ARTICLE **OPEN**

Assessment of heavy metal percolation from electronic waste (mobile phones) through different soil layers in the Niger Delta, Nigeria

Aroloye O. Numbere[1*] and Gabriel George[2]

[1, 2]**Department of Animal and Environmental Biology, University of Port Harcourt, Choba, Nigeria. +2348056002989**

***Corresponding author: aroloyen@yahoo.com**

Abstract:

The proliferation of electronic waste is a global problem. It is hypothesized that heavy metals from buried decomposing mobile phones will percolate through different layers (i.e. top. middle and bottom) of mangrove and farm soils. Sixteen mobile phones were collected and buried in two containers (volume 14, 142.86 cm3) bearing mangrove and farm soils and left for I year to decompose. A total of 60 soil samples were analyzed for Arsenic, Cadmium, Copper, Lead, Nickel and Zinc. There was a significant difference in the concentration of metals ($F_{5, 66}$ = 36.64, $P < 0.0001$). Zinc, Copper, and Nickel had the highest concentration while Cadmium had the least concentration in both soils. Mangrove soil had a higher heavy metal concentration than farm soil even though there was no significant difference ($P > 0.05$). Similarly, there is no significant difference in heavy metal concentration between soil layers and seasons (i.e. dry and wet) ($P > 0.05$). During the dry season heavy metal was higher in the top and middle layers while during the wet season heavy metals was higher in the middle and bottom layers of the soil. The result implies that heavy metal concentration between soil layers was influenced by seasonal fluctuations. Improper disposal of electronic waste in the environment should be discouraged to prevent the contamination of surface and ground water.

Keywords: electronic waste, ground water, heavy metals, mobile phone, pollution, soil profile, waste dump

1 Introduction

Electrical and electronic equipment [1] wastes are made up of refrigerators, air-conditioners, cell phones, stereo systems and computers that are discarded [2].They are any household appliances that are no longer useful and eventually end up in landfill. Electronic and electric wastes cause hazardous effects on the environment. This situation is more serious in many African countries, which over the years had become the destination of manufactured electronic goods from other parts of the world [3, 4]. E-waste recycling in Africa has not gained much attention as experienced in America, Asia and Europe. E-waste recycling involves much labor and environmental legislation [5]. Thus global production of e-waste is put at 20-50 Militonn/year (Mt/yr), which makes 1-3% of global urban waste production. It is predicted that PCs, cell phones and televisions will contribute > 14.0 Mt/yr in 2020. Thus, there has been steady rise in the amount of e-waste in Africa. In Nigeria with rapidly growing population of close to 200 million people [6], the use of different electronic products had increased. Most especially, the use of mobile phones had increased since the late 1990's. Almost every member of a household above ten years has a mobile phone. Some of the phones are sophisticated and expensive while others are simple and less expensive. The life span of these phones is short, i.e. between 2-3 years making them to be easily disposed as compared to other kind of e-waste [7]. Technological advancement and improved income has made many to exchange their old phones for new ones. In addition, the influx of sub-standard phones had resulted to the increase in mobile phone waste at dump sites [8]. Lack of proper management and recycling of e-wastes [9, 10, 11] can lead to their disposal in aquatic environment resulting to public health crisis [12]. Electronic waste is inimical to health because it contains toxic elements such as lead, cadmium, mercury, polychlorinated biphenyls and brominated flame retardant [13, 14, 15, 16]. In some rural areas e-waste is disposed in open dump or land fill **situated** on farm land or virgin forest where they are incinerated. Incineration of phones lead to the melting of the internal components (diode, mother board, IC), which contain heavy metals leading to toxic emissions [17]. Liquefaction of the internal parts of mobile phones makes it possible for heavy metals to enter and contaminate ground water [18]. The farm soil is also contaminated with heavy metals from burnt or decomposing phones [19]. High concentration of heavy metals in the soil lead to high mobility and movement into plants parts via the roots [20]. Contaminated plants when consumed affect human and animal health [21, 22, 23] leading to organ failure and other life-threatening diseases and deficiencies.

