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A Review of the Role of Anthropogenic Effects on Microorganisms in Soil

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Authors' contributions

This work was carried out in collaboration between all authors. Author WMP designed the study and wrote the first draft of the manuscript. All authors managed the literature searches. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Anthropogenic activities are progressively releasing pollutants to the soil, including heavy metals and other pollutants emanating from industries and overpopulated human settlements. Pollution by heavy metals and other physicochemical materials is gradually becoming an area of concern, especially in sub-Saharan Africa. The paper reviews the effects of anthropogenic activities on soil ecosystem integrity including physicochemical parameters as well as biological parameters in the soil. The review focuses on impact of the application of fertilisers in soil and seasonal influence in levels of physicochemical parameters in soil ecosystem as well as microorganism population shifts in soils affected by pollution as a need to alleviate soil contamination. The review established gaps to further understanding of the relationship between soil physicochemical parameters, soil biological parameters and influence of seasonality in the resilience of the soil ecosystem as a way to foster the integrity of soil.

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1. INTRODUCTION

The concept framework (Fig. 1) outlines a structure for understanding how urbanisation, industrialisation and agricultural activities impact on soil ecosystem. The framework highlights the effects of urbanisation, industrialisation and agricultural activities on soil ecosystem integrity. Urbanisation is characterised with increased human population, industrialisation is characterised by increased emissions and agricultural activities involve overuse or misuse of land. Jointly, urbanisation, industrialisation and agricultural activities produce wastes that end up contaminating the environment, consequently leading to acidification, eutrophication, siltation, accumulation of toxic substances, loss of biodiversity and loss of ecosystem processes.

Fig. 2 depicts pathways between soils and both abiotic and biotic components in the environment and shows how soil contaminants find their way to human diet. Polluted soils are interlinked in various ways to human diet. Crops that are planted in contaminated soils are likely to be contaminated in turn. Runoff from polluted soils contaminates water bodies including rivers, lakes and the sea where animals and humans abstract water for consumption. These calls for essence to sporadically determine levels of pollution of soils in order to ensure that adequate measures are put in place to ensure that wastes are disposed of in an amicable manner hence ensure

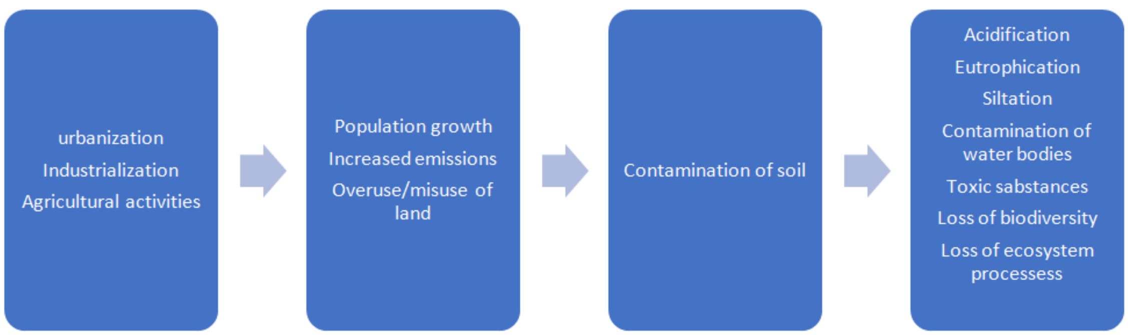

Fig. 1. Showing effects of urbanisation, industrialisation and agricultural activities on soil ecosystem integrity

