Resultant effect of pollution on soil properties and conservation of inhabiting fauna

Paul Olaoluwa Odesola, Olalekan Joseph Soyelu, Rasaq Ola Ajibade

Department of Crop Production and Protection, Obafemi Awolowo University, Ile-Ife 220005, Osun State, Nigeria

DOI: 10.29322/IJSRP.10.09.2020.p10512
http://dx.doi.org/10.29322/IJSRP.10.09.2020.p10512

Abstract- This study investigated the impact of soil pollution on the physical and chemical properties of soil, and faunal richness. Soil samples at depths 0-5 cm, 5-10 cm and 10-15 cm were collected from five polluted sites over a period of twelve months (covering the dry and rainy seasons) for analysis in the laboratory. The nature of pollution in each site differed, ranging from domestic sources to agricultural inputs and industrial wastes. Soil samples from a fallowed plot were also collected in a similar manner for comparison of results. Soil fauna were extracted from the soil samples using the Berlese-Tullgren funnel in the laboratory. The organisms were sorted into separate taxonomic groups and members of each group were counted under a dissecting microscope. The physical (texture) and chemical (organic content and pH) properties of soil in polluted sites were determined following standard procedures and obtained values were compared with those from the fallowed plot. Faunal abundance varied significantly among sites ($P < 0.001$), soil depths ($P < 0.01$) and time of sampling ($P < 0.001$). A significantly higher number of soil fauna was found in the fallowed site, 0-5 cm soil depth and during the rainy season. Faunal species diversity was also richer in the fallowed plot in comparison to polluted locations. The soil texture, organic content and pH($CaCl_2$) varied significantly among the six selected locations and their variation from control values was related to fluctuations in faunal abundance. Although metal residues were detected in all experimental sites, they were considered harmless to soil fauna because they were within the permissible range. The adverse effect of soil pollution on faunal conservation and some components of soil quality were highlighted, and erring nations were advised to emulate countries with effective pollution control measures.

Index Terms- Anthropogenic activities, Faunal conservation, Soil pollution, Soil quality, Species diversity

I. Introduction

The soil is a global resource covering the earth and serving as anchorage for plants and habitat for animals both above and below the ground. Thus, the state of health of the soil determines, to a large extent, the welfare of soil biota (Hervé et al., 2020; Kihara et al., 2020). Soil fauna are key players in several supporting and regulating ecosystem services and they comprise a large variety of animals, such as nematodes, earthworms and microarthropods e.g., mites, Collembola, Symphyla, Chilopoda, Pauropoda and enchytraeids (Dairo and Soyelu, 2017). In addition, a large number of meso- and macro-fauna species (mainly arthropods such as beetles, spiders, diplopods, chilopods and pseudoscorpions, as well as snails) live in the uppermost soil layers, the soil surface and the litter layer (Menta, 2012). The advent of industrial civilization with dependence on fossil fuel has increased the rate of soil disturbance significantly. This is in addition to the appreciable level of soil pollution that happens naturally (Rodríguez-Eugenio, 2018). Irrespective of the source of pollution, physical and chemical properties of soil could be altered and this often affects plants and animals associated with the soil adversely.

The main anthropogenic sources of soil pollution are the chemicals used in or produced as by-products of industrial activities, domestic, livestock and municipal wastes (including wastewater), agrochemicals, and petroleum-derived products. These chemicals are released to the environment accidentally, for example from oil spills or leaching from landfills, or intentionally, as is the case with the use of fertilizers and pesticides, irrigation with untreated wastewater, or land application of sewage sludge. Industrialization, wars, mining and intensification in agriculture have left a legacy of contaminated soils around the world (Luo et al., 2009; DEA, 2010; SSR, 2010; Bundschuh et al., 2012; EEA, 2014). As a result of rapid urban expansion, soil has been turned into a sink where solid and liquid wastes are dumped. Unfortunately, it was erroneously considered that once buried and out of sight, the contaminants would not pose any risk to man and his environment and that they would somehow disappear (Swartjes and Siciliano, 2012). This accumulation of wastes, eventually, constitutes the main source of soil pollution (Cachada et al., 2018) harming soil-dwelling organisms severely, thereby reducing faunal biodiversity and hampering major ecosystem services. Principal sources of heavy metals are coal and metal ore mining, chemical manufacturing, petroleum mining and refining, electric power generation, melting and metal refining, metal plating and to some extent domestic sewage (Gazso, 2001). At very low concentrations, heavy metals such as Cu, Ni and Zn are essential to plants and animals serving as components of enzymes, structural proteins, pigments and maintenance of ionic balance of cells (Kosolapov et al., 2004). However, at higher-than-normal levels, heavy metals constitute a serious threat to man and other forms of biological life because of their toxicity, persistence and non-degradable conditions in the environment (Nwuche and Ugoji, 2008; Aina et al., 2009; Mohiuddin et al., 2010).