There is limited data on electronic waste in the Niger Delta. In this study, two kinds of soils were used namely farm soil and mangrove soil. Farm soil was used because of the significance of soil-crop-food pathway of heavy metals [24]. Similarly, mangrove soil was used because mangrove forest is gradually becoming a dumping ground for municipal solid waste in the Niger Delta. Since mangrove forest is a biodiversity hotspot, it is important to monitor the transmission of pollutant up the food chain to prevent its health effect on humans [25, 26].

Six heavy metals (i.e. Cd, Pb, Zn, Cu, As and Ni) that are products of e-waste were investigated because of their health effect if consumed through food and water. For instance, Arsenic is very poisonous and has carcinogenic and teratogenic effects [27]. Cadmium is poisonous and lethal to aquatic organism. Lead is poisonous and cause instant death to aquatic organisms. It is both carcinogenic and teratogenic.

The change of technology from analog to digital had increased the demand for electronics all over the world [28]. The composition and percentage of different electronic products is shown in Table 1. It indicates the dominance of mobile phone waste in dump sites. Phones are everywhere because of their utility. They range from the expensive android phones to less expensive Nokia phones. The simple phones sometimes are more durable than the expensive ones because of their durability against damage as compared to the android phones that are very fragile and prone to damages from fall.

The objectives of the study were; (1) to determine the percolation of heavy metal from e-waste into different soil layers (2) to determine the soil type with higher heavy metal concentration (3) to determine the effect of seasons on metal percolation in different soil layers.

2.0. Materials and methods

2.1. Soil and phone collection

2.1.1. Soil Sample collection

Soil samples were collected from both farm and mangrove forest with a shovel in Port Harcourt and Okrika respectively. The soils were placed in two sack bags and transported to the laboratory. At the laboratory the soils were loaded into two buckets with the following dimensions: height 36 cm and diameter 30 cm. The soil samples were put in the bucket with area of dimension 14, 142.86cm3.

Two sets of soil samples were collected from the containers, one during the wet season after seven months of phone burial in April (i.e. September, 2017-April, 2018) while the other samples were collected during the dry season at the beginning of October, over one year after burial. In all five soil samples weighing 10 g each were collected from the top, middle and bottom layers of the mangrove and farm soils (n = 60). The soil samples were sent to the laboratory for physico-chemical analysis of the following heavy metals: Arsenic (As), Lead (Pb), Cadmium (Cd), Zinc (Zn), Copper (Cu) and Nickel (Ni).

2.1.2. Electronic waste collection

Discarded e-wastes were picked up at different disposal sites in the city of Port Harcourt, study area (Table 1). The following parameters were measured: individual weight, number in dump sites, percentage composition. The Life span was estimated based on information from literatures (Betts, 2008a; Cobbling, 2008; Li et al. 2009). The values were then used to calculate the annual e-waste production using the formula in Eq. 1.

Annual e-waste production is calculated as $E = MN/L$ ………………………. (1)

Where E (kg/year) = E-waste production, M (kg) = Mass of electronic, its quantity (No) in the market & consumption = N and its average life cycle = L (year)

Categories of e-waste found in several waste dump sites include: large and small household appliances, IT and telecommunications equipment, consumer and lighting equipment, electrical and electronic tools, toys, leisure and sports equipment, medical devices, monitoring and control instruments and automatic dispensers.

Table 1. Types of e-waste in study location: common waste electrical and electronic (WEE) products and their approximate percent (%) composition in a typical waste dump site in Nigeria

Item	Weight (M) (kg)	Life span (L)	No. in dump site (N)	% waste composition	Annual e-waste production
Computer[a]	25	5	2	7.69	10
Mobile phone[b]	0.1	3	10	38.46	0.3
Photocopier	60	3	0	0	0
Radio[b]	2	10	3	11.54	0.6
Television[c]	30	15	5	19.23	10
Video recorder & DVD player[b]	5	1	1	3.85	5
Air conditioning unit	55	3	1	3.85	18.3
Electric heater[b]	5	1	2	7.69	10
Freezer[b]	35	10	0	0	0
Hair dryer[b]	1	2	1	3.85	0.5
iron[b]	1	10	1	3.85	0.1

Source: Adjusted from a(Betts, 2008a), b(Cobbing, 2008) & b(Li et al. 2009)

Sixteen different brands of mobile phones were collected and their data recorded (Table 2, Fig. 1). They were then divided into two groups of eight (8) and then buried in soils placed in buckets and left for one year i.e. from October 2017 to November, 2018.

