ab}	7.37±0.67 ^b	6.93±0.09 ^a	7.30±0.10 ^{ab}	7.20±0.21 ^{ab}
T (°C)	26.00±0.00 ^b	25.10±0.00 ^b	23.40±0.05 ^a	28.20±0.04 ^c	27.50±0.03 ^c	28.30±0.03 ^c
EC (µS/cm)	21.00±1.53 ^c	18.33±1.20 ^{bc}	17.67±0.67 ^{bc}	8.67±0.33 ^a	12.67±2.73 ^{ab}	103.67±3.71 ^d
TDS (ppm)	62.67±1.20 ^b	39.00±1.73 ^a	58.67±0.67 ^b	56.67±3.28 ^b	56.67±4.84 ^b	123.33±6.49 ^c
Cu (mg/l)	0.01±0.00 ^{ab}	0.01±0.01 ^b	0.01±0.00 ^{ab}	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a
Mn (mg/l)	0.02±0.00 ^a	0.02±0.01 ^a	0.02±0.00 ^a	0.19±0.08 ^b	0.05±0.03 ^a	0.11±0.00 ^{ab}
Pb (mg/l)	0.00±0.00 ^a	0.00±0.00 ^a	0.00±0.00 ^a	0.01±0.00 ^a	0.00±0.00 ^a	0.08±0.03 ^b
Cd (mg/l)	0.01±0.00 ^a	0.02±0.00 ^a	0.01±0.00 ^a	0.04±0.00 ^a	0.02±0.01 ^a	2.23±0.07 ^b
Cr (mg/l)	0.09±0.01 ^b	0.05±0.00 ^{ab}	0.01±0.00 ^a	0.04±0.00 ^{ab}	0.07±0.02 ^b	0.80±0.03 ^c
Ar (mg/l)	0.01±0.00 ^a	0.01±0.01 ^a	0.01±0.00 ^a	0.01±0.00 ^a	0.01±0.00 ^a	0.24±0.02 ^b
Ni (mg/l)	0.08±0.01 ^a	0.08±0.01 ^a	0.07±0.00 ^a	0.04±0.01 ^a	0.06±0.02 ^a	0.29±0.09 ^b

All values expressed as mean ± standard error of mean, with superscript based on Duncan's multiple comparison. Different letters indicated significant difference ($p < 0.05$) in mean values among different months across rows.

pH: Hydrogen Ion Concentration; **T:** Temperature; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **Cu:** Copper; **Mn:** Manganese; **Pb:** Lead; **Cd:** Cadmium; **Cr:** Chromium; **Ar:** Arsenic; **Ni:** Nickel.

The seasonal variations of the physicochemical and metallic parameters of the leachate of dumpsites studied in Enugu Metropolis are presented on Tables 11 and 12. Table 11 shows the wet season variations in the dumpsites. The physicochemical parameters of hydrogen ion concentration (pH), temperature (T), electrical conductivity (EC), and total dissolved solids (TDS) investigated significantly ($p < 0.05$) varied in the dumpsites. Hydrogen ion concentration (pH) was higher in Emene dumpsite than the rest of the dumpsites, whereas Asata dumpsite had the least pH value. Similar variations were observed for both electrical conductivity and total dissolved solids; where GRA and Uwani dumpsites had highest and lowest electrical conductivity mean values respectively, as well as New Haven and Borehole GRA having the highest and lowest concentrations of total dissolved solids respectively. The temperature recorded in Trans-Ekulu, Asata and Achara Layout was significantly lower than the rest of the dumpsites. The metallic parameters of copper, manganese, cadmium, chromium, and nickel in the dumpsites showed that the dumpsite with highest concentration varied significantly ($p < 0.05$) with the rest, except for lead and arsenic concentrations that did not show such significant ($p \geq 0.05$) variation in the dumpsites. Hence, the concentrations of copper, manganese, cadmium, chromium, and nickel were higher ($p < 0.05$) in Asata, GRA, New Haven, Uwani, and Achara Layout dumpsites respectively than their counterparts (Table 11).

The dry season variations in the dumpsites were shown on Table 12. The pH and temperature mean values did not vary significantly ($p \geq 0.05$) in the dumpsites. However, it was observed that significant ($p < 0.05$) differences exist in mean values of electrical conductivity and total dissolved solids of the dumpsites. Both GRA and Gariki dumpsites had higher ($p < 0.05$) electrical conductivity than the rest of the dumpsites. Total dissolved solids were higher ($p < 0.05$) in New Haven dumpsite and least in Borehole GRA dumpsite. Variations in the metallic parameters in the dry season were significant ($p < 0.05$) for lead, cadmium, chromium, and

arsenic concentrations, except for copper, manganese, nickel that were non-significant ($p \geq 0.05$). Lead concentration was highest in New Haven dumpsite, while cadmium and chromium were highest in Achara Layout dumpsite. The arsenic concentrations recorded a significantly ($p < 0.05$) lower mean values for dumpsites in Achara Layout and Borehole GRA than the rest of the dumpsites (Table 12).

Table 11: Wet season status of the physicochemical and metallic parameters of sampled dumpsites in Enugu Metropolis

Parameters	Sampled Dumpsites									
	Emene	Abakpa	Trans-Ekulu	GRA	Gariki	Asata	New Haven	Uwani	Achara Layout	Borehole
pH	7.66±0.03 ^f	7.40±0.04 ^e	7.21±0.05 ^{bcd}	7.20±0.06 ^{bcd}	7.34±0.05 ^{de}	6.77±0.08 ^a	7.07±0.03 ^b	7.13±0.06 ^{bc}	7.44±0.08 ^e	7.29±0.07 ^{cde}
T (°C)	26.10±0.00 ^b	25.10±0.00 ^b	23.50±0.05 ^a	26.00±0.00 ^b	26.10±0.00 ^b	23.40±0.05 ^a	26.00±0.00 ^b	25.10±0.00 ^b	23.40±0.05 ^a	26.00±0.00 ^b
EC (µS/cm)	235.56±3.25 ^c	288.78±4.55 ^d	303.89±8.91 ^d	437.33±13.89 ^f	407.44±18.12 ^e	230.78±18.71 ^c	21.67±1.00 ^a	12.22±1.36 ^a	115.89±0.95 ^b	19.00±0.78 ^a
TDS (ppm)	97.00±3.56 ^a	100.89±2.93 ^a	118.00±4.80 ^a	167.78±10.50 ^a	116.78±2.55 ^a	119.33±4.28 ^a	1480.78±219.91 ^c	714.11±114.37 ^b	728.89±162.17 ^b	53.44±3.71 ^a
Cu (mg/l)	0.02±0.00 ^a	0.02±0.00 ^a	0.12±0.02 ^b	0.19±0.01 ^c	0.12±0.01 ^b	0.29±0.05 ^d	0.17±0.04 ^{bc}	0.01±0.00 ^a	0.02±0.00 ^a	0.01±0.00 ^a
Mn (mg/l)	0.03±0.00 ^a	0.02±0.00 ^a	0.27±0.11 ^b	0.64±0.04 ^d	0.47±0.11 ^c	0.18±0.00 ^{ab}	0.26±0.01 ^b	0.28±0.04 ^b	0.11±0.02 ^{ab}	0.02±0.00 ^a
Pb (mg/l)	0.00±0.00 ^a	0.02±0.00 ^d	0.01±0.00 ^{cd}	0.01±0.00 ^{abc}	0.01±0.00 ^{cd}	0.01±0.00 ^{abc}	0.01±0.00 ^{bcd}	0.01±0.00 ^{abcd}	0.00±0.00 ^{abc}	0.00±0.00 ^{ab}
Cd (mg/l)	0.25±0.02 ^{bc}	0.26±0.03 ^{bc}	0.37±0.06 ^c	0.11±0.02 ^{ab}	0.15±0.02 ^{abc}	0.32±0.04 ^{bc}	0.93±0.21 ^d	0.19±0.02 ^{abc}	0.22±0.01 ^{abc}	0.01±0.00 ^a
Cr (mg/l)	0.02±0.00 ^a	0.03±0.00 ^a	0.05±0.01 ^a	0.03±0.00 ^a	0.04±0.01 ^a	0.05±0.00 ^a	0.10±0.02 ^b	0.15±0.03 ^c	0.10±0.02 ^b	0.05±0.01 ^a
Ar (mg/l)	1.22±0.17 ^a	1.15±0.26 ^a	1.49±0.11 ^a	1.21±0.30 ^a	1.71±0.02 ^{bc}	1.36±0.02 ^a	1.50±0.35 ^a	2.17±0.01 ^c	0.02±0.00 ^a	0.01±0.00 ^a
Ni (mg/l)	0.14±0.00 ^a	0.12±0.00 ^a	0.15±0.03 ^a	0.12±0.02 ^a	0.15±0.02 ^a	0.12±0.02 ^a	0.08±0.00 ^a	0.16±0.03 ^a	0.30±0.07 ^b	0.08±0.00 ^a

All values expressed as mean ± standard error of mean (±SEM), with superscript based on Duncan's multiple comparison.

Different letters indicated significant difference ($p < 0.05$) in mean values among different dumpsites across rows.

pH: Hydrogen Ion Concentration; **T:** Temperature; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **Cu:** Copper; **Mn:** Manganese; **Pb:** Lead; **Cd:** Cadmium; **Cr:** Chromium; **Ar:** Arsenic; **Ni:** Nickel.