Soil pollution is a global scourge which requires active cooperation of every nation to overcome. The urgency to conserve soil fauna has continued to grow since the beginning of the millennium as highlighted in international environmental policies such as the Biodiversity Action Plan for Agriculture (*EU 2001*), the Kiev Resolution on Biodiversity (*EU/ECE 2003*) and the EU Soil Thematic Strategy of 2006. Unfortunately, most developing countries still have inadequately formulated and poorly implemented waste management guidelines which are not able to complement efforts of compliant nations. This study was, therefore, carried out to highlight the potential danger of five possible sources of soil pollution that are commonly encountered in a representative country, Nigeria. The relationship between soil pollution and faunal diversity, species abundance and soil properties were established. It is expected that results from this and other related studies would be found useful by appropriate authorities to initiate necessary legislative actions in erring nations.

II. MATERIALS AND METHODS

1. Collection of soil samples and extraction of fauna

Soil samples were collected from five sites (Table 1) that were purposely selected for specific form of pollution while a fallowed plot was chosen for comparison of results. One of the sites had been continuously cultivated with maize (*Zea mays* L.) for over ten years with frequent NPK and Urea fertilizer application while another site had been similarly cultivated with cowpea (*Vigna unguiculata* (L.) Walp.) that required frequent pesticide application. Soil samples were collected monthly from the six sites over a period of twelve months using standard procedures and equipment. In each site, a 15 cm × 15 cm micro plot was marked out each month from which soil samples were collected using a soil auger at 0-5 cm, 5-10 cm and 10-15 cm soil depths. Each soil sample was carefully sealed in a polythene bag and taken to the laboratory. Soil fauna were extracted from collected samples using the Berlese-Tullgren funnel as described by Dairo and Soyelu (2017). The soil samples were placed in the funnel for 72 h and escaping soil fauna were collected in basal plastic vials containing 70% ethanol. Established identification keys were used to sort the extracted organisms into different taxonomic groups and members of each group were counted under a stereo microscope.

Table 1: Description of sites selected for the study in Ile-Ife, Osun State, Nigeria

No.	Nature of site	Location	Coordinate	Pollutant	Distance from the reference point
1	Fallowed plot	T&RF, OAU	7°33’8”N 4°33’25”E (290 m asl)	-	11.0 km
2	Frequent pesticide application	T&RF, OAU	7°29’0”N 4°32’12”E (256 m asl)	Pesticides	10.1 km
3	Frequent fertilizer application	T&RF, OAU	7°33’11”N 4°33’23”E (290 m asl)	Fertilizers	10.4 km
4	OAU central dumpsite	Tonkere Road	7°33’9”N 4°32’58”E (287 m asl)	Municipal waste	1.1 km
5	Auto-mechanic workshop	Ondo Road	7°29’1”N 4°32’12”E (253 m asl)	Spent oil	4.2 km
6	Scrap iron and steel smelting industry	Ibadan Road	7°29’47”N 4°28’33”E (256 m asl)	Metal deposit	6.0 km

The Faculty of Agriculture Building on the University campus was taken as reference point in describing distances separating selected sites. T&RF: Teaching and Research Farm; OAU: Obafemi Awolowo University; asl: elevation above sea level.

2. Physicochemical properties of collected soil samples

2.1 Soil texture

The texture of soil collected from each experimental site was determined at the Soil Testing Laboratory, Faculty of Agriculture, Obafemi Awolowo University using the hydrometer method. To 51 g sieved, air-dried soil sample was added 100 ml 5% sodium hexametaphosphate (Calgon) with 100 cm^3 distilled water. The mixture was stirred with a rod and left to set for 30 min. The suspension was then stirred for 15 min using the Stuart flask shaker multimix machine after which it was transferred into a glass measuring cylinder and made up to the 1000 ml mark with distilled water. A plunger was used to agitate the content of the cylinder to ensure that all particles were in the suspension. The hydrometer was lowered slowly into the suspension until it floated and the first reading on the hydrometer was taken after 40 s, followed by the second reading after 3 h. The temperature of the suspension was also taken at each hydrometer reading. The first reading measured percentage of silt and clay in suspension while the second reading determined percentage of clay alone. Results were corrected to a temperature of 20℃; for every degree above 20℃, 0.36 was added to hydrometer reading before computation and for every degree below 20℃, 0.36 was subtracted. Hydrometer reading of a blank was also taken for comparison of results; the blank consisted of only 100 ml 5% Calgon made up to 1000 ml mark with distilled water.

Given: Hydrometer reading of suspension at 40 s $= H_1$
Hydrometer reading of blank at 40 s $= B_1$
Temperature at 40 s $= T_1$
Hydrometer reading of suspension at 3 h $= H_2$
Hydrometer reading of blank at 3 h $= B_2$
Temperature at 3 h $= T_2$
% Sand $= 100 - 2[H_1 - B_1 + 0.36(T_1 - 20)]$
% Clay $= 2(H_2 - B_2) + 0.36(T_2 - 20)$
% Silt $= 100 - (\% \text{ sand} + \% \text{ clay})$

The textural class of each soil sample was determined by inputting obtained values (i.e. percentage sand, clay and silt) into Textural Triangle, a mobile application developed by the USDA.