Table 2. Recovered phones from waste dump sites: type, model, weigh, color and country of manufacture of discarded mobile phones collected from different waste dump sites around Port Harcourt, Nigeria

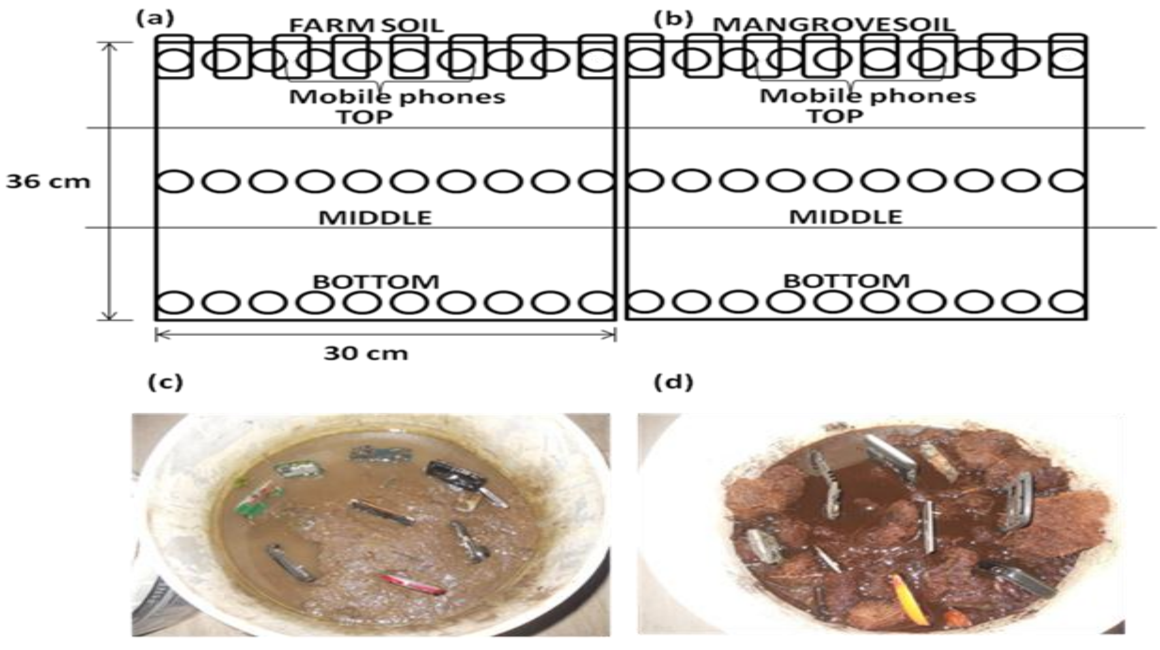
Phone type	Model	Weight (g)	Color	Country of manufacture
Blackberry, CE 0168	REM 71 UW	136.4	White	Hungary
Nokia	S 5	112.3	White & Red	China

G-Tide	E 1	145.2	Black	China
Nokia	5330	107.3	Black	China
Samsung	GT 83653	153.8	Black & Orange	China
Samsung-Galaxy	7986	164.7	Grey	North Korea & China
Blackberry	9700	116.4	Black	China
Blackberry	9800	125.4	Black	China
Samsung	TK 10	121.2	Green	China
Samsung	TK 10	121.5	Green	China
Nokia-225	RM 1011	100.8	Black	Vietnam
Nokia	3310	191.9	Black	China

Fig. 1 Mobile phones recovered from dump sites in some areas in the Niger Delta, Nigeria

2.2. Experimental design

The experimental design is structured block design (Fig. 2). Two containers were used for the experiment (dimension~36 m × 30 m). Ten soil samples were collected equally from each of the three layers i.e. top, middle and bottom and from both farm and mangrove soils making a total of 60 samples i.e. 3 (10) + 3(10) = 30 + 30.



2.3. Statistical analysis

A fixed effect model was performed where heavy metal was treated as a fixed factor and each sample block as random factor [29]. A single factor ANOVA was conducted for heavy metal concentration at different soil layers (i.e. top, middle and bottom) at ten sampling stations in two sets of soil containers [30]. These data were used to test the null hypothesis that there were no significant differences in heavy metal concentration between soil layers and between seasons. Data was log transformed to ensure that they were normal and homogeneous. For seasonal differences, a two factor fixed (Model 1) ANOVA was conducted to determine the effect of season and soil layers on heavy metal concentration in both farm and mangrove soils. All analysis was performed in R statistics [31].