Table 12: Dry season status of the physicochemical and metallic parameters of sampled dumpsites in Enugu Metropolis

Parameters	Sampled Dumpsites									
	Emene	Abakpa	Trans-Ekulu	GRA	Gariki	Asata	New Haven	Uwani	Achara Layout	Borehole
pH	7.14±0.06 ^{ab}	7.08±0.10 ^{ab}	6.80±0.17 ^a	6.77±0.25 ^a	6.73±0.19 ^a	6.81±0.04 ^a	7.14±0.13 ^{ab}	7.29±0.04 ^b	6.91±0.05 ^{ab}	7.14±0.09 ^{ab}
T (°C)	27.00±0.04 ^a	27.20±0.03 ^a	28.30±0.03 ^a	27.00±0.04 ^a	27.20±0.03 ^a	28.50±0.03 ^a	27.20±0.03 ^a	28.30±0.03 ^a	27.20±0.03 ^a	28.10±0.00 ^a
EC (µS/cm)	286.78±9.36 ^{cd}	303.56±4.56 ^{cd}	324.11±17.10 ^d	457.33±3.15 ^e	457.00±39.35 ^e	261.89±7.23 ^c	26.00±3.59 ^a	42.33±14.50 ^a	106.11±1.22 ^b	41.67±15.57 ^a
TDS (ppm)	118.56±6.25 ^a	126.67±8.64 ^a	132.78±7.49 ^a	180.89±12.85 ^a	164.67±19.24 ^a	128.56±2.02 ^a	1263.11±302.66 ^c	633.78±137.04 ^b	132.33±2.67 ^a	78.89±11.39 ^a
Cu (mg/l)	2.51±1.22 ^a	2.54±1.23 ^a	2.47±1.20 ^a	2.49±1.20 ^a	2.51±1.22 ^a	2.49±1.23 ^a	2.41±1.19 ^a	2.54±1.26 ^a	0.02±0.01 ^a	0.00±0.00 ^a
Mn (mg/l)	3.44±1.67 ^a	3.82±1.83 ^a	3.89±1.88 ^a	4.02±1.90 ^a	4.04±1.93 ^a	4.54±1.89 ^a	4.17±1.97 ^a	2.09±0.49 ^a	0.26±0.04 ^a	0.12±0.03 ^a
Pb (mg/l)	0.49±0.21 ^{bcd}	0.34±0.14 ^{abcd}	0.31±0.06 ^{abcd}	0.21±0.10 ^{abc}	0.40±0.16 ^{abcd}	0.66±0.16 ^d	1.05±0.03 ^e	0.58±0.23 ^{cd}	0.12±0.02 ^{ab}	0.03±0.01 ^a
Cd (mg/l)	0.35±0.05 ^{abc}	0.24±0.04 ^{ab}	0.47±0.08 ^{abc}	0.11±0.01 ^a	0.20±0.02 ^{ab}	0.36±0.06 ^{abc}	0.94±0.21 ^c	1.95±0.43 ^d	2.31±0.04 ^d	0.76±0.37 ^{bc}
Cr (mg/l)	0.07±0.01 ^a	0.04±0.01 ^a	0.05±0.01 ^a	0.07±0.02 ^a	0.15±0.04 ^a	0.11±0.02 ^a	0.13±0.02 ^a	0.19±0.03 ^{ab}	0.84±0.05 ^c	0.30±0.13 ^b
Ar (mg/l)	2.56±0.39 ^b	2.47±0.36 ^b	2.42±0.32 ^b	2.43±0.30 ^b	2.14±0.35 ^b	2.21±0.35 ^b	2.65±0.21 ^b	2.81±0.31 ^b	0.24±0.02 ^a	0.09±0.04 ^a
Ni (mg/l)	0.79±0.32 ^{bc}	0.49±0.17 ^{abc}	0.35±0.04 ^{abc}	0.26±0.05 ^{ab}	0.30±0.09 ^{ab}	0.45±0.16 ^{abc}	0.45±0.19 ^{abc}	0.92±0.38 ^c	0.50±0.02 ^{abc}	0.13±0.05 ^a

All values expressed as mean ± standard error of mean (±SEM), with superscript based on Duncan's multiple comparison.

Different letters indicated significant difference ($p < 0.05$) in mean values among different dumpsites across rows.

pH: Hydrogen Ion Concentration; **T:** Temperature; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **Cu:** Copper; **Mn:** Manganese; **Pb:** Lead; **Cd:** Cadmium; **Cr:** Chromium; **Ar:** Arsenic; **Ni:** Nickel.

The comparisons of the seasonal variations of the physicochemical and metallic parameters of the leachate for each of the dumpsites studied in Enugu Metropolis are presented on Figures 2 – 11. Figure 12 shows the overall comparison in all dumpsites.

In Emene dumpsite, the mean value of pH was higher ($p < 0.05$) during the wet season than the dry season. Other physicochemical parameters studied (electrical conductivity, temperature and total dissolved solids) as well as metallic parameters (lead, chromium and arsenic) had significantly ($p < 0.05$) higher values during dry season than the wet season. The concentrations of copper, manganese, cadmium and nickel did not show any seasonal variation ($p \geq 0.05$) in Emene dumpsite (Figure 2).

Figure 3 shows the physicochemical and metallic parameters seasonal comparison in Abakpa dumpsite. The pH value was higher ($p < 0.05$) during wet season than dry season. However, electrical conductivity, temperature and total dissolved solids (physicochemical parameters) as well as lead, arsenic and nickel concentrations (metallic parameters) were significantly ($p < 0.05$) higher during dry season than wet season. The concentrations of copper, manganese, cadmium and chromium did not show any seasonal variation ($p \geq 0.05$) in Abakpa dumpsite (Figure 3).

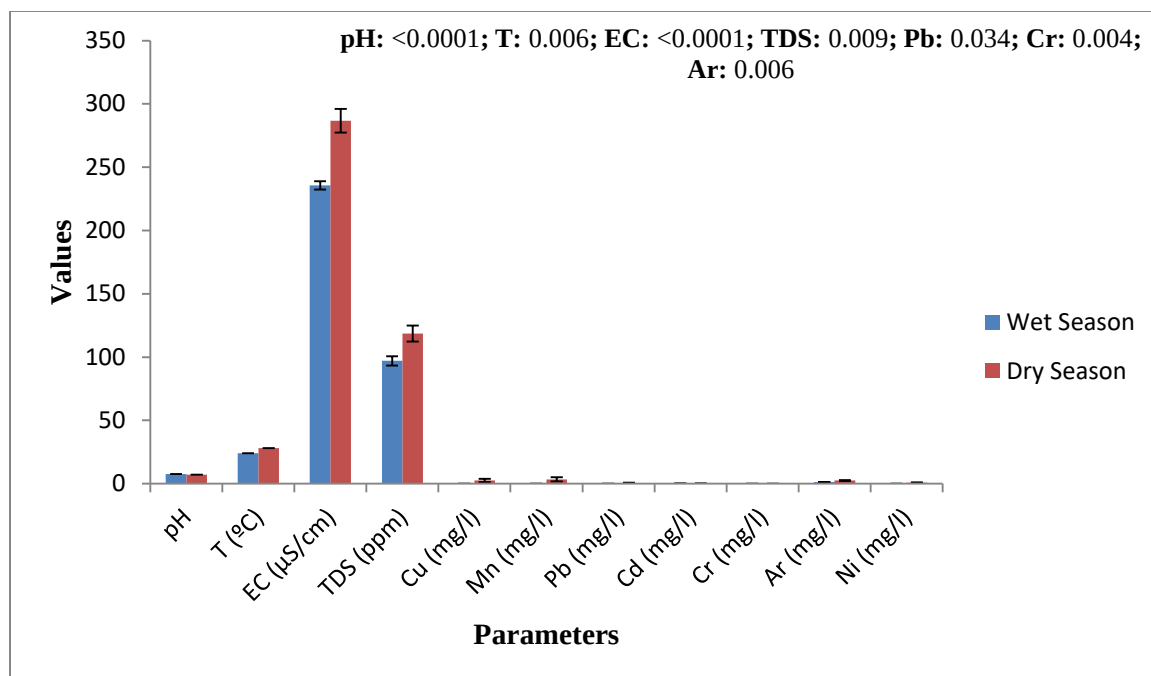


Figure 2: Comparison of seasonal status of the physicochemical and metallic parameters of Emene dumpsite
All values expressed as mean $\pm$ standard error of mean ($\pm$ SEM), with significant p -values from t -test.

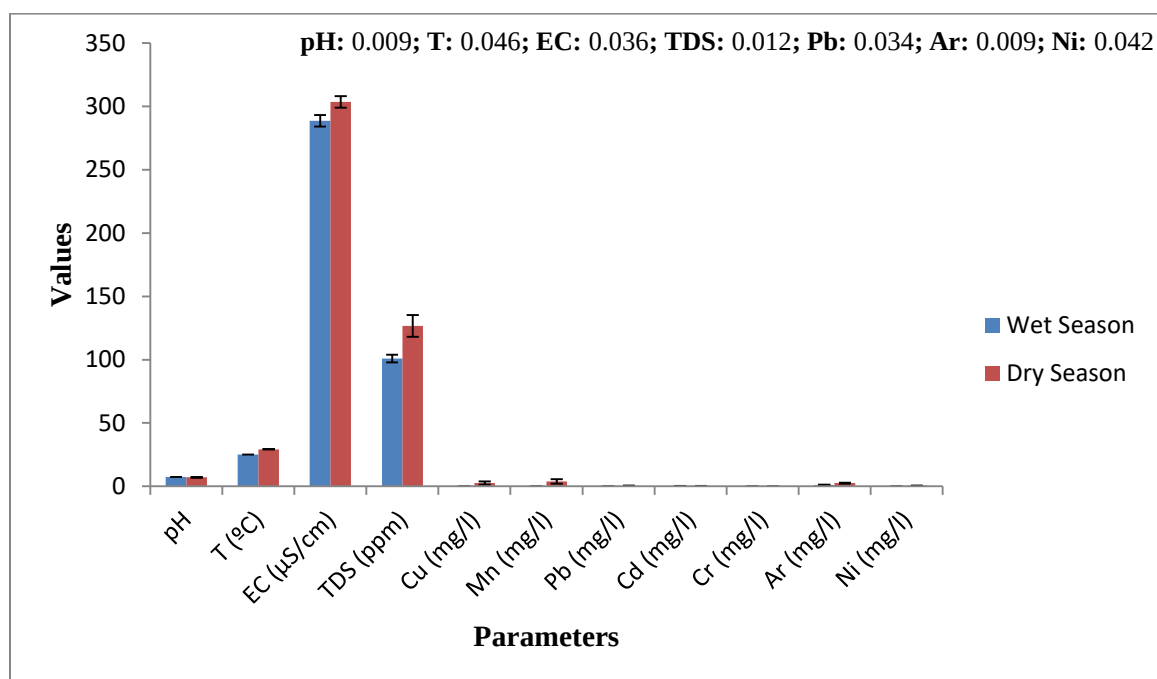


Figure 3: Comparison of seasonal status of the physicochemical and metallic parameters of Abakpa dumpsite
All values expressed as mean $\pm$ standard error of mean ($\pm$ SEM), with significant p -values from t -test.