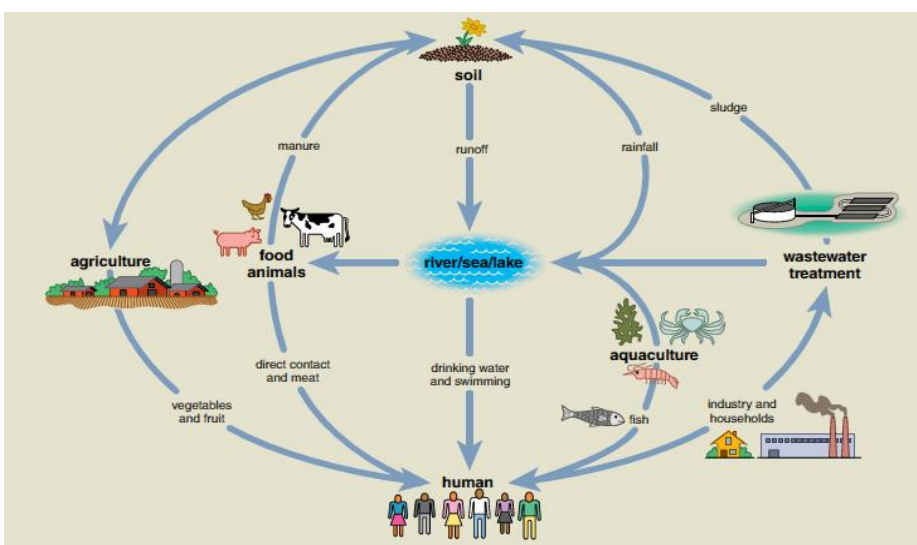

Fig. 2. Showing linkage between polluted soils and human health

soil ecosystem integrity is maintained. This study describes levels of pollution in soils and determines the impact of pollution on biodiversity and distribution of soil microorganisms in the soil.

2. BACKGROUND INFORMATION

Pollution is the introduction of foreign material into an environment thereby compromising the integrity of that environment. According to World Health Organization (WHO), mismanagement of chemicals and wastes cause pollution of air, water and soil. Various advanced effects have accompanied oil production activities in Niger Delta region after discovery crude oil in 1950s. Discovery of crude oil was accompanied with increased pollution associated with population and industrialization. Hence the native human inhabitants and other biotic communities have been directly or indirectly affected by pollution from oil production activities [1], water and soil ecosystems [2,3] and air [2,3]. Pollution is a major threat to biodiversity and ecosystem integrity in the environment [4]. In addition, it is a risk factor to human health and can cause heart diseases, stroke, cancer, infections, developmental disabilities and neurological disabilities among others. Polycyclic aromatic hydrocarbons (PAHs) are carcinogenic and can induce malignant tumors [5].

Among economic activities in Rivers State, Niger delta include; exploration, drilling, processing of crude oil and farming. Intensification of economic activities has increased chances of contamination of the environment with petroleum hydrocarbons. A vast number of additives are used in the exploration and processing of oil and can be sources of contamination of the environment. Such petroleum contaminants are classified as priority pollutants [6]. These pollutions can either occur onshore or offshore. Petroleum hydrocarbons have aliphatics, monoaromatics, polyaromatics, resins, (Benzene, Toluene, Ethylbenzene and Xylenes) BTEX, PAHs and many additives used in the process. Most of the additives are teratogenic, carcinogenic, hemotoxic, anoxic, and metabolic retarders which can cause acute or chronic effects [7]. Microorganisms have been reported to evolve and adapt to these environments by development of mechanisms of degradation of these hydrocarbons [8]. Degradation of hydrocarbons is tough, persistent and can cause irreversible changes to the environment.

3. CHEMICAL SOIL HEALTH INDICATORS

Industrialization, urbanization and agricultural activities are progressively releasing pollutants to soil, including heavy metals. Pollution by heavy metals is gradually becoming an area of concern especially in sub-Saharan Africa, including Nigeria [9]. The major heavy metals of concern include; Arsenic, Lead, Zinc, Cadmium, Nickel, Copper and Mercury [10]. Heavy metals occur naturally in undisturbed soils. These occurrence of heavy metals in soils can be attributed to characteristics of the parent rock, environmental management practices, particle size distribution, soil age and influences from the air that comes in contact with soil. Nickel (Ni) and Zinc (Zn) are essential for plant growth, while Pb is considered a stern environmental contaminant [11]. Heavy metals have been used expansively in herbicides, pesticides or farm chemical throughout the world, to protect crops by eliminating pests and thereby increasing agricultural output. This could be source of residual heavy metal content in agricultural soils [12].

The mostly applied pollution indicator is a chemical concentration. Findings by Adamu [13] reveal that soils around areas of Minnna Railway Station, in Niger State of Nigeria, are contaminated with Zn, Cu and Pb. The soils were classified as moderate to highly contaminated [13]. Pollution of soils around the Railway Station demonstrates the effect of industrialization on soil integrity in the industrialized areas. This was attributed to leakages in fuel storage tanks as well as piping in trains or during repairs of machines. Eventually a cumulative effect can be achieved after a period of spillage. A similar study was conducted by Owolabi and Hekeu [14], in Lagos and Ota in Nigeria. Heavy metal resistant bacterial isolates; *Aerononas spp, Anthrobacter spp, Corynebacterium spp, Pseudomonus spp and streptococcus spp* were isolated and tested in the laboratory and analyzed against levels of tolerance to different concentrations of Cd, Cr and Pb. Bioremediation of environments that are contaminated with aromatic hydrocarbons such as BTEX has gained attention. *Pseudomonus spp* has been closely associated with Benzene, Toluene, Ethylbenzene and Xylenes (BTEX) contaminated environments and have been said to be useful in decontamination of the environments that are polluted with BTEX [15]. Rate of degradation of BTEX by organisms can be affected by presence of other contaminants present in the soil [16].