3.0. Results

3.1. Electronic waste composition in dump sites

Percentage electronic waste in waste dump sites in the stud area indicate that mobile phone waste had the highest composition (38.46%) followed by television (19.23%) and radio (11.54%) (Table 1).

3.2. Effect of soil types on metal percolation

There was a significant difference in the concentration of the six heavy metals analyzed ($F_{5, 66} = 36.64$, $P < 0.0001$). Copper, Nickel and Zinc had the highest overall concentration (Figure 3). The concentration of most of the metals analyzed was above the standard by the Federal Ministry of Environment (FMENV) (Table 3).

Table 3. Comparison of heavy metal concentration: in farm and mangrove soil with Federal Ministry of Environment (FMENV) maximum concentration for ground water protection

Heavy metals constituents	FMENV limit (mg/l)	Farm soil Conc. (mg/l)	Mangrove soil Conc. (mg/l)
Arsenic	0.05	2.31 ± 1.41	0.80 ± 0.47
Cadmium	0.01	0.04 ± 0.03	0.09 ± 0.04
Lead	0.05	3.38 ± 0.74	4.36 ± 0.88
Zinc	0.05	23.62 ± 2.85	21.32 ± 6.75
Copper	0.05	16.77 ± 11.48	21.86 ± 18.20
Nickel	0.05	3.55 ± 1.06	23.18 ± 14.47

Similarly, heavy metal concentration in both soils does not vary significantly ($F_{1, 70} = 0.09$, $P > 0.05$, Fig. 3). But, concentration of heavy metal is relatively higher in mangrove than in farm soil.

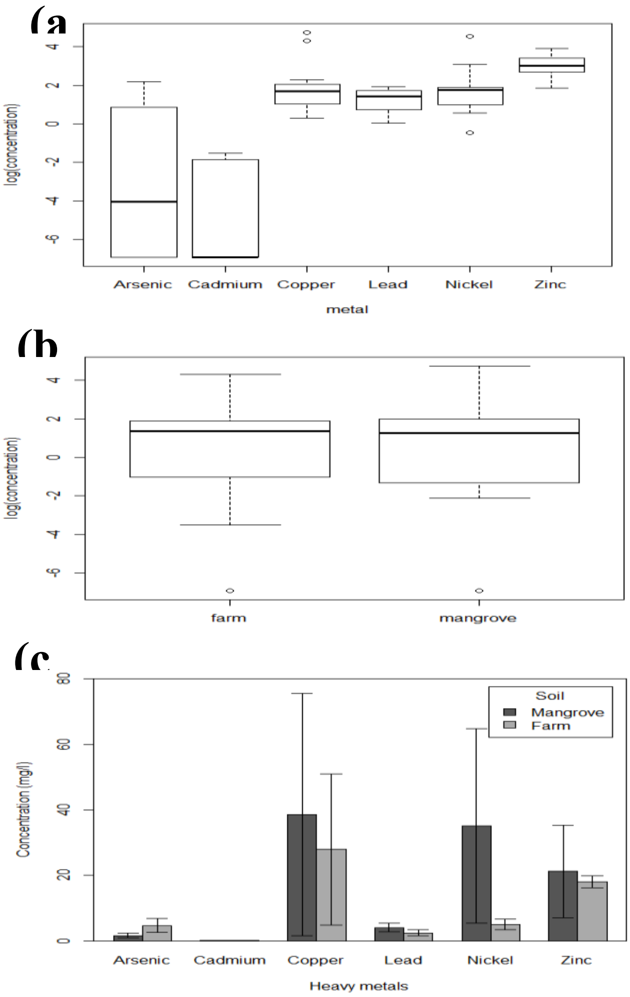


Fig. 3 Box plots of normality and bar graph of heavy metal concentration in soils

3.3. Effect of soil layer on metal percolation

The concentration of heavy metals in the different soil layers did not vary significantly ($F_{1, 70} = 1.76$, $P > 0.05$), but the concentration of heavy metals was significantly higher in the top soils than in the middle and the bottom soils (Fig. 4). The mobile phones were buried in the top soil that is why there was higher heavy metal concentration at the top soil. The concentration indicates that there is a trickledown effect from the top to the bottom soil layer.