Figure 4 shows the physicochemical and metallic parameters seasonal comparison in Trans-Ekulu dumpsite. The result showed that the pH value for the wet season was higher ($p < 0.05$) than the dry season, and that the concentrations of lead, arsenic and nickel varied significantly ($p < 0.05$) between the two seasons with dry season having higher ($p < 0.05$) mean values than the wet season. The physicochemical parameters of electrical conductivity, temperature and total dissolved solids, and other heavy metals like copper, manganese, cadmium, chromium did not show any significant ($p \geq 0.05$) seasonal variation (Figure 4).

Figure 5 shows the physicochemical and metallic parameters seasonal comparison in GRA dumpsite. The result recorded no significant ($p \geq 0.05$) differences between the wet and dry season physicochemical parameters, except for temperature ($p = 0.026$). For the metallic parameters, significantly ($p < 0.05$) higher lead, arsenic and nickel concentrations were observed during the dry season than wet season. The concentrations of other heavy metals for GRA dumpsite did not vary significantly ($p \geq 0.05$) in both seasons (Figure 5).

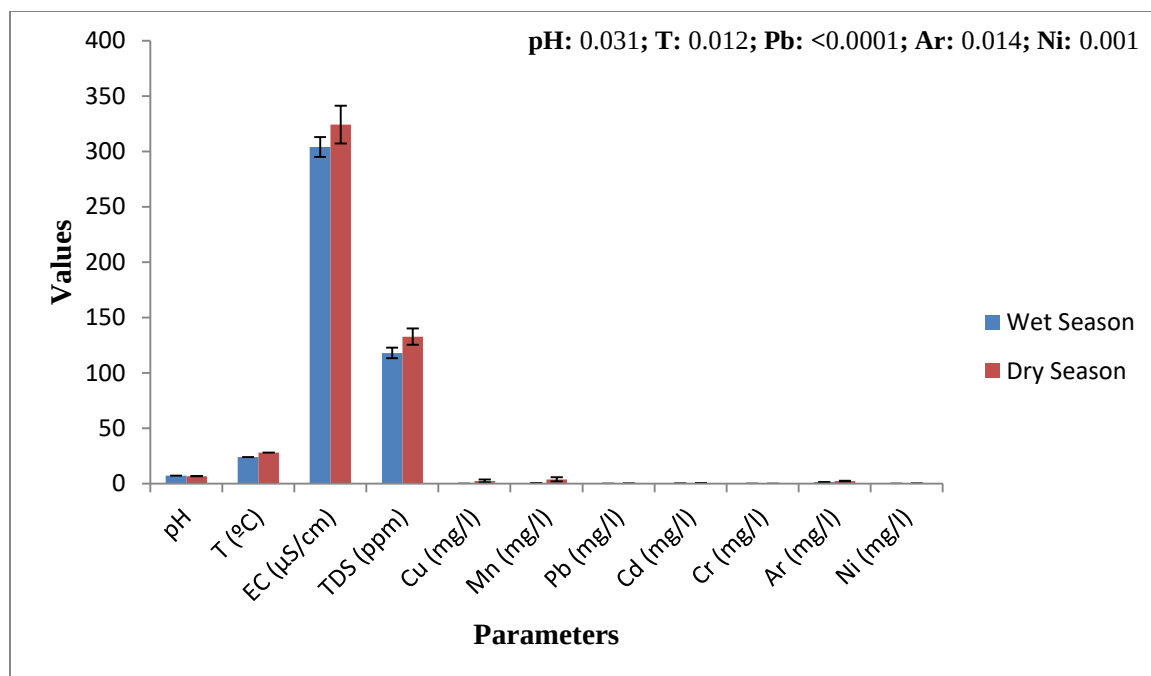


Figure 4: Comparison of seasonal status of the physicochemical and metallic parameters of Trans-Ekulu dumpsite
All values expressed as mean $\pm$ standard error of mean ($\pm$ SEM), with significant p -values from t -test.

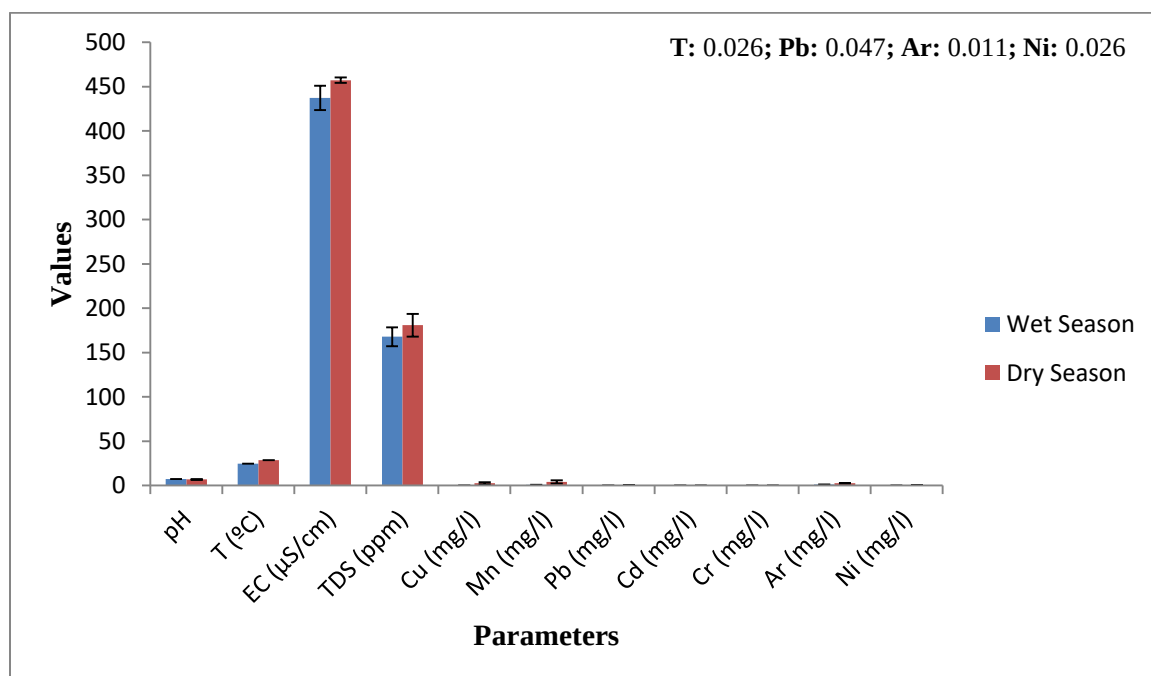


Figure 5: Comparison of seasonal status of the physicochemical and metallic parameters of GRA dumpsite
All values expressed as mean $\pm$ standard error of mean ($\pm$ SEM), with significant p -values from t -test.

Figure 6 shows the physicochemical and metallic parameters seasonal comparison in Gariki dumpsite. The pH value for the wet season was higher ($p < 0.05$) than the dry season; while temperature and total dissolved solids were higher ($p < 0.05$) in dry season than wet season. Lead and chromium concentrations were higher ($p < 0.05$) in dry season than wet season. The result showed that the levels of electrical conductivity, copper, manganese, cadmium, arsenic and nickel for Gariki dumpsite were similar ($p \geq 0.05$) in both seasons (Figure 6).

Figure 7 shows the physicochemical and metallic parameters seasonal comparison in Asata dumpsite. Significant ($p < 0.05$) variations in the seasonal values were recorded for manganese, lead, chromium and arsenic. In all, the dumpsite during dry season had higher ($p < 0.05$) metallic concentrations than during wet season. Copper, cadmium and nickel seasonal variations were insignificant ($p \geq 0.05$). Similarly, the physicochemical parameters (except for temperature) in Asata dumpsite did not show any significant ($p \geq 0.05$) differences in both seasons (Figure 7).

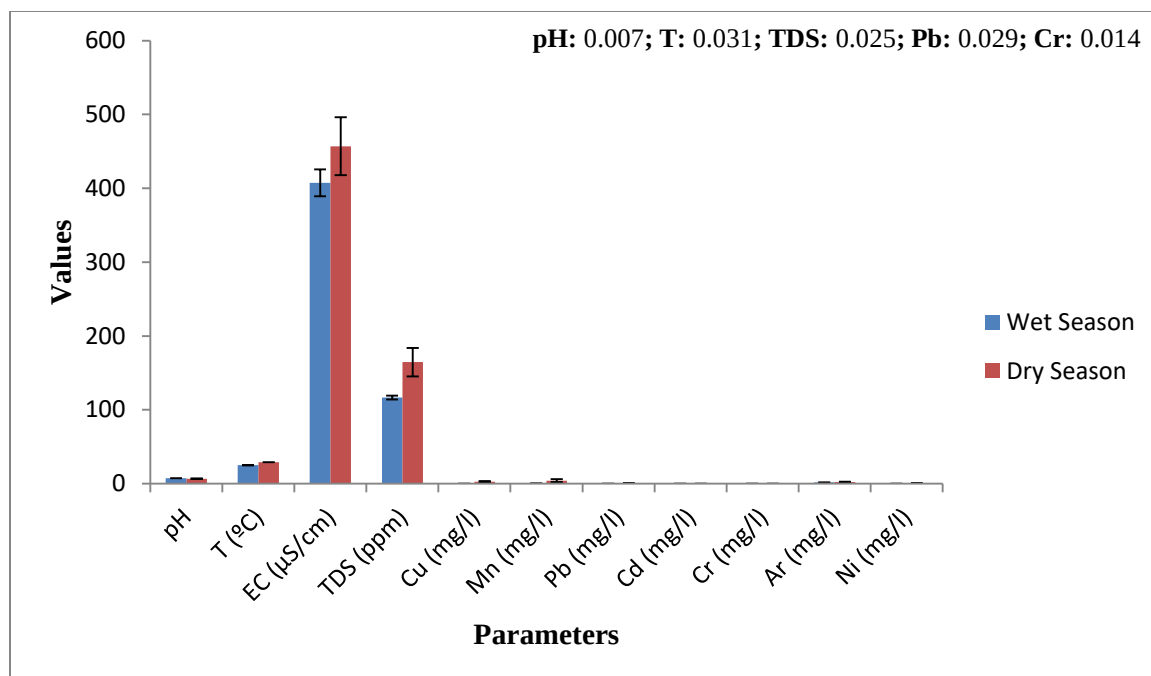


Figure 6: Comparison of seasonal status of the physicochemical and metallic parameters of Gariki dumpsite
All values expressed as mean $\pm$ standard error of mean ($\pm$ SEM), with significant p -values from t -test.