Osterreicher-Cunha [16] described ethanol to reduce the rate of degradation of BTEX and bioventing reduced effect of ethanol on reduction of rate of degradation of BTEX. Benzene, Toluene, Ethylbenzene and Xylenes (BTEX) often creates an anoxic environment and consequently anaerobic bioremediation techniques are preferred. Aromatic compounds for example Benzene and Toluene are electron donors for nourishment of bacteria [15].

4. MICROORGANISMS AS SOIL HEALTH INDICATORS

Typically, soil contains 10^8 to 10^{10} bacteria per gram of soil [17]. Evolution of complex microbial communities in soil is driven by both abiotic and biotic pressures. Microorganisms continue to adapt their ever-changing environment by acquiring genes that previously were unavailable through either point mutations that alter regulation of enzyme kinetics or genes acquired through horizontal or lateral gene transfer [18]. Microorganisms change rapidly and unlike macroscopic organisms. However, microorganisms cannot be observed directly, but can be cultured and their morphological and selected physiological characteristics used to classify them.

Bacteria are least structurally complex microorganisms but offer greatest diversity and metabolic flexibility. Bacteria are microscopic single celled organisms that can inhabit varied ecosystems in the environment. Bacteria can be grouped into decomposers or heterotrophs, mutualists, pathogenic, lithotrophs or chemoautotrophs [19]. Decomposers rely on carbon materials; pesticides, hydrocarbons and other pollutants. Mutualists form close relationship with plants for example nitrogen fixing bacteria. Pathogenic bacteria include; *Xymomonas*, *Erwinia spp*, and other agrobacterium that cause gall formation in plants. Lithotrophs or chemoautotrophs, obtain their energy from compounds of nitrogen, sulfur, iron or hydrogen but not carbon compounds [20]. Bacteria from the four groups are very important integral component of the ecosystem. Bacteria are part of nutrient cycling and produce substances that bind soils together into small aggregates. Bacteria competes with disease causing organisms, nitrogen fixing bacteria form symbiotic relationship with roots of legumes, nitrifying bacteria transform NH_4^+ to NO_2^- then to NO_3^-, while denitrifying bacteria convert nitrate to nitrogen (N_2) or nitrous oxide (N_2O) gas. *Actinomycetes* decompose a wide range of compounds that are rigid to decompose, for instance, cellulose and chitin, as they are active at high pH [21,22].

Soil microorganisms play a vital role in nutrient cycling [23]. They are actively involved in cycling of Nitrogen, Sulphur and Phosphorus. The symbiotic relationship between microorganisms and plants contributes above 20% of all plant nitrogen requirements [24]. Microorganisms degrade organic materials into mineralized carbon dioxide, water, mineral nitrogen and phosphorous among others. Thus, microorganisms play a vital role in soil formation and maintenance of soil ecosystem integrity by production of secretions and their cellular debris upon their death. Biological adaptation and responses to environmental changes are among factors that drive need to assess soil integrity and evolution of microorganisms to suit their evolving habitats. Evaluation of diversity of microorganisms in soil is a reliable indicator of soil integrity and changes in soil integrity [25].

Microorganisms can easily be used as soil health indicators. Fecal indicators indicate the presence of fecal contamination for example *Escherichia coli* [26]. In addition, microorganisms can also be used as process indicators, for instance total heterotrophic bacteria or total coliforms can indicate disinfection [27]. The total coliform includes; *Escherichia, Enterobacter, Klebsiella* and *Citrobacter species*. Total coliforms are easy to detect and specifically include all aerobic, gram-negative, non-spore forming and rod-shaped bacteria that produce gas upon fermentation of sugars in culture media within 48 hours at 35°C. Bacteria have been proven to grow on natural surfaces [28]. Microbes that inhabit harsh areas like polluted areas are prone to develop abilities that eventually enable them to survive, hence microorganisms are very resilient. Bacteria play a role in degradation of hydrocarbons in polluted areas [8]. These include bacterial species of genera *Azotobacter, Pseudonomus, Micrococcus, Cellulomonas* among others. Thus, microorganisms have been employed in degradation of toxins in the environment and have also been used in microbial enhanced oil recovery [29].