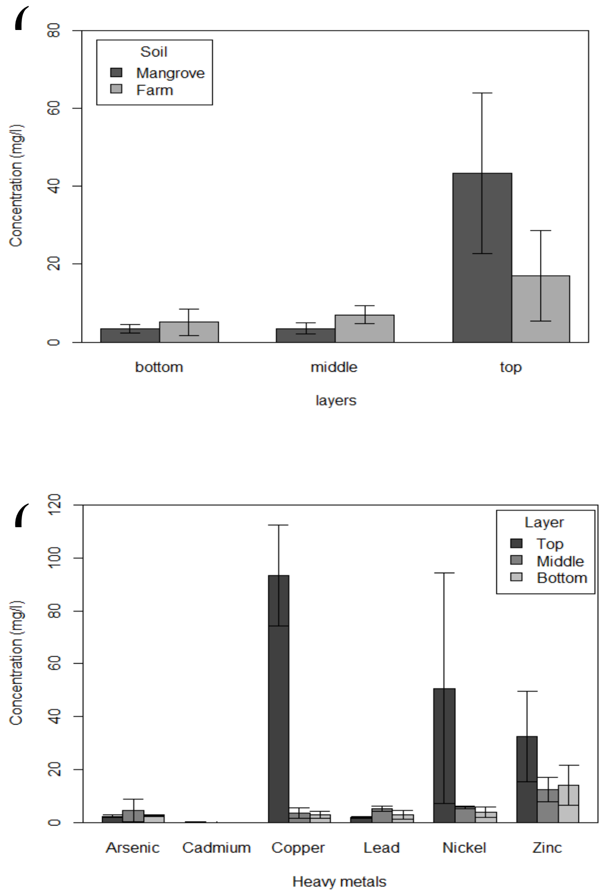


Fig. 4 Concentration of six heavy metals in three different soil layers

3.4. Control soil versus soil with buried mobile phone

Before the burial of the mobile phones soil samples were sent to the laboratory for analysis and served as control to test for the presence of heavy metals. The result showed a baseline concentration, which in comparison to the soil after the burial of the phones indicates slight increase in heavy metal concentration (Figure 5). The highest increase was recorded at the top soil where the phones were buried

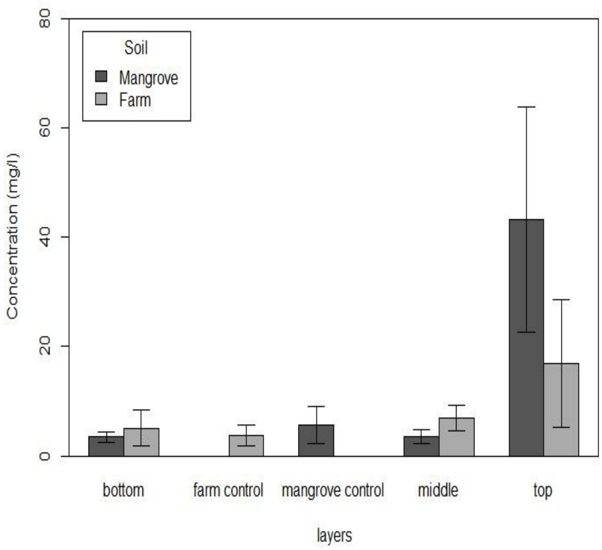


Fig. 5 Graph of heavy metal concentration before (control) and after the burial of the phones.

3.5. Effect of seasons on metal percolation

There was no significant difference in heavy metal concentration between wet and dry seasons ($F_{1, 70} = 2.91$, $P > 0.05$). However, the interaction effect of season and soil layer indicate seasonal influence on the percolation of heavy metals from top to bottom soil layers (Figure 6). For both soil types during the dry season heavy metal was slightly higher between the top and middle layer, but during the wet season heavy metal was higher from the middle to the bottom layer, which indicates percolation of pollutants with movement of water down the soil profile (Figure 6).