2.2 Organic content

The organic carbon (OC) and organic matter (OM) contained in collected soil samples were determined following standard procedures. To 1.0 g air-dried soil sample was added 10 ml 0.5 M ammonium ferrous sulphate solution. Concentrated H_2SO_4 (20 ml) was added to the mixture and the flask was allowed to stand for 20-30 min. The resulting suspension was diluted with 200 ml distilled water; 10 ml 85% H_3PO_4 and 0.2 g NaF were added with 1 ml diphenylamine indicator to show the endpoint. The colour of the solution at the beginning was dark green due to Cr^{3+}, shifting to turbid blue as the titration proceeded and changed sharply to a bright green at the end-point.

$$\text{Organic carbon (\%)} = \frac{(\text{Blank} - \text{Titre}) \times 0.5}{0.5} \times 0.39; \text{ Organic matter (\%)} = \text{OC} \times 1.72$$

2.3 Soil pH

The soil pH in $CaCl_2$ was determined following the method of Hendershot et al. (2007). Ten grams (10 g) of each soil sample was measured into a pH cup and 20 ml 0.01 M $CaCl_2$ was added. The suspension was stirred intermittently for 30 min and left to stand for about 1 h. A combination electrode was immersed into the clear supernatant and the pH was recorded once the reading was constant.

2.4 Heavy metal determination

For extraction of heavy metals, 5 g soil samples were measured into conical flasks after which 50 ml HCl was added. Mechanical shaker was used for 30 min and filter paper was used to extract heavy metals into plastic bottles. Concentrations of heavy metals in extracted samples were determined at the Agronomy Laboratory, University of Ibadan, Oyo State.

3. Statistical analysis

The monthly faunal population data were natural log-transformed before analysis of variance (ANOVA) was carried out using Statistical Analysis Software (SAS) v. 9.0 and mean values were separated using Tukey's Honestly Significant Difference (HSD) test at 0.05 level of probability. Data for organic content of soil samples were also subjected to ANOVA and mean values were separated using the $LSD_{0.05}$ test.

III. RESULTS AND DISCUSSION

A. Species composition and relative abundance of soil fauna

The sampling site ($P < 0.001$), soil depth ($P < 0.01$) and period of sampling ($P < 0.001$) had significant effect on population of soil fauna (Table 2). Population of soil-dwelling organisms is known to vary with land use (Silva et al., 2018; Nanganoa et al., 2019) and degree of soil pollution (Austruy et al., 2016; Kanwal and Rana, 2020). Generally, faunal abundance and species richness are higher in fallowed soils but decrease with increasing pollution (Xie et al., 2016; Dairo and Soyelu, 2017). This trend was reported in the present study with significantly lower soil fauna population at sites polluted with chemical fertilizers, municipal waste, spent oil and metal deposits (Table 3). A combination of toxicity, alteration of faunal behaviour by pollutants and interference with physiological processes has been offered as possible explanation for depletion of fauna in polluted soils (Odesola, 2020).

Soil depth is one of the natural factors that affect faunal distribution (Will et al., 2010, Eilers et al., 2012), and similar to previous reports (Baldrian et al., 2012; Ko et al., 2017), it had a significant inverse relationship with faunal population in the current study. Occupation of the first few centimeters of soil by a higher number of fauna appears to be an adaptive feature as it becomes increasingly difficult for them to dig deeper into the soil. This might also explain why the faunal distribution pattern remains unchanged despite contamination in some soils (Goberna et al., 2005). Reduction in faunal population with increasing depth has also been attributed to changes in edaphic factors such as pH, moisture contents, quality and quantity of organic matters, and oxygen concentrations throughout the soil depth profile (Ko et al., 2017).

There are two seasons in Nigeria but the duration of each varies between the southern and northern parts of the country. In southern Nigeria where this study was carried out, the rainy season starts in mid-March and extends to mid-October while the dry season covers late October to early March with peak dry conditions between early December and late February (CTN, 2011). A significantly lower faunal population was recorded during the dry season (Fig. 1) and the lowest recorded between January and February (27-28 individuals) coincided with the peak period of dry season for 2019. This peak period was characterized by high temperature (27.25℃) and low relative humidity (70.33%) while July-August marked by a significant increase in faunal population had a lower temperature (26.86℃) and higher moisture level (90.48%). Adejuyigbe (1989) recorded low numbers of soil arthropods when there was low soil moisture content and high soil temperature while Badejo (1990), working on abundance of springtails, reported a positive correlation between soil moisture content and abundance of soil-dwelling Collembola on one hand with a negative correlation between soil temperature and number of Collembola on the other. However, Choi et al. (2006) identified soil moisture content as the most important factor determining distribution of soil organisms. In order to escape drought, soil animals either move deeper into the soil or disperse to moist patches (Xiang et al., 2008).