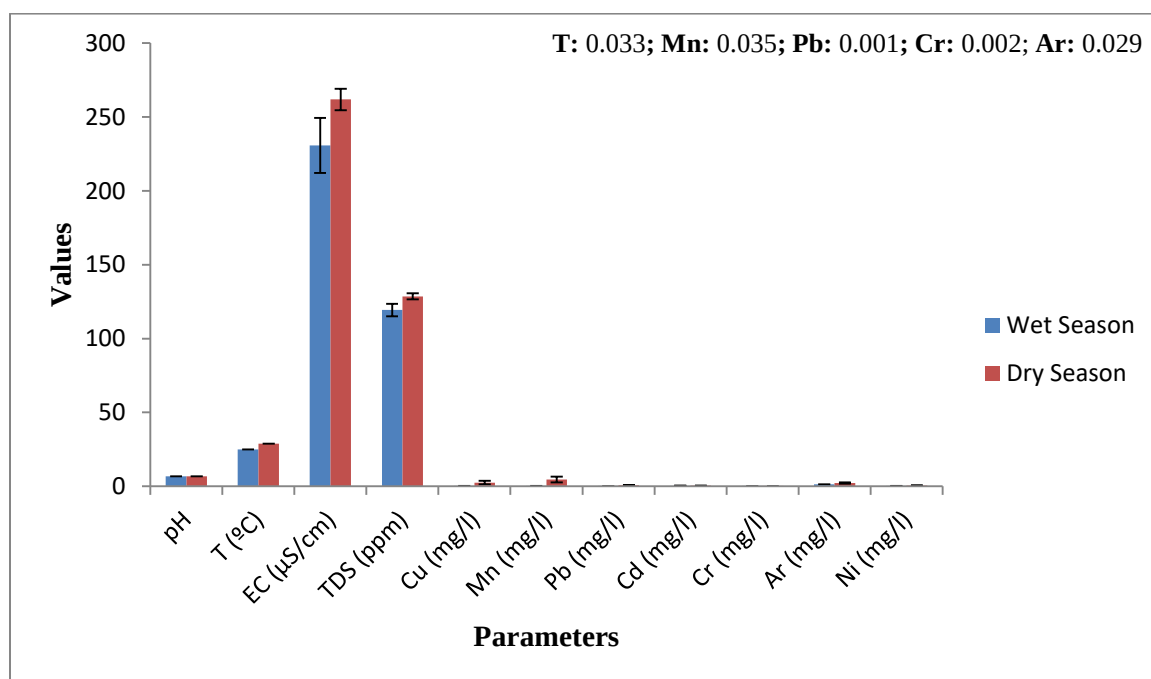


Figure 7: Comparison of seasonal status of the physicochemical and metallic parameters of Asata dumpsite
All values expressed as mean $\pm$ standard error of mean ($\pm$ SEM), with significant p -values from t -test.

Figure 8 shows the physicochemical and metallic parameters seasonal comparison in New Haven dumpsite. From the result, it was observed that the lead and arsenic concentrations for the dry season were significantly ($p < 0.05$) higher than those of wet season. Other metallic constituents of the dumpsite leachate like copper, manganese, cadmium, chromium and nickel were not significantly ($p \geq 0.05$) different in both seasons. Apart from temperature that was higher in dry season than wet season ($p = 0.036$), other examined physicochemical parameters like pH, electrical conductivity and total dissolved solids did not vary ($p \geq 0.05$) in both seasons (Figure 8).

Figure 9 shows the physicochemical and metallic parameters seasonal comparison in Uwani dumpsite. The concentrations of the manganese, lead and cadmium during dry season were significantly ($p < 0.05$) higher than during the wet season. The rest of the metallic parameters did not differ significantly ($p \geq 0.05$) between seasons. Also, none of the studied physicochemical parameters showed any significant ($p \geq 0.05$) differences in season, except for temperature ($p = 0.001$; Figure 9).

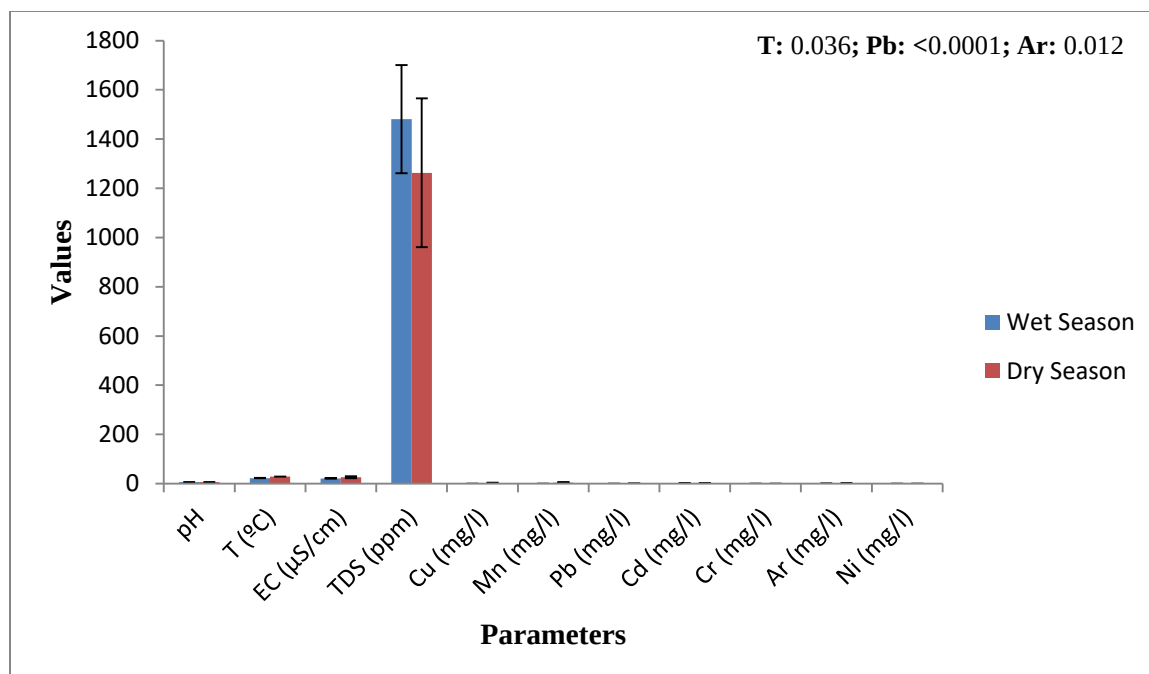


Figure 8: Comparison of seasonal status of the physicochemical and metallic parameters of New Haven dumpsite
All values expressed as mean $\pm$ standard error of mean ($\pm$ SEM), with significant p -values from t -test.

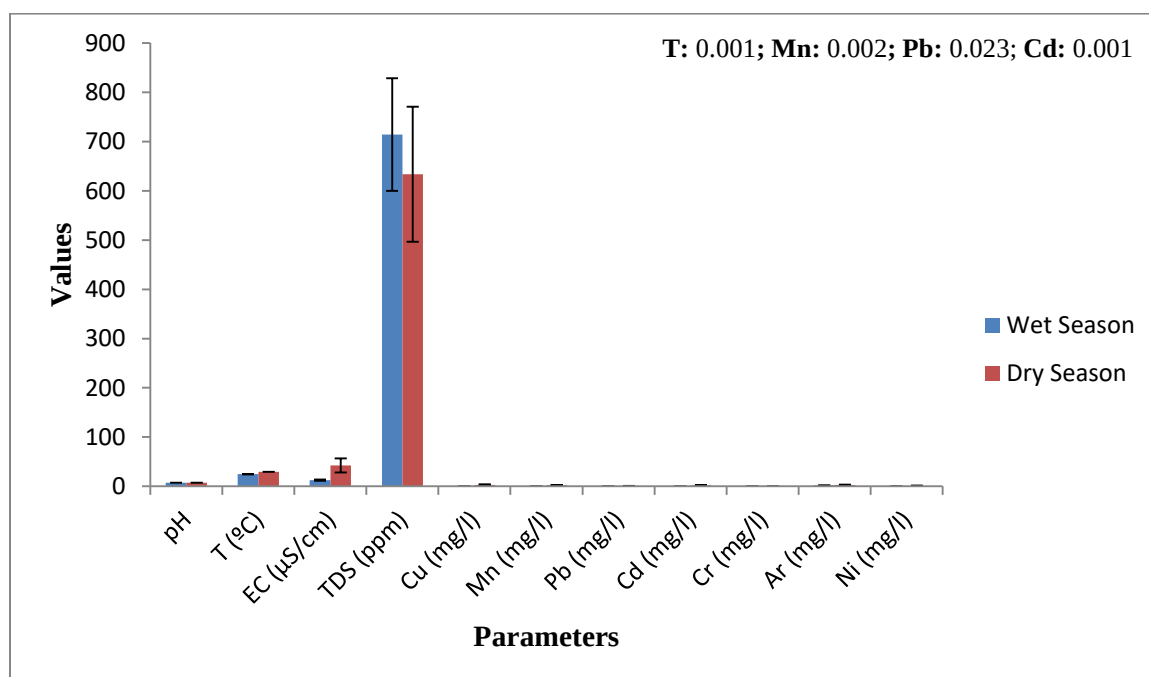


Figure 9: Comparison of seasonal status of the physicochemical and metallic parameters of Uwani dumpsite
All values expressed as mean $\pm$ standard error of mean ($\pm$ SEM), with significant p -values from t -test.

Figure 10 shows the physicochemical and metallic parameters seasonal comparison in Achara Layout dumpsite. It was observed from the result that for the examined physicochemical parameters of hydrogen ion concentration, electrical conductivity and total dissolved solids, the wet season values were significantly ($p < 0.05$) higher than that of dry season, but however, vice versa for temperature. All the heavy metals studied, except copper showed significantly higher concentrations during dry season than wet season ($p < 0.05$).

Figure 11 shows the physicochemical and metallic parameters seasonal comparison in Borehole GRA dumpsite. The concentrations of copper and manganese varied significantly ($p < 0.05$) in seasons. Whereas the concentration of copper was higher ($p < 0.05$) in wet season than dry season, manganese concentration was higher ($p < 0.05$) in dry season than wet season. The physicochemical parameters (with the exception of temperature), metallic parameters aside copper and manganese showed no significant ($p \geq 0.05$) differences in their mean values between seasons in Borehole GRA dumpsite (Figure 11).