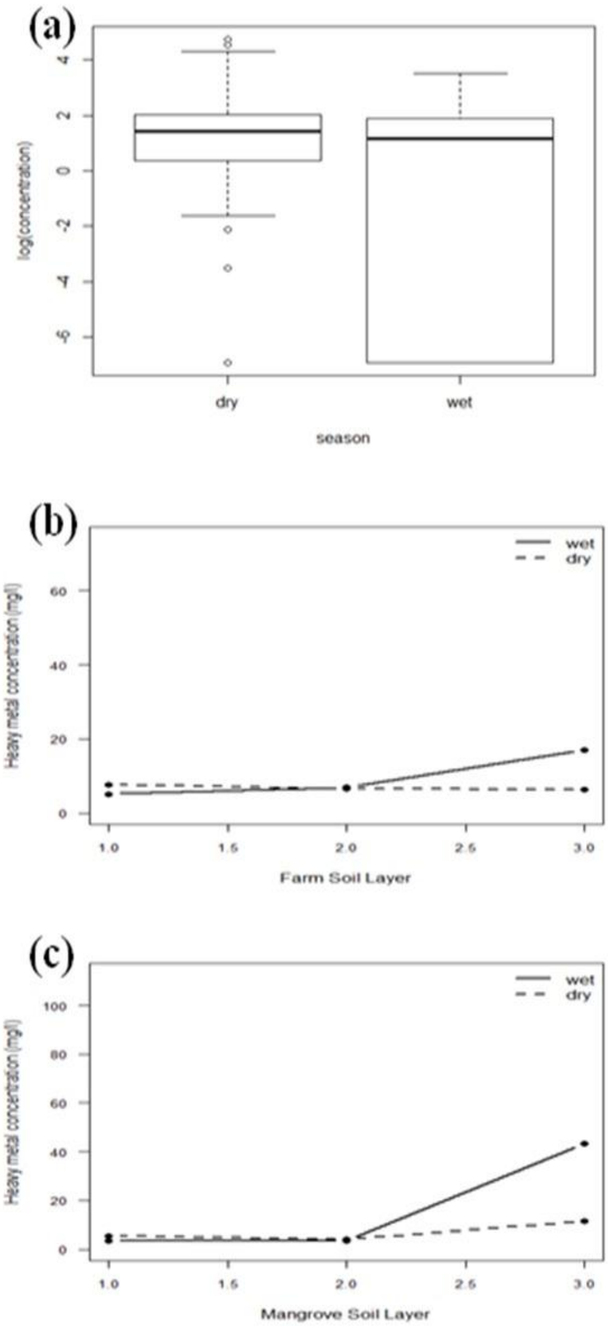


Fig. 6 Box plots and line graph of seasonal differences in heavy metal percolation through different soil layers

4.0. DISCUSSION

The uncontrolled disposal of mobile phones in open waste dump or land fill can have long term effect on the environment. This is because toxic heavy metals, which are by-products of degradation of the phones when buried in the soil can be harmful when they percolate into ground water. In the same vein, high concentration of heavy metals beyond acceptable limits can put the health of humans and other living organisms who consume it at risk [5]. This study showed that almost all the heavy metals analyzed were above the acceptable limits of between 0.01─0.05 mg/l (Table 4). For instance Lead is 70─80 times more than the acceptable limits in farm and mangrove soils respectively Similarly, Arsenic is 16─ 46 times more than the required limit in mangrove and farm soils respectively. These metals have teratogenic effect when consumed via food by man [22]. Farm soils are used for crop production therefore the presence of discarded phones due to unregulated disposal can create an access route for food poisoning by toxic materials. Even though humans don't directly absorb heavy metal from the soil, they can absorb it through transfer from the food chain, and can get increased in concentration through bioaccumulation.

Mangrove forest is regarded as the food basket of the sea [32], therefore any contamination of the mangrove soil will be devastating to all organisms that are linked to it. From this study mangrove soil has a slightly higher concentration of all the heavy metals analyzed (Table 2), this indicates that they are at a greater risk of e-waste disposal as compared to farm soil. Mangrove soil has higher plasticity, which increases its' metal retention capacity. Farm soils are loose and loamy because of the presence of compost manure formed from farm by-products. This would have resulted to the rapid metal degradation leading to low concentration of the metal in the soil.

