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Assessing The Effects Of Flooding On Soil Quality In Some Parts Of Maiduguri, Borno State, Nigeria

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Abstract

This study examined the physicochemical and microbial properties of soils in the flooded and control areas of Maiduguri, Borno state. Four soil samples were taken from each selected site and homogenized to form a composite sample. These were repeated in all four sites selected at each study site. The soil samples were taken by using a soil corer, from a depth of 0-15cm and 15-30cm, placed in individual plastic bags, and transported to the Soil Science laboratory of the University of Maiduguri for physicochemical and microbial analysis. Laboratory analysis showed that the physical properties of the soil samples in the study areas show that in all locations and across depths, the sand texture classes were dominated by loamy, sandy clay, and clay. In summary, the soil of London Ciki and Gwange were sandy loamy at all depths, Galtiamari were clay loamy at 0-15cm and sandy loamy at 15-30cm while Fori was sandy loamy at 0-15cm and loamy sandy at 15-30cm, while the chemical properties of soils had values ranging from pH, (7.4±0.01-7.7±0.01), EC (0.10±0.09 - 0.41±0.0 ds/m^{-1}), TEA (0.2±0.1-0.4±0.1Cmolkg^{-1}), Ca^{2+} (11.4±0.1-28±1 Cmolkg^{-1}), Mg^{2+} (11.6±0.1 - 35±1 Cmolkg^{-1}), K^{2+} (0.12±0.0 - 0.17±01 Cmolkg^{-1}), Na^{2+} (0.050±0.01-0.160±0.01 Cmolkg^{-1}), TEB (29.48±1.01-63.31±1.01Cmolkg^{-1}), ECEC (29.78±1.01-63.51±1.01Cmolkg^{-1}), PBS (98.9±1.01-99.7±1.01%), N (0.2±0.1-0.57±0.01g/kg), OC (0.03±0.01- 2.42±0.01g/kg), OM (1.28±0.01- 4.17±0.01%), C: N (3.17±0.01- 4.26±0.01%), P (5.95±0.1- 30.8±0.1g/kg). Multivariate Analysis of Variance (MANOVA) and Pearson Product-Moment Correlation were used to test for significant differences in the physical and chemical properties of soils from the study areas. The means were compared using the Least Significant Difference Test (LSD). The results disclosed that all the physicochemical properties showed significant differences at $p \leq 0.05$ between control and flooded soils, as well as across the depths and sites. The study revealed strong correlations between various chemical properties of flooded and control soils. Electrical conductivity (EC) was strongly related to magnesium (Mg^{2+}), total exchangeable base (TEB), and effective cation exchange capacity (ECEC). Organic carbon (OC) and organic matter (OM) were interchangeable measures of soil organic content. Soil pH played a crucial role in determining nutrient availability, while EC served as a good indicator of soil fertility. These findings highlight the importance of considering these chemical properties in soil management practices. The results showed that the soils were slightly alkaline to neutral (pH 7.4-7.7). Electrical conductivity (EC) ranged from 0.10 to 0.41

dS/m^{-1}, with significant differences among sites. The concentrations of calcium, magnesium, potassium, sodium, and phosphorus varied significantly among sites and depths. Total exchangeable bases (TEB) and effective cation exchange capacity (ECEC) ranged from 29.48 to 63.59 $Cmol/kg^{-1}$ and 29.78 to 63.51 $Cmol/kg^{-1}$, respectively. The study highlights the impact of flooding on soil chemical properties and their potential effects on plant growth and nutrient availability. Thus, it is concluded that some nutrients are leached during flooding; some are added as deposits, while some are unaffected by flooding. Regularly monitor soil microbial communities and nutrient levels to better understand the impacts of flooding and inform management decisions. Further studies are encouraged to explore the long-term effects of flooding on soil microbiology and ecosystem functioning.

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I. Introduction

Background of study

The quality of soil depends both on its physical properties (color, texture, moisture contents, pH, organic matter content, etc) and chemical properties (cation exchange capacity, organic matter contents, phosphate phosphorus, nitrate nitrogen, nitrite nitrogen, etc). The physical and chemical properties determine the suitability of a soil for its planned use and management requirements, allowing it to remain productive to a limited extent. The fertility of a soil, in turn, determines its potential uses and, to a larger extent, its yields (Sani *et al*., 2012).

Soils in agricultural production play a vital part in the ecological system that produces food and fiber for human use. Currently, sustainable and productive agriculture is highly related to soil quality. Floodplain soils worldwide are highly beneficial for agricultural production and food security due to their vast reserves of available nutrients for crop use (Achimota, 2021).