4.1 Total Heterotrophic Bacteria

The total heterotrophic bacteria include all bacteria that utilize organic nutrients as a source of their energy [30]. Heterotrophic bacteria are found all over the world in water, soil, air, food, and on vegetation. Heterotrophic microorganisms can be grouped as photoheterotrophs, chemoheterotrophs, organotrophs and lithotrophs [31]. Examples of heterotrophic bacteria include *Bacillus spp, Criptobacter spp, Escherichia Coli, Micrococcus spp, Pseudomonus spp, Serratia spp* and *Staphylococcus spp* among others [32]. Heterotrophic plate count refers to particular microbes isolated by a particular standard method of isolation by use of sufficient media time and conditions. Other terminologies have been used to refer to heterotrophic bacteria including; standard plate count, total viable count, total count, plate count, total bacterial count, water plate count, aerobic mesophilic count, colony count and autochthonous flora [30]. Heterotrophic bacteria refer to all bacteria requiring organic nutrients for growth, however, diverse methods target only particular subpopulation of total heterotrophs in a sample. It is difficult to differentiate which subpopulation includes pathogenic or nonpathogenic organisms [30].

4.2 Total Fungi

Fungi are chemoheterotrophs and mostly obligatory, which means they derive their energies from chemicals, and need to devour other organisms in order for them to survive [33]. Fungi are physically larger organisms as compared to bacteria which are most abundant. Similar to protozoans; 18S rRNA gene is being used for fungal identification, by use of internal subscribed spacer (ITS) [34]. Fungi are primarily found in soil but can be described as ubiquitous. Fungi are important in industrial processes of biotechnology and fermentation. Anaerobic fungi ferment sugars to produce ethanol, wine, lactic acid and acetic acid. They also produce secondary metabolites which have revolutionized agriculture and medicine through production of penicillin by *Penicilliun notatun,* griseofluvin produced by *Penicillium griseofulvum* and biotechnology.

It is hypothesized that fungi help reduce competition from other microorganisms for nutrients [35]. Saprophytic fungi are known to secrete extracellular enzymes that breakdown complex polymers; cellulose, lignin and chitin to simple forms [35]. Fungi has been found to degrade a variety of complex environmental contaminants; *Aureobasidium pullulans* decgrades polyvinyl chloride [36], *Penicillium, Stachbotrys, Allescheriella*, and *Phlebia* degrade aromatic petroleum hydrocarbons and agrochemicals [37,38]. Mycorrhizae form important symbiotic relationship in the environment. They colonize plant roots in exchange for CO_2 from the plant and the mycorrhizal fungi in turn solubilize phosphorous and bring soil nutrients; nitrogen, phosphorous and water. For example, the ectomycorrhizae that grows on root surfaces and the endomycorrhizae that grows within the root cells of plants. Parasitic and pathogenic fungi are a major problem in farming as it has been associated with reduction of yields and economic losses. *Pythium, Rhizoctonia* and *Verticillium* are pathogenic to roots of plants [35]. Fungal genera that has been isolated and identified in different levels of industrialization (highly, moderate, low and very low) in Port Harcourt, where *Mucor, Aspergillus, Candida, Penicillium, Rhizopus, Trichosporon* and *Sacharomyces spp* have been isolated and identified [32]. Industrialization influences distribution and abundance of microorganisms in soil [32].

4.3 Distribution of Microorganism Communities in the Environment

Microorganism communities are complex environmental components that are necessary for maintenance of soil ecosystem integrity [39]. Soil aggregates and pores within and around them create microhabitats that support different microorganism communities [40]. Within soil habitats, there is difference in quantity and chemistry of organic substances that are likely to be drivers of the microbial community difference [40]. Environmental conditions within and between soil aggregates such as physicochemical parameters are varied and thus resulting in diverse microorganism community among the different soil microhabitats [40]. Soil microorganisms plays vital roles in the soil ecosystem; regulates release of nutrients and maintenance of soil structure and texture [41]. When microorganisms are well established within soil aggregate, microbial structure and microbial community plays an important role in processing and protecting soil organic matter [40]. Soil microorganisms are associated with various biochemical processes and are important in maintenance of soil fertility [42], and also maintenance of ecosystem functions [43]. Microorganisms play a very important role in regulation of carbon dynamics in soil ecosystems [44,45]. Further, soil function, processes and integrity are influenced by soil microorganisms [46-48].