Dumping of mobile phones in farm soil is bad, but dumping them in a mangrove forest is worse. The mangrove forest have a lot of ecosystem services such as serving as spawning ground for fishes, shelled and non-shelled organisms like crabs. Mangroves swamps are also used as rice paddies and for the production of other agricultural products. Mangrove forest purifies water and act as water channel to neighboring ground water aquifer, which supply nearby communities. Pollution of the water source will thus have great consequences on the health of humans who feed on the by-products from the forests.

A major finding of this study is the seasonal difference in heavy metal percolation within different soil layers. There was no evidence of an interaction between soil layers and season ($P > 0.05$), which shows that the effect of soil layers was consistent across both seasons. Cumulative heavy metal concentration was greater in wet season than dry season and declined linearly from top to middle layer, but as the wet season set in from middle to bottom layer there was an increase in heavy metal concentration. This means rainfall does not only improve the percolation of heavy metals, but also increase the concentration down the soil profile. This is because liquefaction of the soil via rain fall causes increased accumulation and mobility of metals [33]. This is the aspect cause great public health concern because most people depend on ground water as their major source of drinking water. The concentration of heavy metals at bottom layer is higher in mangrove soil than farm soil. This further shows how vulnerable the mangrove ecosystem is. Mobile phones have caused a breakthrough in communication globally, but they should not be disposed in such a manner as to pose public health problem especially in Africa that has gradually become the dumping ground for phones. They should be managed sustainably to prevent contamination [34, 35]. This can be done through strategic collection, recycling and effective disposal program to prevent public health disaster. There is a seasonal influence of heavy metal increase in sub-surface soil therefore there should be constant monitoring of ground water in farm and mangrove soils at both seasons to forestall increase above acceptable limits.

Acknowledgement

We wish to thank our research assistants Mr. Chimezie Brown for assisting in soil sample collection, and Mr. Chris Okonu for the collection of discarded phones.

References

[1] Directive R (2003). Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment. Official Journal of the European Union, 13, L37.

[2] Network BA (2004) Mobile toxic waste: recent findings on the toxicity of end-of-life cell phones. Basel Action Network.

[3] Breivik K, Armitage JM, Wania F, Jones KC (2014) Tracking the global generation and exports of e-waste. Do existing estimates add up? Environ Sci and Tech 48(15): 8735-8743.

[4] UNEP (2011) Basel Convention on the Control of Transboundary Movements of Hazardous Waste and their Disposal. Protocol on Liability and Compensation for Damage Resulting from Transboundary Movements of Hazardous Wastes and their Disposal: Texts and Annexes. United Nations Environment Programme.

[5] Widmer R, Oswald-Krapf H, Sinha-Khetriwal D, Schnellmann M, Böni H (2005) Global perspectives on e-waste. Environ impact assess Rev 25 (5):436-58.

[6] NPC (2017) Current population of Nigeria. www.npc.org. Accessed 26 May 2017.

[7] Robinson BH (2009) E-waste: an assessment of global production and environmental impacts. Sci of the Total Environ 408(2): 183-191.

[8] Sajjadi SA, Aliakbari Z, Matlabi M, Biglari H, Rasouli SS (2017) Environmental impact assessment of Gonabad municipal waste landfill site using Leopold Matrix. Electronic Physician 9(2): 3714.

[9] Schluep M, Hagelueken C, Kuehr R, Magalini F, Maurer C, Meskers C, et al (2009) Sustainable Innovation and Technology Transfer Industrial Sector Studies: Recycling—From E-Waste to Resources. United Nations Environment Programme and United Nations University/StEP Initiative.

[10] Hischier R, Wäger P, Gauglhofer J (2005) Does WEEE Recycling make sense from an environmental perspective? The environmental impacts of the Swiss take-back and recycling systems for waste electrical and electronic equipment (WEEE). Environ Impact Assess Rev 25: 525-539.

[11] Arensman R (2000) Ready for Recycling? Electronic Business, The Management Magazine for the Electronics Industry.

[12] Freeman MH (1989) Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw-Hill Company, USA.

[13] Schmidt C (2002) E-Junk explosion. Environ Health Perspect 110: A188–A194.

[14] Soderstrom G, Marklund S (2002) PBCDD and PBCDF from incineration of waste-containing brominated flame retardants. Environ Sci Technol 36: 1959–1964.