According to Sani *et al*. (2012), the physical and chemical properties largely determine the suitability of soil for its planned use and management requirements to keep it most productive to a limited extent, the fertility of soil determines its possible uses, and to a larger extent, its yields.

A major consequence of climate change is the fluctuation in the rainfall regime, which increases the probability of extreme events in the form of excessive rainfall in certain areas and drought in others. Increased urbanization, land use, land cover change, and density of population and infrastructure in the urban centers have increased the quantum of loss sustained in flood disasters. In some cases, especially in the context of developing countries, poor planning has also increased the exposure of urban centers to flooding (UNISDR, 2013; Samuel *et al*., 2014).

Floods are environmental hazards caused by climate and human activity. They occur in both developed and developing countries and often cause catastrophic loss of life and property, suffering, difficulty, disease, and hunger (Jenkwe, 2023). Floods are extremely high discharge rates in a constantly changing environment that engulfs land next to streams, rivers, or lakes. They are typically brought on by heavy or prolonged rainfall (Ibrahim *et al*., 2024).

According to Merten *et al.* (2021), floods are purely environmental hazards that result from several basic causes. The most frequent are climatological, but they are very often induced by man's improper utilization or abuse of the environment. Soil particles separate and move due to shear stress from overland flow. Detached material settles when the flow's carrying capacity is exceeded (Nilsson, 2018).

Flooded soils are anaerobic, which kills microorganisms. The soil's free oxygen usually diminishes within a few days after a flood (Liu *et al*., 2022). Despite its significant environmental impact, flooding helps preserve key ecosystem processes and biodiversity in various natural systems. A flood brings organic materials and minerals from rivers and oceans to land, making it more fertile and productive (Jenkwe, 2023).

Therefore, inundation circumstances arise when rainfall exceeds the usual amount for a site (Mensah and Ahadzie, 2020). This state can be caused by natural (heavy rainfall, dam collapse, clogged rivers) or manmade (building structures on natural waterways, urbanization, deforestation, etc.) factors (Mfon *et al*., 2022).

Flooding often kills people and destroys property. Additionally, it has long-term psychological effects (Glago, 2021). Flash flooding is common in Nigeria during the rainy season May to September. Torrential rains in Nigeria, nearby Cameroon, and Niger from July to September 2021 increased overflowing water reservoirs, causing officials to open dams (Lamingo dam and Lagdo dam in Cameroon's Northern sector) (Ajanaku, 2022). According to Nilsson, (2018), floods contribute positively to soil properties through the provision of nutrients that may be lacking in the soil. Soil properties such as total nitrogen, moisture content, pH, and organic carbon were higher in the soil after flooding than before flooding (Glago, 2021).

Statement of the problem

Prolonged and frequent flooding in parts of Maiduguri, Borno State, Nigeria, has raised concerns about its impact on soil quality. The floods, often prompted by substantial rainfall and poor drainage systems, can lead to soil erosion, nutrient depletion, and pollution. However, there is a shortage of experimental data on the specific effects of flooding on soil quality in this region. This knowledge gap hinders the development of effective strategies for mitigating the negative impacts of flooding on soil health and agricultural productivity. Therefore, this study aims to investigate the impacts of flooding on soil properties in selected areas of Maiduguri, with a focus on assessing changes in physical, chemical, and biological soil properties.

Objectives of the study

The objectives of the study are to:

i. determination of some physicochemical parameters, such as pH, clay, silt, sand, Electrical conductivity, organic carbon, Cation Exchange Capacity, P, Na, Ca, Mg, K, N, TEB, C: N, and PBS in the soil sample of the study sites.
ii. assess the relationship between the physicochemical parameters of the soil in selected areas.
iii. determine the microbial population of the soil in the study area (Bacteria and fungi).

Significance of the study

The study will contribute to the existing data on the effects of flooding on soil quality, particularly in the context of Maiduguri, Borno State, Nigeria. The findings will provide valuable insights for policymakers, agricultural extension managers, and farmers on the best management practices to mitigate the effects of flooding on soil quality.

Scope of the study

The study was restricted to assessing the physical properties of soil (texture), chemical properties (pH, clay, silt, sand, electrical conductivity, organic carbon, Cation Exchange Capacity, P, Na, Ca, Mg, K, N, TEB, C: N, and PBS in the soil sample), and microbial (bacteria and fungi) of flooded and control soils in Maiduguri.

II. Literature Review

Soil

The soil is the most important constituent for the accomplishment of all the basic needs of human beings. The physical and chemical condition of whatever land is indispensable for the proper implementation of other management practices. Thus, the physicochemical study is very important (Kekane *et al.*, 2015).