Table 2: Analysis of variance showing effect of location, soil depth and period of sampling on population of fauna in polluted soils

Source of variation	df	Sum of squares	Mean square	F value
Sampling site	5	4250.98	850.19***	11.38
Soil depth	2	706.93	353.46**	4.73
Time of sampling	11	5768.76	524.43***	7.02
Replication	2	4.32	2.16	0.01
Error	627	147120.43	234.64	
Total	647	157851.42		

**, ***: $P < 0.01$ and $P < 0.001$, respectively

Table 3: Average number of fauna extracted from soil samples collected from different sites and soil depths

Fallowed plot	Frequent pesticide application	Frequent fertilizer application	OAU dumpsite	Mechanic workshop	Smelting industry
175.00a	162.22a	85.56c	128.89b	80.56c	53.89d

Soil depth		
0-5 cm	5-10 cm	10-15 cm
133.89a	118.89b	90.28c

Soil fauna play vital roles in biological processes such as respiration, mineralization, litter decomposition, soil structure maintenance and community energetics (Ruan et al., 2005; Huhta, 2007; Briones, 2014) which are indices of soil health. As a result of these sensitive processes, soil fauna have been widely recommended as bioindicators (Bileva et al., 2014; Ertiban, 2019) and a significant change in their population or total absence in response to soil pollution usually signals caution. A positive correlation exists between faunal biomass and rate of soil processes (Ruan et al., 2005). Soil fauna belonging to eighteen (18) taxonomic groups were extracted and counted in the present study; while all the groups were present in fallowed soil samples, some taxonomic groups were not found at polluted sites (Table 4). Three taxonomic groups were absent in soil samples taken from the site with frequent fertilizer application while four groups were absent in soil samples from the mechanic workshop and smelting industry. Their absence was indicative of their intolerance to soil pollutants and this had adverse effect on biological processes that they mediate in the soil (Gillet and Ponge, 2003).

B. Physical and chemical properties of soil samples

The textural characterization, organic content and pH($CaCl_2$) of experimental soil samples are presented in Table 5. The soil samples were mostly sand along with varying amounts of clay and silt. The proportion of sand, silt and clay determines the extent to which pollutants are mobile or available within the soil (van Deuren et al., 2002; Hanson et al., 2017). This in turn affects remediation efficiency (Falciglia and Vagliasindi, 2015; Koul and Taak, 2018). Most organic and inorganic pollutants tend to bind, either chemically or physically, to the fine (i.e., clay and silt) fraction of a soil, thereby, making them less amenable to remediation interventions. The removal kinetics of pollutants increases significantly with an increasing sandy fraction. However, too much sand in the soil will inhibit the soil's ability to hold nutrients and provide adequate moisture needed for healthy growth (Parikh and James, 2012; Stack, 2016).

ISSN 2250-3153

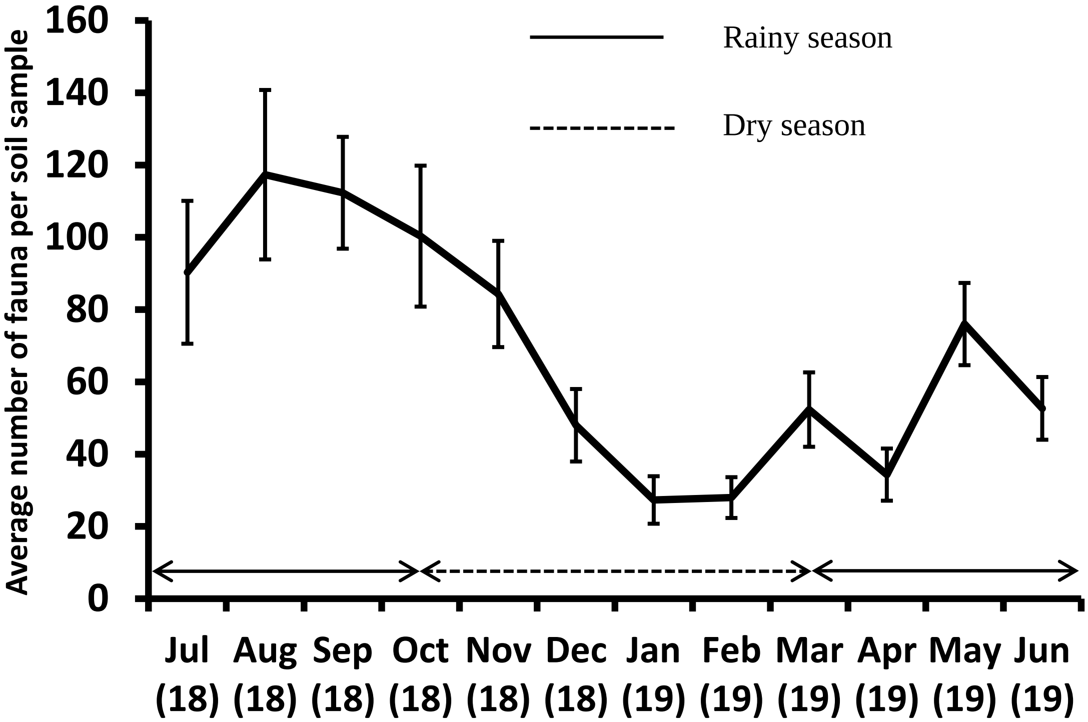

Figure 1: Relative abundance of soil fauna in experimental soil samples over a period of twelve months