Changes in environmental conditions promote complex changes of soil microorganism composition. Effects on major communities are more detectable as compared to minor communities and can be realized through enrichment cultures including sulfate reduction, methane oxidation, halophilic and alkaliphilic and thermophilic responses among others [39]. Complex organic matter including phenols and alkyls has been proven as strong selective force on soil bacterial communities [40]. There is need to advance understanding influence of soil pollution and seasonality on soil microorganism community changes and cycling organic matter in soil [40]. Slight changes in environmental parameters cascades change in microorganism community in same environment and therefore determines the soil ecosystem integrity [39]. Shifts in composition of microbial community is followed up by changes in extracellular enzyme activities in environment which affects soil ecosystem integrity [49]. Specific enzyme activities can have a positive or a negative correlation with soil pH [49]. This suggests that microorganisms in environment adapt to environmental stresses with time through enhancing availability of C and other nutrients [49]. Variation in microorganism diversity in response to increasing pollutant deposition in environment remains uncertain [50], and calls for further studies. Addition of pollutants like nitrogen (N) and change in levels of pH have been described to influence ecosystem functions and can compromise the soil ecosystem integrity [50]. For instance, microorganism biomass is influenced by addition of N, [51-53,50]. Effects of pollutants on microorganism distribution varies among different ecosystems [54,50]. Addition of N to soil decreases soil pH [55], and consequently reduced pH enhances leaching of magnesium and calcium and mobilization of aluminum [50]. Aluminum poisoning and calcium and magnesium limitation to microorganism growth under N condition may affect diversity of soil microorganisms [56,50]. Increased levels of N influence fungal and bacterial diversities in soil ecosystems [50]. Negative effect of addition of N has been reported, which suggested an overall decline in microorganism biodiversity [50].

Fungi are considered to have higher carbon use efficiency as compared to bacteria [57,48]. Composition of soil microorganism community; fungi and bacteria can potentially help describe the unique variations in soil ecosystem integrity [48]. Treatment of soils with fertilizers influences richness and distribution of microorganisms in different soil ecosystems [48]. Chemical NPK fertilizer can influence distribution of soil microorganisms [48]. It is important to conduct studies in soils of cropping system because healthy soils foster food security [42].

Studies reveal that distribution of microorganisms in environment are influenced by level of heavy metal pollution, while other studies reveal that biomass of microorganisms in environment is not influenced by heavy metal pollution levels in environment [41]. Other studies reveal that microorganism biomass in environment can be influenced by other physicochemical parameters rather than heavy metals. Frequent quantification of heavy metals and other physicochemical parameters on their influence on distribution of soil microorganisms will give a clear representation of influence of heavy metals on distribution of microorganisms in natural ecosystems [41].

5. EFFECT OF PHYSICOCHEMICAL PROPERTIES ON DISTRIBUTION OF MICROORGANISMS IN SOIL

Physicochemical and biological properties of soil are affected by soil minerals, organic components and microorganisms [58]. Minerals, organic matter and microorganisms in soil ecosystems should rather be handled as dependent rather than independent entities [58]. Soil properties are influenced by cultivation, management, urbanization and industrialization and are responsible for declined and contaminated yields [42]. Activities of microorganisms in soil depend on physicochemical properties of that particular soil [59]. Land use types can affect soil physicochemical parameters and consequently affect soil microbial properties of soil [59]. Microorganism activities in soil are directly or indirectly influenced by physicochemical parameters in soil [60,59] or weather conditions like precipitation and temperatures. Some of soil physicochemical parameters that are influenced by land-use practices include; TOC, Total Nitrogen and pH [59]. Excess N can acidify soils, deplete soil nutrients, alter amount of organic matter and affect biodiversity [49]. Intensified anthropogenic activities; use of fertilizers, combustion of fuels, cultivation of leguminous plants, among others, can increase N deposition in environment and it is therefore important to know how N levels in environment can influence distribution of microorganisms [49]. The pH and N levels can influence shifts in microorganism community composition in environment [49]. Long term exposure of microorganisms to N in environment can decrease microbial biomass in environment [49]. Fungi are sensitive to elevated N inputs and high levels of N can decrease abundance of fungi and thus a lower fungi/bacteria ratio. This is in contrast to N-rich but phosphorus and other nutrient limited environment [49]. Soils acidification can inhibit growth of microorganisms but fungi are more tolerant to acidic environments as compared to bacteria [61,49] which may reduce soil microbial biomass [62,63,49]. Low pH, elevated electrical conductivity and ammonium concentration mainly inhibits bacteria rather than fungi in environments of high N content [49]. Fungi are able to adapt to acidic environment and bacteria prefer neutral conditions [49]. Shifts in abundance and composition of microorganism community in soils are cascaded with changes in functional activities of microorganisms in various environments and affect soil ecosystem integrity [64,65,49]. Differential effects of activities on different land-use types affects distribution of soil microorganisms in different soil ecosystems found in urbanized, industrialized and agricultural areas [59].