[15] Jang Y, Townsend T (2003) Leaching of lead from computer printed circuit boards and cathode ray tubes by municipal solid waste landfill leachates. Environ Sci Technol 37: 4778–4784.

[16] Wong M, Wu S, Deng W, Yu X, Luo Q, Leung A, Wong C, Luksemburg W, Wong A (2007) Export of toxic chemicals: a review of the case of uncontrolled electronic-waste recycling. Environ Pollut 149: 131–140.

[17] Gullett BK, Linak, WP, Touati WS. Wasson J, Gatica S King CJ (2007) Characterization of air emissions and residual ash from open burning of electronic wastes during simulated rudimentary recycling operations. J Mater Cycl Waste Manag 9: 69-79.

[18] Dagan R, Dubey B, Bitton G, Townsend T (2007) Aquatic toxicity of leachates generated from electronic devices. Archives of environmental contamination and toxicology, 53(2): 168-173.

[19] Fu J, Zhou Q, Liu J, Liu W, Wang T, Zhang Q, Jiang G (2008) High levels of heavy metals (Oryza sativa L) from a typical E-waste recycling in southeast China and kits potential risk to human health. Chemosphere 71: 1269-1275.

[20] Getter CD, Ballou TG, Koons CB (1985) Effects of dispersed oil on mangroves. Synthesis of a seven-year study. Marine Pollution Bulletin 16: 318-324.

[21] Gupta U, Gupta S (1998) Trace element toxicity relationships to crop production and livestock and human health: implications for management. Commun Soi. Sci Plant Anal 29: 1491–1522.

[22] Jarup L (2003) Hazards of heavy metal contamination. British Med Bull 68 (1): 167-182.

[23] WHO (1993. Evaluation of certain food additives and contaminants (41st report of the joint FAO/WHO expert committee on food additives). WHO Tech. Reports Series No. 837.

[24] Zhao G, Xu Y, Han G, Ling B (2006) Biotransfer of persistent organic pollutants from a large site in China used for the disassembly of electronic and electrical waste. Environ Geochem Health 28 (4): 341–351.

[25] Frazzoli C, Orisakwe OE, Dragone R, Mantovani (2010) A. Diagnostic health risk assessment of electronic waste on the general population in developing countries' scenarios. Environ Impact Assess Rev 30: 388–99.

[26] Grant K, Goldizen FC, Sly PD, Brune MN, Neira M, van den Berg M, Norman RE (2013). Health consequences of exposure to e-waste: a systematic review. The Lancet Global Health, 1(6), e350-e361.

[27] Baars A, Theelen R, Janssen P, Hesse J, van Apeldoorn M, Meijerink M, Verdam L, Zeilmaker M (2001) Re-evaluation of human toxicological maximum permissible risk levels. RIVM Report 711701 025.

[28] Fishbein BK (2002) End-of-life management of electronics abroad, Waste in the wireless world: the challenge of cell phones, INFORM Inc., NewYork, http://www.informinc.org.

[29] Logan M (2010) Biostatistical design and analysis using R: a practical guide. John Wiley and Sons, England.

[30] Quinn GP, Keough KJ (2002). Experimental design and data analysis for biologists.Cambridge University Press, London.

[31] R Development Core Team (2013). R. A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

[32] Widmer R, Oswald-Krapf H, Sinha-Khetriwal D, Schnellmann M, Böni H (2005) Global perspectives on e-waste. Environ impact assess Rev 25 (5):436-58.

[33] Järup L (2003) Hazards of heavy metal contamination. British Med Bull 68(1):167-82.

[34] Ibe AC (1996). The Niger Delta and sea level rise. In sea level rise and coastal subsidence. Springer, Dordrecht, 249-267.

[35] Tam NF, Wong YS (1997). Accumulation and distribution of heavy metals in a simulated mangrove system treated with sewage. Hydrobiologia, 352: 67–75.

[36] Terazono A, Murakami S, Abe N, Inanc B, Moriguchi Y Sakai, Wong MH (2006) Current status and research on e-waste issues in Asia, J Mater Cycles Waste Manage. 8(1): 1-12.

[37] Kuehr R, Magalini F (2013) UNU & WHO Survey on E-Waste and its Health Impact on Children. Final Report. United Nations University Institute for Sustainability and Peace–Sustainable Cycles (UNU-ISP SCYCLE