Table 4: Different categories of soil fauna extracted from the six experimental sites

Taxonomic group	Fallowed plot	Frequent pesticide application	Frequent fertilizer application	OAU dumpsite	Mechanic workshop	Smelting industry
Acari	+	+	+	+	+	+
Araneae	+	+	−	+	−	+
Chilopoda	+	+	+	+	+	+
Coleoptera	+	+	+	+	+	+
Collembola	+	+	+	+	+	+
Diplopoda	+	+	+	+	−	+
Diplura	+	+	+	+	+	+
Diptera	+	+	+	+	+	+
Hemiptera	+	+	+	+	+	+
Hymenoptera	+	+	+	+	+	+
Isopoda	+	+	+	+	+	–
Isoptera	+	+	+	+	+	+
Lepidoptera	+	+	+	–	−	+
Lumbricidae	+	+	+	+	+	–
Opiliones	+	+	+	+	+	+
Orthoptera	+	–	–	+	+	+
Protura	+	+	+	+	+	–
Pseudoscorpiones	+	+	−	+	–	–

+, − : present and absent, respectively

Table 5: The textural properties, organic content and pH of examined soil samples

Nature of site	Textural characterization				Organic content		$pH(CaCl_2)$
	Sand (%)	Silt (%)	Clay (%)	Class	OC (%)	OM (%)	
Fallowed plot	59	17	24	Sandy clay loam	3.354	5.769	5.44
Frequent pesticide application	79	9	12	Sandy loam	0.897	1.545	3.80
Frequent fertilizer application	81	7	12	Sandy loam	0.741	1.275	3.92
OAU dumpsite	69	17	14	Sandy loam	0.663	1.140	7.60
Mechanic workshop	59	17	24	Sandy clay loam	3.159	5.433	5.90
Smelting industry	89	1	10	Loamy sand	0.312	0.537	7.78
				$LSD_{0.05}$	0.127	0.284	

OC: Organic carbon; OM: Organic matter

The organic matter (OM) and organic carbon (OC) are components of the soil organic content that was quantified in this study. Both components were significantly lower in polluted sites and the depletion was most severe at the smelting industry with predominant metal deposit. The soil OM serves as food for the inhabiting fauna, thus, encouraging biodiversity and build-up of faunal biomass (van Noordwijk et al., 1993) as evident in this study. The OM also improves overall health of the soil by enhancing soil structure, moisture holding capacity, nutrient availability and activity of soil organisms (Bot and Benites, 2005; Huhta, 2007; Frouz, 2018). A healthy soil contains a large number and variety of organisms which interact to provide a wide variety of ecosystem services that favour agriculture (Griffiths et al., 2019). The soil OC also plays an important role in the C cycle which is crucial for supporting ecosystem services (Schmidt et al., 2011).

The soil pH varied widely (3.8-7.8) among experimental sites, being < 4 in soil samples from sites with frequent pesticide and fertilizer applications. Fertilizers are major sources of hydrogen ions in the soil and pH values as low as 1.5 can be found in a zone immediately around a fertilizer band (Harter, 2007). Both extremely acidic (3.5-4.4) and extremely alkaline (> 9.5) conditions are generally detrimental to animal life; an indication that a critical review of types and frequency of application of fertilizers and pesticides at the Teaching and Research Farm is necessary. Nevertheless, tolerance of soil fauna to acid pH is highly variable, even among closely related species. Generally, microarthropods and Enchythraeidae have maximum abundances in acid soils (pH < 5) whereas nematodes and litter-dwelling earthworms prefer slightly acid pH (5-6). On the other hand, soil-dwelling earthworm species prefer pH of 6-7 (Lavelle et al., 1995).

Modern farming, industrialization, and increased vehicular use have led to high concentrations of heavy metals such as Pb, Ni, Cr, Cd, Al, Hg, and Zn (Atafar et al., 2010) and they are usually toxic in the environment when present beyond permissible levels. Although heavy metal residues were present in all the sites (either naturally or as a result of human activities) (Table 6), they were considered safe to soil fauna because the levels were within permissible range.

Table 6: Heavy metal residues in soil samples collected from different experimental sites

Nature of site	Iron	Copper	Zinc	Chromium	Cadmium	Lead	Nickel
	mg/l						
Fallowed plot	1.31	0.41	7.01	0.00	0.00	0.15	0.12
Frequent pesticide application	15.32	1.10	14.41	0.00	0.02	1.04	0.25
Frequent fertilizer application	2.44	0.25	0.61	0.00	0.00	0.28	0.15
OAU dumpsite	9.11	1.81	10.81	0.00	0.21	1.89	0.21
Mechanic workshop	21.26	0.96	16.90	0.00	0.04	0.80	0.31
Smelting industry	99.10	13.00	137.51	0.29	0.19	10.40	1.55
*Maximum permissible level	50,000.00	100.00	300.00	100.00	3.00	100.00	50.00

* Source: Chiroma et al. (2014).