5.1 Effect of Fertilizers on Changes of Microorganism Composition in Soil

Fertilizers are used to enhance harvest of crop in agriculture, but if misused can affect soil ecosystem integrity [66]. The expanse/capacity of different types of soil to lose nutrients and pollutants is an important factor affecting ability of soil to lose fertilizers [67]. This to a greater extent can be related to Al, Ca and Fe in a situation of inorganic and organic P and to cation exchange capacity in case of potassium and ammonium. This may consequently decrease loss of nutrients to water and air hence reduces availability of nutrients to crops. Further, value for fertilizers in soil, depend on several reasons; the ratio and nature of organic and mineral components of soil [68], length of growing season climate that determine crop uptake, weather conditions and history of application [69,45].

Distribution of soil microorganisms is influenced by concentration of pollutants. A study conducted at Ebony State, Nigeria, revealed that inorganic fertilizers contribute to spatial distribution of soil microorganisms [70]. Microbial population decreases with increase in levels of soil contaminants [71]. Levels of cations in soil have also been attributed to influence development in bacteria. A study by Hai-Hang Li [72], used *Rhodotorula glutinins* and *pseudomonas spp* to demonstrate that Al^{2+}, Ca^{2+}, CU^{2+}, Zn^{2+}, Mn^{2+}, Mg^{2+}influence bacterial distribution in the environment. Levels of organic matter, soil moisture, soil structure and soil texture affect hydrology and also influence mineralization of soil through influence on soil microorganism activities [73]. Clay content in soil plays an important role in protection of organic matter from microbial degradation [74,75].

Unfavorable pH values can impede decomposition of organic materials by soil microorganisms hence reduced nutrients as there is reduced nutrient cycling. Consequently, there may arise competition for limited nutrients may arise among microorganisms and between microorganisms and plants. Specific microbes are responsible for decomposition of different organic matter hence there is specialization in areas they source for energy, therefore recovery of some nutrients in soil can be increased by suppressing rather that stimulating particular groups of soil microorganisms, for example urea hydrolyzers or ammonium nitrifiers [76]. It is rather necessary to quantify levels of chemicals in soil and their association with soil organisms.

Application of fertilizers in soil during crop production affects soil microorganisms which are a cognitive indicator of soil health [77]. Long-term trials reveal that mineral fertilizer increase microorganism population compared to unfertilized soils which is in contrast to grassland ecosystems where microorganism population is reduced by increased N input [52,54,77]. Biomass of bacteria, actinomycetes and fungi increases with increased fertilization using mineral fertilizers [77]. Fertilizers affect ratio of bacteria to fungi and also increases ratio of Gram-positive to Gram-negative bacteria [77]. Studies on effect of fertilizers on changes of microorganism populations and communities remain inconsistent as some studies report increasing soil microorganisms with increased fertilizer levels while others report decreasing soil microorganism populations with increased fertilizers concentrations in growth media [78] [79-81,77], which are attributed to site specific factors including soil properties and climate [77]. Fertilization affects microorganism community composition through changes in soil properties which depends on initial characteristics of soil. Effect of fertilizer application strongly depends on environmental factors which is considerably variable among different locations [77]. It is therefore necessary to conduct research on effect of fertilizer application on microorganism population and diversity shifts in polluted environments, in order to have a clear understanding of effects of fertilizers on distribution of microorganisms in soil.