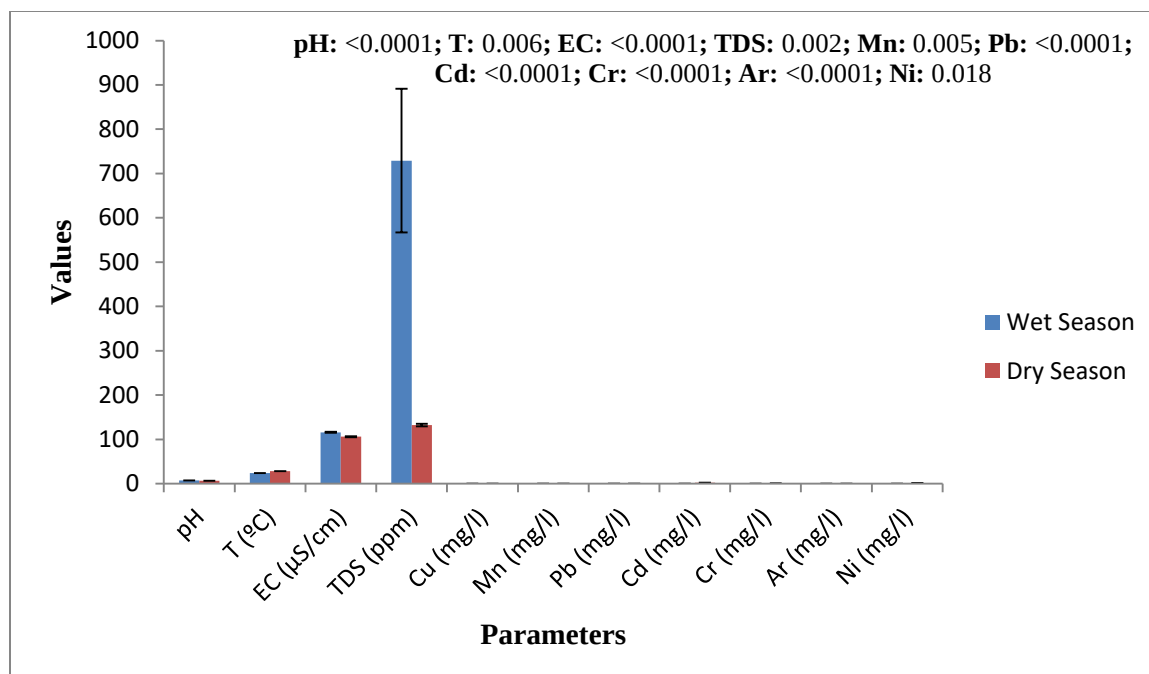


Figure 10: Comparison of seasonal status of the physicochemical and metallic parameters of Achara Layout
All values expressed as mean $\pm$ standard error of mean ($\pm$ SEM), with significant *p*-values from *t*-test.

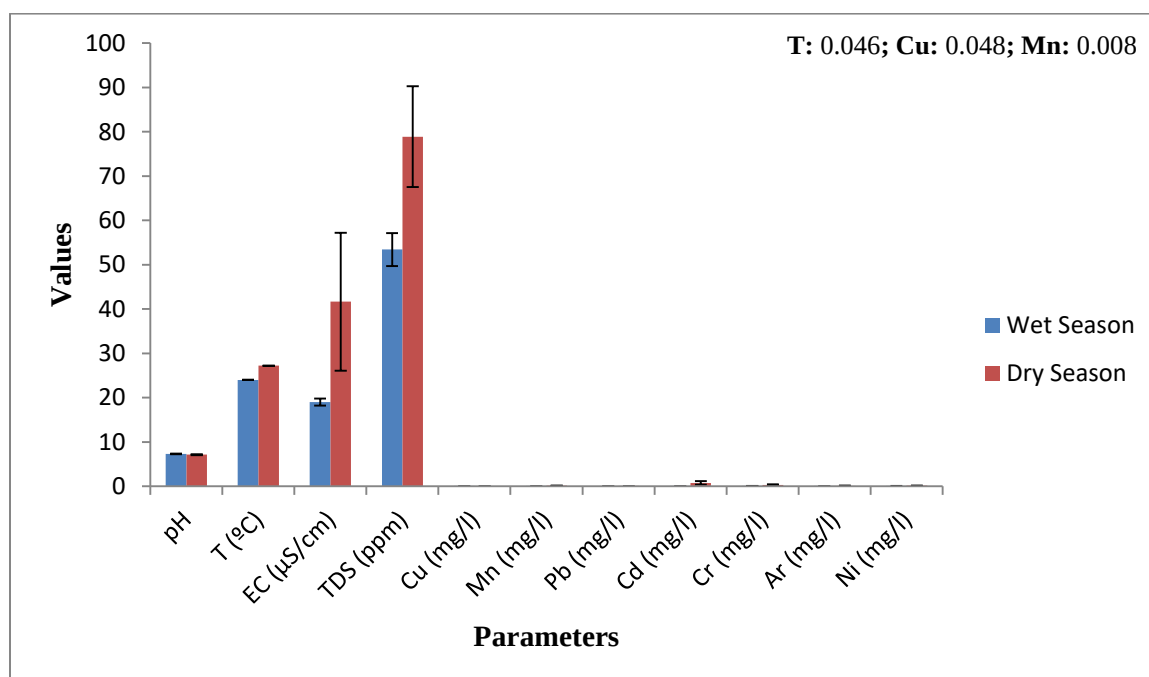


Figure 11: Comparison of seasonal status of the physicochemical and metallic parameters of Borehole GRA dumpsite
All values expressed as mean $\pm$ standard error of mean ($\pm$ SEM), with significant *p*-values from *t*-test.

Figure 12 shows the overall seasonal comparison of the physicochemical and metallic parameters in Enugu Metropolis dumpsites. For the physicochemical parameters, the pH showed significantly ($p < 0.05$) higher value in wet season than dry season. Temperature was higher in dry season than the wet season. Both electrical conductivity and total dissolved solids variations were non-significant ($p \geq 0.05$). All the heavy metals concentrations showed significantly ($p < 0.05$) higher values during dry season than wet season (Figure 12).

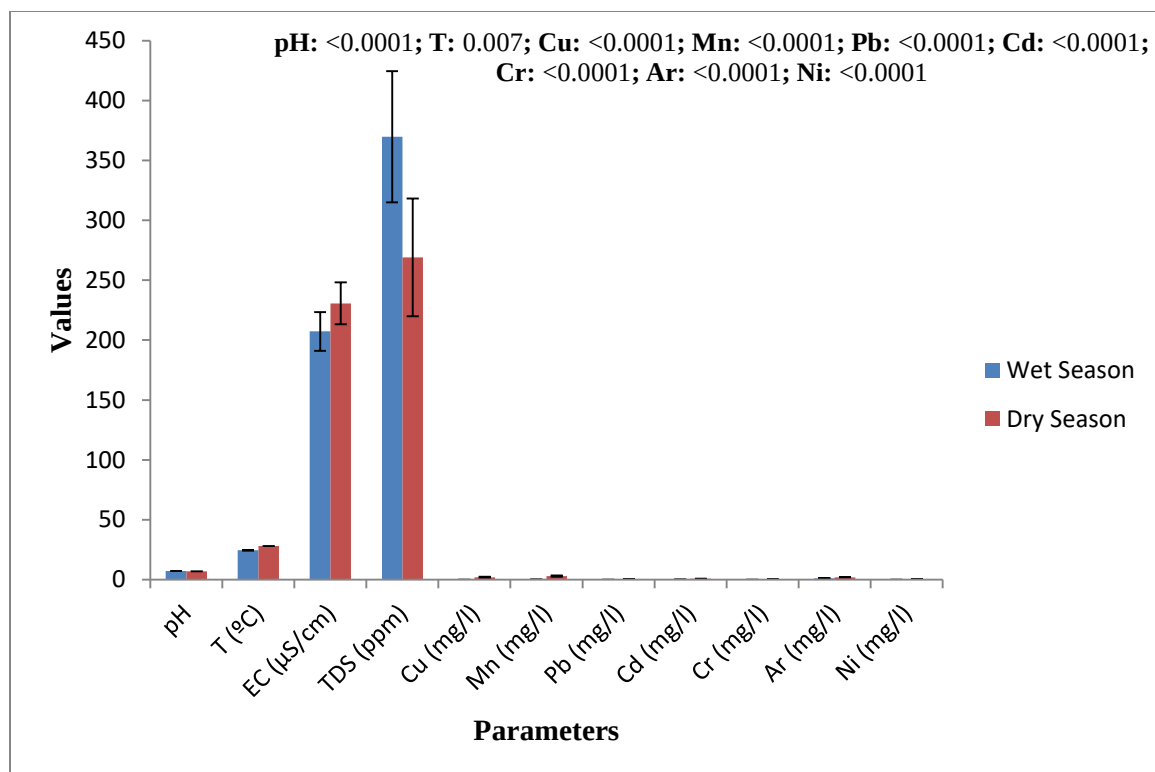


Figure 12: Comparison of seasonal status of the physicochemical and metallic parameters of all studied dumpsites in Enugu Metropolis
All values expressed as mean $\pm$ standard error of mean ($\pm$ SEM), with significant p -values from t -test.

3.2 Relationships of the Physicochemical and Metallic Parameters of Leachates of Dumpsites in Enugu Metropolis

The overall correlations for the physicochemical and metallic parameters are presented on Table 13. From the result, the electrical conductivity showed a significantly ($p < 0.05$) negative correlation to the pH ($r = -0.232$, $p = 0.002$) and total dissolved solids ($r = -0.463$, $p = 0.0001$). Hydrogen ion concentration (pH) were observed to significantly ($p < 0.05$) correlate negatively with copper ($r = -0.462$, $p = 0.0001$), manganese ($r = -0.496$, $p = 0.0001$), lead ($r = -0.376$, $p = 0.0001$), arsenic ($r = -0.389$, $p = 0.0001$) and nickel ($r = -0.152$, $p = 0.042$). Temperature had a significant negative correlation with pH ($r = -0.331$, $p = 0.0001$), but positive correlations with the studied metals ($p < 0.05$). Electrical conductivity had significant ($p < 0.05$) positive correlation with copper ($r = 0.203$, $p = 0.006$), manganese ($r = 0.229$, $p = 0.002$) and arsenic ($r = 0.292$, $p = 0.0001$) but negative correlation with cadmium ($r = -0.383$, $p = 0.0001$) and chromium ($r = -0.270$, $p = 0.0001$). The total dissolved solids correlated negatively with copper ($r = -0.151$, $p = 0.044$) and positively with cadmium ($r = 0.385$, $p = 0.0001$; Table 13).