IV. CONCLUSION

The obtained results showed that pollution affected physicochemical properties of soil adversely and threatened survival of soil fauna. It is, therefore, very crucial that closer attention is given to environmental impact assessment of human activities in order to ensure wholesome soil and conservation of soil-dwelling organisms. In addition, nations with poor records of pollution control should adopt some of the effective measures implemented by successful ones. For instance, the Integrated Pest Management policies which have been mandated in the European Union and other similar practices being promoted in many parts of the world could be embraced. The *Intergovernmental Technical Panel on Soil* through the FAO's *Global Soil Partnership* has also developed some guidelines (Hammond, 2017) which could be adopted for sustainable soil management.

ACKNOWLEDGMENT

The authors appreciate Dr. A.I. Ajao of the Atmospheric Physics Research Group, Department of Physics, Obafemi Awolowo University for providing the meteorological data used in this study.

REFERENCES

Adejuyigbe, T.A. **(**1989**)**. The effect of 3-cyclohexyl-6-(dimetyl-amino)-1-methl-1,3,5- triazine-2,4(1h,3h)-dione (velpar) on soil surface and soil inhabiting arthropods of a cultivated plot in the Teaching and Research Farm of Obafemi Awolowo University**,** Ile-Ife. Obafemi Awolowo University, Faculty of Agriculture, Ile-Ife, 58 pp.

Aina, M., Matejka, G., Mama, D., Yao, B., Moudachirou, M. (2009). Characterization of stabilized waste: evaluation of pollution risk. *International Journal of Environmental Science and Technology*, 6, 1, 159-165.

Atafar, Z., Mesdaghinia, A., Nouri, J., Homaee, M., Yunesian, M., Ahmadimoghaddam, M., Mahvi, A.H. (2010). Effect of fertilizer application on soil heavy metal concentration. *Environmental Monitoring and Assessment*, 160, 83-89.

Austruy, A., Laplanche, C., Mombo S., Dumat, C., Deola, F., Gers, C. (2016). Ecological changes in historically polluted soils: metal(loid) bioaccumulation in microarthropods and their impact on community structure. *Geoderma*, 271, 181-190.

Badejo, M.A. (1990). Seasonal abundance of springtails in two contrasting environments. *Biotropica*, 23, 4, 382-390.

Baldrian, P., Kolarik, M., Stursova, M., Kopecky, J., Valaskova, V., Vetrovsky, T., Zifcakova, L., Snajdr, J., Ridl, J., Vlcek, C., Voriskova, J. (2012). Active and total microbial communities in forest soil are largely different and highly stratified during decomposition. *ISME Journal*, 6, 248-258.

Bileva, T., Stefanova, V., Haytova, D. (2014). Assessment of nematodes as bioindicators of soil health in agroecosystems. *Turkish Journal of Agricultural and Natural Sciences*, Special Issue: 1, 568-573.

Bot, A., Benites, J. (2005). Creating drought-resistant soil. In: The importance of soil organic matter: key to drought-resistant soil and sustained food production. FAO Soils Bulletin 80. FAO, Rome. http://www.fao.org/3/a0100e/a0100e08.htm

Briones, M.J.I. (2014). Soil fauna and soil functions: a jigsaw puzzle. *Frontiers in Environmental Science*, 2, 7. doi: 10.3389/fenvs.2014.00007

Bundschuh, J., Litter, M.I., Parvez, F., Román-Ross, G., Nicolli, H.B., Jean, J.-S., Liu, C.-W., López, D., Armienta, M.A., Guilherme, L.R.G., Cuevas, A.G., Cornejo, L., Cumbal, L., Toujaguez, R. (2012). One century of arsenic exposure in Latin America: a review of history and occurrence from 14 countries. *The Science of the Total Environment*, 429, 2-35.

Cachada, A., Rocha-Santos, T., Duarte, A.C. (2018). Soil and pollution: an introduction to the main issues. In: Soil Pollution, Academic Press, Cambridge, 1-28. https://www.sciencedirect.com/science/article/pii/B9780128498736000017).

Chiroma, T.M., Ebewele, R.O., Hymore, F.K. (2014). Comparative assessment of heavy metal levels in soil, vegetables and urban grey waste water used for irrigation in Yola and Kano. *International Refereed Journal of Engineering and Science***,** 3, 2, 1-9.

Choi, I.W., Moorhead, L.D., Neher, A.D., Ryoo, I.M. (2006). A modelling study of soil temperature and moisture effects on population dynamics of *Paronychiurus kimi* (Collembola: Onychiuridae). *Biology and Fertility of Soils*, 43, 69-75.

CTN, 2011. Nigeria: climate. https://web.archive.org/web/20110511223039/http://www.cometonigeria.com/nigeria/climate.html

Dairo, O.S., Soyelu O.J. (2017). Consequences of prolonged agronomic practices: faunal composition and abundance in cultivated and fallowed soils. *International Journal of Conservation Science*, 8, 3, 509-518.