6. EFFECT OF SEASONALITY ON DISTRIBUTION OF SOIL MICRO-ORGANISMS

Moisture content in soil limits oxygen availability and influences solubility, mobility and bioavailability of soil pollutants [82]. Wetting and drying cycles can alter bioavailability of organic contaminants in soil [82]. Heavy precipitation episodes and floods lead to increased water erosion and consequently disperse soil pollutants away from polluted sites [82]. Fluctuations in quantities and frequencies of precipitation affect the activities of soil microorganism and ultimately soil ecosystem integrity [82]. In wet seasons, the pH of soils is altered by frequent flooding and drainage [83]. During rainy season pH of acid soils increase while pH of alkaline soils decrease [84,83]. Rain water has high pH which favors ion exchange between OH_- and phosphate in soils which release P into flood water [83]. Higher concentration of Fe^{3+} in rainwater causes Fe^{3+} and Fe^{2+} form mixed Fe^{2+} -Fe^{3+} hydroxide with a larger specific surface area, which increases adsorption of soluble P [85,83]. Calcium (Ca) compounds in alkaline soils play an important role in retention of P as most inorganic P is bound to Ca compounds [86,83].

Reduction in levels of rainfall can have major effect in microorganism biomass but minor effect on community compositions. Increase or decrease in quantity of rainfall can cause alteration of carbon cycle in terrestrial ecosystems and hence such ecosystems depend on low-ground microorganism community for resilience of biological processes in soil. However, there is diverse and uncertain findings surrounding seasonal effect on microbial diversity in soil ecosystems [87,88] as there is more than only rainfall as an influencing factor, but complex interactions between microorganisms and biotic and abiotic components. Rainfall reduction can cause change biomass and community of microorganism either directly or indirectly. Reduced moisture levels in soil decreases solute mobility and constrains the supply of substrate to microorganisms, which is a direct effect that inhibits growth of microorganisms which are decomposers, and consequently cause reduced carbon and nitrogen from detritus entering the soil ecosystem [89,89]. On contrary, some microorganisms, including, Gram-positive bacteria, Actinobacteria and Arbuscular mycorrhizal fungi are tolerant to water logged areas [90]. This indicates that fluctuation in seasonality and rainfall patterns have impact on composition of soil microorganism communities [91,92].

Available moisture or water content controls collisions of soil particles and microorganisms [91,93,45]. Reduced rainfall affects soil total microorganism population [45]. Rainfall reductions affect ability of microorganisms to obtain required nutrients from soil [94,45]. However, not all areas show relationship between rain reductions and microorganism populations [45]. This can be attributed to evolutionary adaptation of soil microorganism population to harsh conditions; temperature and water stress [95,93,96,45]. Fungal populations can withstand reduced rainfall more than bacteria can do [97,93,45]. This can be attributed to possession of filamentous structure that allows fungi to reach and exploit substrates that are available in soil at very low moisture levels [45]. Further, the adaptive traits; thicker cell walls, ability of hyphae to obtain available nutrients in fungi affects responses to rainfall reduction [45]. Thick cell walls assist fungi to withstand high osmotic pressure from environment [98,45]. This can also apply to bacteria, where Gram-positive bacteria have advanced osmoregulatory mechanisms and stronger cell walls as compared to Gram-negative and consequently can manifest better in varied seasonality. For example, *Acidobacteria* and *Actinobacteria* are drought tolerant and are hardly affected by rainfall levels [98,45]. Total decrease in microorganism population can also be attributed to warming effects experienced over the dry period [99,100] [45], suggesting that soil microorganisms can be varied according to different ecosystems, for example, rainfall reductions can affect soil microorganisms in a forested area and at same time fail to affect microorganism population in a close by grassland [92,45]. Factors driving microorganism populations among different ecosystems maybe varied with difference in structures of ecosystems [45]. Therefore, reduced microorganism populations in soil can negatively affect soil carbon dynamics by causing a decline in carbon levels [101-104,45]. Hence seasonal fluctuations may affect microorganism population shifts in polluted areas.

Influence of rainfall on soil microorganisms remains uncertain [105]. Rainfall reductions decrease soil microorganism biomass but with less effect on fungi as compared to bacteria [105]. Rainfall has minor influence on microorganism community composition but can majorly influence microorganism biomass [105]. Increased rainfall declines soil organic carbon and soil respiration which has a positive relationship with changes in microorganism biomass [105]. Microorganism communities respond differently to different levels of precipitations in specified ecosystems [91,92] [106,107,105]. There is still much uncertainty surrounding description of patterns of distribution among microorganism communities to change in rainfall patterns [87,88,105]. Since distribution and abundance of soil microorganisms is dependent on both biotic and abiotic factors, it is difficult to predict microorganism related dynamics in environment [108,109,105]. Decrease in solute mobility constrains substrates that are necessary for growth of microorganisms and therefore inhibits their growth [93,89,105]. Seasonal influence in availability of oxygen in soil has a cascaded effect to microorganism community population and mainly decomposers [77]. Under anaerobic conditions decomposition of cell wall components is reduced and degradation of leachable and easily hydrolysable compounds is similar under both aerobic and anaerobic conditions [77].