Table 13: Correlation matrix of the physicochemical and metallic parameters in the studied dumpsites

Parameters	<i>r</i>	pH	T	EC	TDS	Cu	Mn	Pb	Cd	Cr	Ar	Ni
pH	1		- 0.331** 0.0001	- 0.232** 0.002	- 0.031 0.677	- 0.462** 0.0001	- 0.496** 0.0001	- 0.376** 0.0001	- 0.053 0.481	- 0.121 0.107	- 0.389** 0.0001	- 0.152* 0.042
T			1	0.070 0.353	- 0.068 0.363	0.410** 0.0001	0.408** 0.0001	0.518** 0.0001	0.268** 0.0001	0.323** 0.0001	0.383** 0.0001	0.406** 0.0001
EC				1	- 0.463** 0.0001	0.203** 0.006	0.229** 0.002	0.021 0.784	- 0.383** 0.0001	- 0.270** 0.0001	0.292** 0.0001	0.023 0.762
TDS					1	- 0.151* 0.044	- 0.132 0.078	0.136 0.068	0.385** 0.0001	0.018 0.815	0.111 0.138	- 0.136 0.068
Cu						1	0.960** 0.0001	0.784** 0.0001	- 0.169* 0.023	- 0.103 0.170	0.745** 0.0001	0.784** 0.0001
Mn							1	0.715** 0.0001	- 0.137 0.066	- 0.108 0.151	0.712** 0.0001	0.639** 0.0001
Pb								1	0.036 0.633	0.023 0.758	0.692** 0.0001	0.752** 0.0001
Cd									1	0.714** 0.0001	- 0.071 0.344	- 0.003 0.968
Cr										1	- 0.238** 0.001	0.123 0.100
Ar											1	0.571** 0.0001
Ni												1

Significant correlation, *r* at $p < (0.05^*$ and $0.01^{**})$ using coefficients from Pearson's Correlation.

pH: Hydrogen Ion Concentration; **T:** Temperature; **EC:** Electrical Conductivity; **TDS:** Total Dissolved Solids; **Cu:** Copper; **Mn:** Manganese; **Pb:** Lead; **Cd:** Cadmium; **Cr:** Chromium; **Ar:** Arsenic; **Ni:** Nickel.

Table 14 show the component matrix for the principal components of physicochemical and metallic parameters of leachates in all studied dumpsites. The dimensions of the studied parameters were reduced to three components which explained a total of 73.65% variance. Component 1 explained 41.15% variance which extracted hydrogen ion concentration (pH), temperature, copper (Cu), manganese (Mn), lead (Pb), arsenic (Ar) and nickel (Ni). The correlations of the extracted metals were strong, while the physicochemical parameters were moderate. The pH had inverse relationship with the others. Component 2 explained 20.74% variance and extracted electrical conductivity (EC), total dissolved solids (TDS), cadmium (Cd) and chromium (Cr). From the components, EC was inversely related to TDS, Cd and Cr. Component 3 with 11.75% variance explanation contained TDS and Cr. The Cr was inversely related to TDS. The extractable eigenvalues of the three components are shown (Table 14). A biplot of the relationship matrix among the physicochemical and metallic parameters of the dumpsites shows an obvious negative relationship between pH and most of other parameters (temperature, Cu, Mn, Pb, Ar and Ni) under the first component as shown (Figure 13). The pH loadings had less variance during the wet season. Also, under the second component, EC had a moderate negative relationship with TDS, Cd and Cr.

Table 14: Component matrix of the physicochemical and metallic parameters in the studied dumpsites

Parameters	Component Matrix		
	PC 1	PC 2	PC 3
Hydrogen ion concentration	- 0.539	- 0.098	0.192
Temperature (°C)	0.573	0.392	- 0.357
Electrical conductivity (µS/cm)	0.266	- 0.616	- 0.454
Total dissolved solids (ppm)	- 0.097	0.502	0.736
Copper (mg/l)	0.955	- 0.086	0.051
Manganese (mg/l)	0.915	- 0.090	0.027
Lead (mg/l)	0.868	0.202	0.202
Cadmium (mg/l)	- 0.087	0.889	- 0.120
Chromium (mg/l)	- 0.046	0.785	- 0.510
Arsenic (mg/l)	0.830	- 0.078	0.248
Nickel (mg/l)	0.791	0.131	0.014
Initial Eigenvalues			
Total	4.527	2.282	1.293
% Variance	41.152	20.742	11.751
Cumulative %	41.152	61.894	73.645

Dimensions reduced to 3 components by factor extraction with Initial Eigenvalues and coefficients from Principal Component Analysis (PCA).

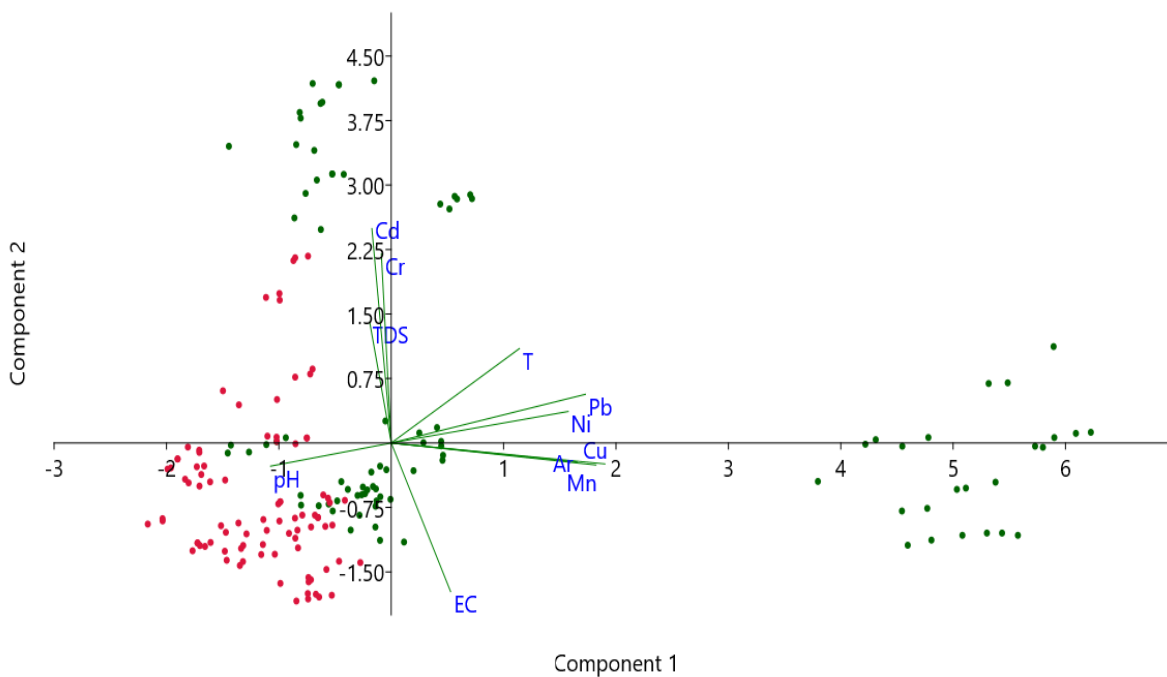


Figure 13: A biplot of the first two principal components of the physicochemical and metallic parameters in the studied dumpsites.

Key: Wet season (crimson dots); dry season (darkgreen dots).

Table 15 shows the component matrix for the principal components of physicochemical and metallic parameters of leachates in all studied dumpsites in dry season. The dimensions of the studied parameters as observed were reduced to four components which explained a total of 84.26% variance. Component 1 explained 42.62% variance which extracted copper (Cu), manganese (Mn), lead (Pb), cadmium (Cd), arsenic (Ar) and nickel (Ni). Their strong correlations show that increase in one leads to increase in others, except for Cd that has a negative moderate correlation. Component 2 explained 18.42% variance and extracted electrical conductivity (EC), total dissolved solids (TDS), lead (Pb) and cadmium (Cd). EC had inverse relationship with the other components. Component 3 explained 12.98% variance and extracted temperature, TDS and chromium (Cr). TDS had inverse relationship with temperature and Cr. Component 4 explained 10.23% variance and extracted principally only pH. The extractable eigenvalues of the four components are shown (Table 15). A biplot of the relationship matrix among the physicochemical and metallic parameters of the dumpsites during the dry season shows an obvious negative relationship between Cd and most of other parameters (Cu, Mn, Pb, Ar and Ni) under the first component as shown (Figure 14). Also, under the second component, EC had a strong negative relationship with TDS, Pb and Cd.

Table 15: Component matrix of the physicochemical and metallic parameters in the studied dumpsites during the dry season

Parameters	Component Matrix			
	PC 1	PC 2	PC 3	PC 4
Hydrogen ion concentration	-0.464	0.077	-0.017	0.827
Temperature (°C)	0.391	-0.067	0.567	0.099
Electrical conductivity (µS/cm)	0.414	-0.707	-0.013	-0.317
Total dissolved solids (ppm)	-0.193	0.595	-0.677	-0.173
Copper (mg/l)	0.952	0.167	0.108	-0.028
Manganese (mg/l)	0.902	0.117	0.063	-0.155
Lead (mg/l)	0.767	0.514	-0.156	0.061
Cadmium (mg/l)	-0.550	0.684	0.162	-0.255
Chromium (mg/l)	-0.448	0.472	0.621	-0.311
Arsenic (mg/l)	0.890	0.141	-0.297	0.053
Nickel (mg/l)	0.713	0.382	0.331	0.330
Initial Eigenvalues				
Total	4.688	2.026	1.428	1.126
% Variance	42.623	18.420	12.983	10.234
Cumulative %	42.623	61.043	74.026	84.260

Dimensions reduced to 4 components by factor extraction with Initial Eigenvalues and coefficients from Principal Component Analysis (PCA).