DEA (2010). Framework for the management of contaminated land. Department of Environmental Affairs, Republic of South Africa. http://sawic.environment.gov.za/documents/562.pdf

EEA (2014). Progress in management of contaminated sites. European Environment Agency. https://www.eea.europa.eu/data-and-maps/indicators/progress-in-management-of-contaminated-sites/progress-in-management-ofcontaminated-1

Eilers, K.G., Debenport, S., Anderson, S., Fierer, N. (2012). Digging deeper to find unique microbial communities: the strong effect of depth on the structure of bacterial and archaeal communities in soil. *Soil Biology and Biochemistry*, 50, 58-65.

Ertiban, S.M. (2019). Soil fauna as webmasters, engineers and bioindicators in ecosystems: implications for conservation ecology and sustainable agriculture. *American Journal of Life Sciences*, 7, 1, 17-26.

Falciglia, P.P., Vagliasindi, F.G.A. (2015). Remediation of hydrocarbon polluted soils using 2.45 GHz frequency-heating: influence of operating power and soil texture on soil temperature profiles and contaminant removal kinetics. *Journal of Geochemical Exploration*, 151, 66-73.

Frouz, J. (2018). Effects of soil macro- and mesofauna on litter decomposition and soil organic matter stabilization. *Geoderma*, 332, 161-172.

Gazso, L.G. (2001). The key microbial processes in the removal of toxic metals and radionuclides from the environment: a review. *Central European Journal of Occupational and Environmental Medicine*, 7, 3, 178-185.

Gillet, S., Ponge, J-F. (2003). Changes in species assemblages and diets of Collembola along a gradient of metal pollution. *Applied Soil Ecology*, 22, 2, 127-138.

Goberna, M., Insam, H., Klammer, S., Pascual, J.A., Sánchez, J. (2005). Microbial community structure at different depths in disturbed and undisturbed semiarid Mediterranean forest soils. *Microbial Ecology*, 50, 315-326.

Griffiths, B., McDonald, C., Lawrie, M-J. (2019). Soil biodiversity and soil health. Farm Advisory Service Technical Note 721. https://www.fas.scot/downloads/tn721-soil-biodiversity-and-soil-health/

Hammond, T. (2017). Tackling the growing challenge of soil pollution. UNEP Ecosystems and Biodiversity Story. https://www.unenvironment.org/news-and-stories/story/tackling-growing-challenge-soil-pollution

Hanson, B., Cross, A., Bond, C., Jenkins, J. (2017). Pesticide binding affinity fact sheet; National Pesticide Information Center, Oregon State University Extension Services. npic.orst.edu/factsheets/bindingaffinity.html.

Harter, R.D. (2007). Acid soils of the tropics. ECHO Technical Note. http://courses.umass.edu/psoil370/Syllabus-files/Acid_Soils_of_the_Tropics.pdf

Hendershot, W.H., Lalande, H., Duquette, M. (2007). Soil reaction and exchangeable acidity. In: *Soil sampling and methods of analysis*. 2nd Edition, Kindle Edition, CRC Press, Boca Raton, Florida, 173-178.

Hervé, M.E.T, Renault, M., Plaas, E., Schuette, R., Potthoff, M., Cluzeau D., Nicolai, A. (2020). From practices to values: farmers' relationship with soil biodiversity in Europe. *Sociologia Ruralis*, 60, 3, 596-620. https://doi.org/10.1111/soru.12303

Huhta, V. (2007). The role of soil fauna in ecosystems: a historical review. *Pedobiologia*, 50, 489-495.

Kanwal, S., Rana, N. (2020). Use of sewage wastewater in agriculture and its effects on soil macrofauna. *Pakistan Journal of Agricultural Science*, 57, 3, 655-663.

Kihara, J., Bolo, P., Kinyua, M., Nyawira, S.S., Sommer, R. (2020). Soil health and ecosystem services: lessons from sub-Sahara Africa (SSA). *Geoderma*, https://doi.org/10.1016/j.geoderma.2020.114342

Ko, D., Yoo, G., Yun, S-T, Jun, S-C, Chung, H. (2017). Bacterial and fungal community composition across the soil depth profiles in a fallow field. *Journal of Ecology and Environment*, 41, 34. DOI: 10.1186/s41610-017-0053-0

Kosolapov, D.B., Kuschk, P., Vainshtein, M.B., Vatsourina, A.V., Wiebner, A., Kasterner, M., Miler, R.A. (2004). Microbial processes of heavy metal removal from carbon deficient effluents in constructed wetlands. *Engineering in Life Sciences*, 4, 5, 403-411.

Koul, B., Taak, P. (2018). Chemical methods of soil remediation. In: *Biotechnological strategies for effective remediation of polluted soils*. 1st Edition, Springer, Singapore, 77-84.

Lavelle, P., Chauvel, A., Fragoso, C. (1995). Faunal activity in acid soils. In: *Plant-soil interactions at low pH: principles and management*. Proceedings of the Third International Symposium on Plant-Soil Interactions at Low pH. Brisbane, Queensland, Australia, 12-16 September, 1993. Kluwer Academic Publishers, Netherlands, 201-211.

Luo, Y., Wu, L., Liu, L., Han, C., Li, Z. (2009). Heavy metal contamination and remediation in Asian agricultural land. Paper presented at MARCO Symposium, Japan.