7. EFFECT OF URBAN SETTLEMENTS ON DISTRIBUTION OF SOIL MICROORGANISMS

It is vital to assess effects of urbanized settlements on soil ecosystem integrity in order to form a baseline for reference on positive and negative implications that may occur in soils out of the settlement. In order to realize long-term agricultural productivity, soil fertility must be monitored and maintained at its optimal level. Knowledge on soil quality is important for effective management of farms as it forms baseline data for strategies to maintain and improve soil fertility [42].

Metabolic activities of soil microorganisms are mainly influenced by temperature and physicochemical parameters [110]. In a study by Eze [111], microorganisms were isolated from soils contaminated with cassava effluent. Soils were described to have *Escherichia coli, Pseudomonus spp, Bacillus spp, Proteus spp and Penicillin spp.* The study revealed presence of microorganisms in soils contaminated with cyanide at a concentration of 3.0 mg/kg. These was an indication that waste material should be well treated before being discharged to the environment. Since poor waste disposal methods leads to contamination of soils [111]. Soil pollution by heavy metal influences population and diversity of soil microorganisms. Microbial functional diversity decreases with increase in level of contamination with cadmium (Cd) [71]. Presence of low levels of microorganisms is correlated to increase cadmium intoxication in soils [71]. Exposure of microorganisms to concentration of pollutants in soil is thus causative in development of adaptive characteristics among different species found in contaminated soils.

Soils in market places (Uyo, Umuabia, Sokoto and Oka) in Nigeria are polluted and contaminated with heavy metals which influenced distribution of soil microorganisms [112-115]. Growth of microalgae (*Microcystis flos-aquae*) in crude oil contaminated media revealed an exponential growth and reduction of crude oil in media. This is an indication of potential of microalgae in degradation of oil in polluted environments [116] and adaptation by shift in microbial populations, species richness and diversity, hence the role played by microorganisms is diverse.

In Calabar Cross River State of Nigeria, used oil spills has been found to influence distribution of microorganisms in soil [117]. Some of the heterotrophic bacteria isolated from these soils included; *Pseudomonus spp, Bacillus spp, Klebsiella spp, Proteus spp, Enterococcus faecalis* and *Flavobacterium spp* [117]. The total hydrocarbon oxidizing bacteria isolated include; *Bacillus spp, Pseudomonas spp* and *Micrococcus spp* [117]. The highly prevalent genera were *Pseudomonas spp and Bacillus spp* an indication that oil degrading microbes are more abundant in areas with oil contamination [117].

8. CONCLUSION

Industrialization, urbanization and agricultural activities remain doubtfully associated with contamination of environment. Sporadic determination of soil physiochemistry and biological parameters is thus of essence in resilience of soil ecosystem integrity. Microorganisms are integral part of ecosystem where they continue to adopt to new niches in the environment hence need for continuous research in order to isolate groups of microorganisms that are resistant to harsh conditions encountered in polluted soils in order to enhance bioremediation of contaminated soils. It is necessary to ascertain the compounded impact of anthropogenic activity on soil ecosystem integrity including both biological and physicochemical parameters as opposed to isolated cases of either biological or physicochemical parameters, in order to develop compounded indication of impact magnitude of anthropogenic activities on soil ecosystem integrity. There is need to advocate for deeper understanding on influence of soil pollution and seasonal variations in soils on microorganism community changes and levels of soil contaminants. Variation in microorganism diversity remains uncertain in unique niches, and is unclear if pollutant influence or does not influence distribution of microorganisms in soil. Influence of fertilizer on bacteria to fungi ratio as well as microorganism population shifts are unique to different habitats and it is therefore important to check how the ratio of bacteria and fungi are affected in different human settlements; urbanized, industrialized and agricultural areas. Individual parameters of soil may seem to carry minimal effect when analyzed in isolation. However, compounded impact may be more descriptive of the soil ecosystem integrity, where the positive and negative impact are assessed simultaneously. This will foster for food security and hence a healthy population as enshrined in the Sustainable Development Goals (SDGs).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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