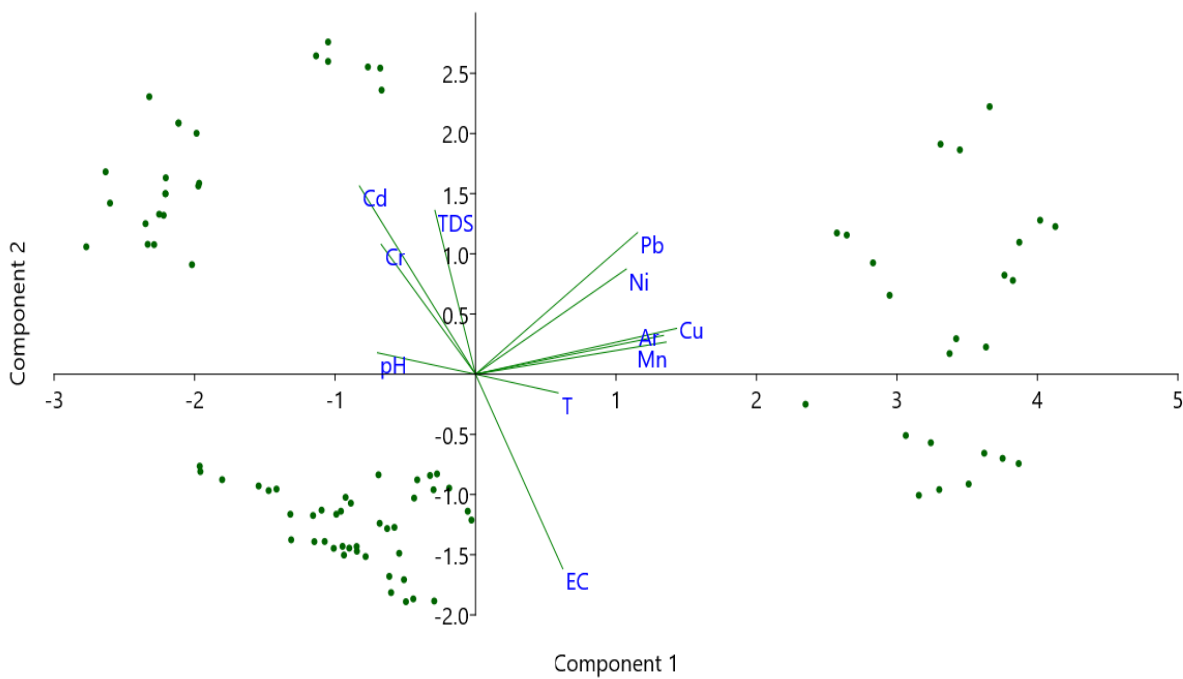


Figure 14: A biplot of the first two principal components of the physicochemical and metallic parameters in the studied dumpsites in dry season (darkgreen dots).

Table 16 shows the component matrix for the principal components of physicochemical and metallic parameters of leachates in all studied dumpsites in wet season. From the result, the dimensions of the studied parameters were reduced to four components which explained a total of 69.65% variance. Component 1 which explained 25.47% variance extracted hydrogen ion concentration (pH), total dissolved solids (TDS), copper (Cu), cadmium (Cd) and arsenic (Ar). Whereas Cd had strong correlation, pH, TDS, Cu and Ar had moderate correlation. Further, the pH had an inverse relationship with the others. Component 2 explained 21.19% variance with extraction of electrical conductivity (EC), Cu, Mn, and chromium (Cr). EC had strong correlation, while Cu, Mn and Cr were moderately correlated to one another, although Cr was negatively so. Component 3 explained 12.96% variance and contained principally pH, Pb and Ni in a moderate relationship with one another. Component 4 explained 10.03% variance and extracted principally only temperature. The extractable eigenvalues of the four components are shown (Table 16). A biplot of the relationship matrix among the physicochemical and metallic parameters of the dumpsites during the wet season shows an obvious negative relationship between pH and most of other parameters (TDS, Cu, Cd and Ar) under the first component as shown (Figure 15). Also, under the second component, Cr had a moderate negative relationship with EC, Cu and Mn.

Table 16: Component matrix of the physicochemical and metallic parameters in the studied dumpsites during the wet season

Parameters	Component Matrix			
	PC 1	PC 2	PC 3	PC 4
Hydrogen ion concentration	-0.589	-0.218	0.540	-0.100
Temperature (°C)	0.249	-0.344	0.470	0.546
Electrical conductivity (µS/cm)	-0.096	0.860	0.346	0.142
Total dissolved solids (ppm)	0.702	-0.480	0.076	-0.435
Copper (mg/l)	0.656	0.571	-0.226	-0.068
Manganese (mg/l)	0.265	0.600	0.108	-0.119
Lead (mg/l)	0.430	0.076	0.547	0.136
Cadmium (mg/l)	0.808	-0.193	-0.035	-0.218
Chromium (mg/l)	0.319	-0.615	-0.141	0.422
Arsenic (mg/l)	0.668	0.257	0.156	0.314
Nickel (mg/l)	0.056	-0.151	0.618	-0.474
Initial Eigenvalues				
Total	2.801	2.331	1.426	1.103
% Variance	25.465	21.193	12.963	10.029
Cumulative %	25.465	46.659	59.622	69.651

Dimensions reduced to 4 components by factor extraction with Initial Eigenvalues and coefficients from Principal Component Analysis (PCA).

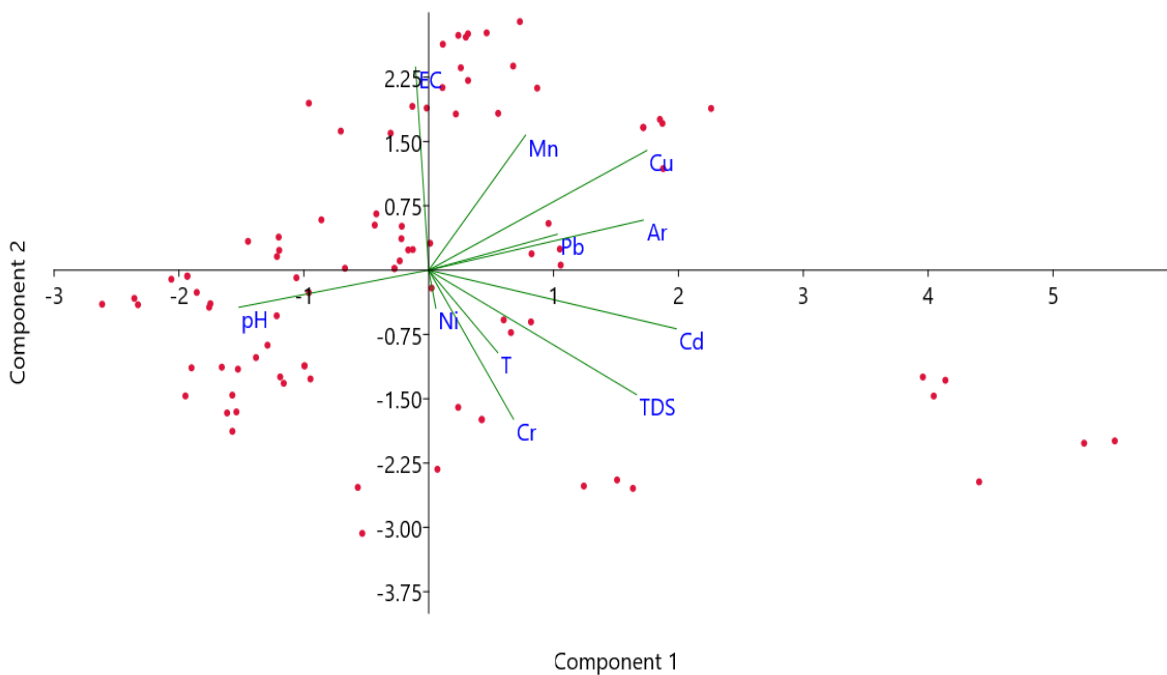


Figure 15: A biplot of the first two principal components of the physicochemical and metallic parameters in the studied dumpsites in wet season (crimson dots).

CHAPTER FOUR

DISCUSSION AND CONCLUSION

4.1 Leachate Composition of Dumpsites

In the study, a total of 11 leachates quality parameters were investigated as follows: physicochemical (hydrogen ion concentration, pH; temperature, T; electrical conductivity, EC; and total dissolved solids, TDS); metallic (copper, Cu; manganese, Mn; lead, Pb; cadmium, Cd; chromium, Cr; arsenic, Ar; and nickel, Ni) of 10 major dumpsites in Enugu Metropolis. The dumpsites are known for all sorts of waste materials that includes unused or discarded foodstuff, vegetables, plastics, bones, discarded animal parts, electronic and electrical components, etc. The rate and characteristics of leachate production depends on a number of factors such as solid waste composition, particle size, degree of compaction, hydrology of the sites, age of the dumpsite, mixture and temperature of the condition and availability of oxygen. Wastes at dumpsites overtime are expected to biodegenerate and produce leachates which could become point source of pollution into soil and groundwater (Bayode *et al.*, 2012). The persistence of refuse dumping at dumpsites pollutes the soil by downward migration of leachates (Amadi, 2011). Dumpsite leachates have been implicated to cause higher concentration levels of physicochemical and metallic parameters in closer water samples than those far away (Adeyemi and Temowo, 2010). The present findings on the composition of the dumpsites leachates revealed that the leachates may be potential source of adjacent water sources contamination. This has recently been documented by various authors that the leachates are also one of the main sources of river water contamination (Ayandiran *et al.*, 2018; Hobson *et al.*, 2018; Kayembe *et al.*, 2018; Mor *et al.*, 2018; Wu *et al.*, 2018; Xiong *et al.*, 2018; Xu *et al.*, 2018; Zhao *et al.*, 2018; Deng *et al.*, 2019; Kang *et al.*, 2019; Qu *et al.*, 2019; Rai *et al.*, 2019; Yuan *et al.*, 2019).