Menta, C. (2012). Soil fauna diversity – function, soil degradation, biological indices, soil restoration. In: *Biodiversity conservation and utilization in a diverse world*. IntechOpen, London, 59-94.

Mohiuddin, K.M., Zakir, H.M., Otomo, K., Sharmin, S., Shikazono, N. (2010). Geochemical distribution of trace metal pollutants in water and sediments of downstream of an urban river. *International Journal of Environmental Science and Technology*, 7, 1, 17-28.

Nanganoa, L.T., Okolle, J.N., Missi, V., Tueche, J.R., Levai, L.D., Njukengafac, J.N. (2019). Impact of different land-use systems on soil physicochemical properties and macrofauna abundance in the humid tropics of Cameroon. *Applied and Environmental Soil Science*, 2, 1-9.

Nwuche, C.O., Ugoji, E.O. (2008). Effects of heavy metal pollution on the soil microbial activity. *International Journal of Environmental Science and Technology*, 5, 3, 409-414.

Odesola, P.O. (2020). Detrimental effect of soil contaminants on lower organisms using the maize weevil, *Sitophilus zeamais* Motschulsky, as a model. Obafemi Awolowo University, Faculty of Agriculture, Ile-Ife, Nigeria, 65 pp.

Parikh, S.J., James, B.R. (2012). Soil: the foundation of agriculture. *Nature Education Knowledge*, 3, 10, 2

Rodríguez-Eugenio, N., McLaughlin, M., Pennock, D. (2018). Soil Pollution: a hidden reality. FAO, Rome, 142 pp.

Ruan, H., Li, Y., Zou, X. (2005). Soil communities and plant litter decomposition as influenced by forest debris: variation across tropical riparian and upland sites. *Pedobiologia*, 49, 529-538.

Schmidt, M.W., Torn, M.S., Abiven, S., Dittmar, T., Guggenberger, G., Janssens, I.A., Kleber, M., Kögel-Knabner, I., Lehmann, J., Manning, D.A., Nannipieri, P., Rasse, D.P., Weiner, S., Trumbore, S.E. (2011). Persistence of soil organic matter as an ecosystem property. *Nature*, 478, 49-56.

Silva, R.A., Siqueira, G.M., Costa, M.K.L., Filho, O.G., Silva, E.F.F. (2018). Spatial variability of soil fauna under different land use and managements. *Revista Brasileira de Ciência do Solo*. 42:e0170121. https://doi.org/10.1590/18069657rbcs20170121

SSR (2010). Soil contamination in West Africa. Shift Soil Remediation, UK. https://www.scribd.com/doc/71599035/SoilContamination-in-West-Africa

Stack, L.B. (2016). Soil and plant nutrition: a gardener's perspective. Master Gardener Volunteers Manual, Cooperative Extension, The University of Maine. https://extension.umaine.edu/gardening/manual/soils/soil-and-plant-nutrition/

Swartjes, F.A., Siciliano, S.D. (2012). Dealing with contaminated sites: from theory towards practical application. *Soil Science Society of America Journal*, 76, 2, 748. https://doi.org/10.2136/sssaj2011.0004br

van Deuren, J., Lloyd, T., Chhetry, S., Liou, R., Peck, J. (2002). *Remediation technologies screening matrix and reference guide*. 4th Edition, Platinum International, Inc., USA. Available online: https://frtr.gov/matrix2/top_page.html

van Noordwijk, M., de Ruiter, P.C., Zwart, K.B., Bloem, J., Moore, J.C., van Faassen, H.G., Burgers, S.L.G.E. (1993). Synlocation of biological activity, roots, cracks and recent organic inputs in a sugar beet field. *Geoderma*, 56, 265-276.

Will, C., Thurmer, A., Wollherr, A., Nacke, H., Herold, N., Schrumpf, M., Gutknecht, J., Wubet, T., Buscot, F., Daniel, R. (2010). Horizon-specific bacterial community composition of German grassland soils, as revealed by pyrosequencing-based analysis of 16S rRNA genes. *Applied and Environmental Microbiology*, 76, 6751-6759.

Xiang, S-R., Doyle, A., Holden, P.A., Schimel, J.P. (2008). Drying and rewetting effects on C and N mineralization and microbial activity in surface and subsurface California grassland soils. *Soil Biology and Biochemistry*, 40, 9, 2281-2289.

Xie, Y., Fan, J., Zhu, W., Amombo, E., Lou, Y., Chen, L., Fu, J. (2016). Effect of heavy metals pollution on soil microbial diversity and bermudagrass genetic variation. *Frontiers in Plant Science*, 7, 755. doi: 10.3389/fpls.2016.00755

AUTHORS

Paul Odesola – M.Sc., Department of Crop Production and Protection, odesolapaulo@gmail.com
Olalekan Soyelu – Ph.D., Department of Crop Production and Protection, jlekan2001@yahoo.co.uk
Rasaq Ajibade – B.Sc., Department of Crop Production and Protection, ajibaderasaq@gmail.com

Correspondence Author – Olalekan Soyelu, jlekan2001@yahoo.co.uk, soyelu@oauife.edu.ng, +234 706 325 0322.