4.2 Physicochemical Parameters of the Studied Dumpsites Leachates in Enugu Metropolis

The ranges for hydrogen ion concentration of leachates recorded at the dumpsites during the period of study were within the acceptable standards range of 6.5-9.5 as stipulated by WHO (2008) and USEPA (2009) for drinking water. The pH value of the dumpsites ranged from 6.77 – 7.66 in the wet season and 6.73 – 7.29 in the dry season. Seasonal differences in pH value were recorded in Emene, Abakpa, Trans-Ekulu, Gariki and Echara New Layout dumpsites. Overall, the pH value dropped significantly during the dry season. Soil pH influences a number of factors affecting microbial activity, like solubility and ionization of inorganic and organic soil solution constituents, and these will in turn affect soil enzyme activity (Voroney, 2007). However, pH alone does not necessarily have any direct negative effect on the ecosystem, but highlights certain interactions of other chemical constituents in the solution that potentially poses a threat. Consequently, it is one of the most important operational leachate and water quality parameters. In leachates, pH is controlled principally by a series of chemical reactions. The most important reaction is the degradation of organic materials to produce carbon dioxide and small amounts of ammonia. These dissolve in the leachate to form ammonium ions and carbonic acid. The carbonic acid dissociates with ease to produce hydrogen cations and bicarbonate anions, which influence the level of pH of the system. In this study, pH values were found to range from slightly acidic to slightly alkaline. This observed variation is due mainly to the composition of deposited waste, biochemical decomposition process and dilution effect within the various dumpsites. All the dumpsite leachates except for Asata during the wet season were alkaline. However, during the dry season, leachates of Trans-Ekulu, GRA, Gariki and Echara New Layout became slightly acidic. The alkaline pH values obtained are consistent with the anticipated

methanogenic fermentation stage of the biochemical decomposition of leachate (Kjeldsen *et al.*, 2002). Accordingly, the pH of the resulting leachate remains comparably high despite the possibility of other leachates at the acidic stage of decomposition. The dumpsites with decreased (acidic) pH values indicate higher anthropogenic or natural factors leading to generation of new acidic leachates, which mix and eventually reduce the alkaline nature of the resultant leachate. The trend of the pH values therefore reveals that less active dumpsites generate more alkaline leachates than active dumpsites. This suggests that active dumpsites are less stable and pose a greater risk to the soil and local water resources, compared with the less active dumpsites, which are comparably more stabilized.

Electrical conductivity of the dumpsites ranged from 12.22 – 437.33 in wet season and 26.00 – 457.33 in dry season. Also, the total dissolved solids values for both seasons ranged between 53.44 – 1480.78 (wet season) and 78.89 – 1263.11 (dry season). The total dissolved solids consist mainly of carbonates, bicarbonates, chlorides, sulphates, phosphates and possibly nitrates of calcium, sodium, potassium with traces of manganese and other substrates (Akan *et al.*, 2012) and hence its contents can be raised by addition of chemical wastes and drainage waters from irrigated land. However, the total dissolved solids recorded during the entire sampling period were within the FEPA (1991) maximum levels of 2000 mg/L, but above the acceptable standard of 500 mg/L by WHO (1997) in New Haven, Uwani and Echara New Layout dumpsites. This calls for urgent concern. The electrical conductivities of leachates at the dumpsites were all below the USEPA (2009) maximum level of 2500 $\mu\text{S}/\text{cm}$. These observations are in line with the findings of Gupta (2009) and Navnect *et al.* (2010). The GRA and New Haven dumpsites had the highest values of electrical conductivity and total dissolved solids respectively for both seasons. The pH value was highest in Emene dumpsite during the wet

season, but during the dry season Uwani dumpsite became the highest. Whereas dumpsites in Emene and Abakpa had increased electrical conductivity and total dissolved solids in the dry season, the Echara New Layout dumpsite electrical conductivity and total dissolved solids decreased. The electrical conductivity and total dissolved solids of the dumpsites generally did not show seasonal differences. Electrical conductivity and total dissolved solids are generally influenced by the total amount of dissolved organic and inorganic materials present in the solution, and are used to demonstrate the degree of salinity and mineral contents of leachates. High concentrations of TDS decrease the palatability of water and may also cause gastrointestinal irritation in humans and laxative effects particularly upon transits (WHO, 1997). The total mineral content further reflects the strength and overall pollutant load of the leachate. The values were comparably higher in the more active dumpsites than the less active ones. Hence, salinity is higher in leachates of active dumpsites because more salts become soluble to acidic pH. This implies that more active dumpsites like Asata, Trans-Ekulu, GRA, Gariki, and Echara New Layout are more likely to have higher polluting tendencies than those that are less active. Physicochemical constituents of the leachates studied showed varied characteristics, which indicate the diverse nature of the different dumpsites. This variation concurs with previous reports that leachate compositions vary significantly among dumpsites, depending on waste composition, age of disposal and the unique properties and nature of the site (Christensen *et al.*, 2001; Henry *et al.*, 2002).

4.3 Metallic Parameters of the Studied Dumpsites Leachates in Enugu Metropolis

Heavy metals as essential nutrients can also be regarded as contaminants. The present study heavy metals evaluation showed significantly increased copper (wet season: 0.01 – 2.29; dry season: 0.00 – 2.54), manganese (wet season: 0.02 – 0.64; dry season: 0.12 – 4.54), lead (wet

season: 0.00 – 0.02; dry season: 0.03 – 1.05), cadmium (wet season: 0.01 – 0.93; dry season: 0.11 – 2.31), chromium (wet season: 0.02 – 0.15; dry season: 0.04 – 0.84), arsenic (wet season: 0.01 – 2.17; dry season: 0.09 – 2.81), and nickel (wet season: 0.08 – 0.30; dry season: 0.13 – 0.92) levels during the dry season. The concentrations of the heavy metals in the wet season followed this sequence in decreasing order: $Ar > Cd > Mn > Ni > Cu > Cr > Pb$. Arsenic and chromium were highest in Uwani dumpsite, cadmium levels highest in New Haven, manganese levels highest in GRA, nickel was highest in Echara New Layout, copper was highest in Asata, and lead was highest in Abakpa dumpsites. The dry season sequence in decreasing order is as follows: $Mn > Ar > Cu > Cd > Pb > Ni > Cr$. The heavy metals highest values were recorded in Asata for manganese, Uwani for arsenic and nickel, Abakpa and Uwani for copper, Echara New Layout for cadmium and chromium, and New Haven for lead concentrations. On the overall, the dumpsites with the most and least metallic nutrients are Uwani and Borehole GRA dumpsites respectively. These metals may come from natural sources, leached from soils according to their geochemical mobility or come from anthropogenic sources. These trace metals are dangerous because they tend to bioaccumulate resulting in heavy metal poisoning (Abolude *et al.*, 2009). Their different concentrations at the dumpsites fall above the WHO permissible values (WHO, 1985, 1997). Their concentrations at dumpsites showed significant seasonal influence, in favour of the dry season. This also calls for urgent concern. The presence of high levels of heavy metals in the leachate suggests their origin could be from the various wastes dumped at the sites. Elevated levels of lead in leachate had also been observed by Moturi *et al.* (2004) and this may be attributed largely to the disposal of batteries, lead-based paints and lead pipes found at the site. The discarding of dry cell batteries and paint cans are possible sources of cadmium. The high concentration of cadmium, arsenic and manganese in dry season may be due to the decay of

abandoned electric batteries, spent petroleum products and other electronic components (Mull, 2005). The spatial and seasonal variations in the concentration level suggest point sources pollution. High copper concentration could result from the decomposition of electrical materials, roofing sheets, cooking utensils, alloys, electroplating and chemical effluents (Odero *et al.*, 2000).

In leachates, dissolved metals can be present in the form of free ions or may form complexes with organic or inorganic ligands. The presence of free heavy metal ions in leachate is not only affected by the amounts present in the waste mass, but also the degradation processes within the dumpsite; these are predominantly dependent on pH (Kjeldsen *et al.*, 2002). With the increase in solubility of many heavy metals under acidic conditions in the fermentation stage and decrease in the methanogenic stage under neutral to alkaline conditions, samples are expected to have significantly high concentrations of these metals in leachates with relatively acidic pH.

4.4 Relationships of the Leachates Parameters of Dumpsites in Enugu Metropolis

In total, the study showed that copper levels have strong positive correlations with manganese, lead, arsenic and nickel concentrations. Also, manganese correlates with lead, arsenic and nickel. Cadmium correlates with chromium, while arsenic correlates with nickel. All the metallic correlations were positively strong. This suggests source pollution of the dumpsites with similar waste materials and local geology and hydrogeology. Copper and manganese had negative correlations, but that of cadmium was positive.

4.5 Conclusion

The results obtained in this study show that the leachates generated from the dumpsites could have harmful impact on the groundwater quality in the study area. The observation of elevated levels of heavy metals and total dissolved solids in leachates above the WHO

permissible limits in dumpsites is an indication that in the absence of a leachate collection system, the uncontrolled accumulation of leachates over time at the dumpsites will represent a significant threat to the groundwater quality. Considering the effects of waste materials at dumpsite on the composition of its generated leachate, the compositional variation is a function of the varying characteristics and leaching abilities of the waste components. Furthermore, local environmental conditions at dumpsites and their management will have enormous implications on how the composition of leachates will vary. The extent of scavengers and animal activities, as well as the amount of water that eventually reaches the sites, also varies significantly. These factors contribute to the observed variations in the leachate compositions. Generally, the leachates studied were found to have significantly high salinity and alkalinity especially during the wet season. Hence, the leachates were considered to contain significant loads of contaminants to pose threat to the underlying groundwater aquifer. It was also observed that leachates from the more active disposal sites were comparably more loaded with contaminants than those from less active dumpsites.

4.6 Recommendations

The findings obtained from this study therefore suggest that the surface and groundwater of the study sites is unreliable for drinking purposes, with emphasis on the need to improve on waste management practices and construct properly engineered leachate collecting system at dumpsites to curtail pollution of surface and/or groundwater. This is because during flooding and heavy rains, leachates and runoffs from far and near carry pollutants to the river, thereby compromising its water quality (Iskandar, 2010).

The government should periodically monitor the water quality status of these acquired dumpsites to control the spread of pollutants and contaminants. Also, the natives should avoid

the use of surface well water and boreholes close to these dumpsites to avoid toxicity resulting from contamination. This is because the studied dumpsites were neither engineered nor properly managed and regulated; hence there is a high tendency of leachate migration to the soil and water resources. This can result in contamination of the soil, surface water and subsurface water resources, which, in turn, poses a significant threat to the environment and public health.

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