Soils in agricultural production play a vital part in the ecological system that produces food and fiber for human use. Currently, sustainable and productive agriculture is highly related to soil quality. Floodplain soils worldwide are very useful for agricultural production and food security due to the huge reserve of available nutrients for crop plant utilization (Achimota, 2021).

Soil productivity is decreased as the population of various microorganisms (bacteria, Actinomycetes, and free-living N-fixing bacteria) decreases due to irrigation by well waters polluted with discharge of industrial effluents (Williams, 2018). Once the microbial population is disturbed, the soil productivity decreases, resulting in reduced nutrient availability and plant production. Nitrogen of plants is affected due to the inhibition of Nitrogen-fixing organisms' activities and nitrification rate (Williams, 2018).

Flood

A flood is defined as a very large amount of water that has overflowed from a source such as a river, a pond, or a broken pipe to cover a previously dry area. It occurs when soil and vegetation cannot absorb all the water; the water then runs off the land in quantities that cannot be carried in stream channels or retained in natural ponds and constructed reservoirs such as dams and levees (Njoku, 2013).

Floods affect the physical properties of soil by lowering the nutrient level often associated with subsoil, and hence provide less protection to the soil. Flooding leads to poorer structure and lower organic matter. Sediment can be deposited on downslope properties and can contribute to road impedance damage, also leading to a loss in revenue, finances, and impediments to urbanization (Danjuma, 2021).

According to Ubuoh *et al*. (2016), flooding generally affects the soil through its physical and chemical properties. Floods have been identified as a serious environmental problem with a multiplicity of social and economic consequences. Flooding uses disastrous forms of land degradation whose effects are multi-dimensional.

Flooding

African cities are more prone to flooding, not only because of their vulnerable locations but also because they lack the requisite infrastructure or physical planning and are populated largely by the poor who live in vulnerable locations and cannot predict, cope, resist, and recover from flood events (Adelekan, 2010).

According to Njoku *et al*. (2011), when soil is flooded and not controlled, its oxygen supply decreases to zero in less than a day. The rate of atmospheric oxygen diffusion is 10,000 times slower through water layers or water-filled pores than through air- or air-filled pores. Aerobic microorganisms quickly consume the remaining oxygen and become dormant or die. Anaerobes or facultative anaerobes multiply rapidly and take over the organic matter decomposition process, using instead of oxygen, oxidized soil components as electron acceptors.

Danjuma (2021) stated that the chemical status of flooded soil differs widely from that of upland soil. The former is characterized by a deficiency of oxygen and an excess of carbon dioxide. The effect of flooding is to initiate anaerobic decomposition of organic matter and an increase in solubility of phosphates and silica. It also results in the presence of sulphides and a large amount of reduced iron and magnesium, the absence of nitrate, and an increase in electrical conductivity.

Njoku *et al*. (2011) concluded that flooded soils are low in pH, organic matter, and exchangeable cations. Despite the significant consequences of flooding on the environment, flooding plays an important role in maintaining key ecosystem functions and biodiversity in many natural systems. Floods deposit organic materials, minerals, and essential nutrients from rivers and oceans into the land, which makes the soil richer, more fertile, and more productive (Ubuoh *et al*., 2016). However, these environmental benefits come at a high price when excessive flooding occurs, since natural systems can no longer be resilient to the effects of large and excessive floods (Visser *et al*., 2003).

Physicochemical and Soil Quality

All agricultural production and development depend upon the physicochemical parameters of the soil (Kekane *et al*., 2015). Soil testing is increasing due to the public's interest in the quality of products obtained from it and the different practices carried out for their output. The soil quality analysis includes an analysis of parameters and processes that affect the soil's ability to operate efficiently as a component of a sound ecosystem (Tale & Ingole, 2015). Soil quality may include a capacity for water retention, carbon sequestration, plant productivity, waste remediation, and other functions, or it may be defined more narrowly. The soil's chemical and physical attributes as determinants of soil quality (Kekane *et al*., 2015).

pH

The most substantial property of soil is its pH level and its effects on all other parameters of soil. Therefore, pH is considered while analyzing any kind of soil. If the pH is less than six, then it is said to be acidic soil; the pH ranges from 6-8.5, its normal soil, and greater than 8.5, then it is said to be alkaline soil (Chaudhari, 2013).

Soil pH is an indication of the acidity or alkalinity of soil. From pH 7 to 0, the soil is increasingly more acidic, and from pH 7 to 14, the soil is increasingly more alkaline or basic. Soil pH measurement is useful because it is a predictor of various chemical activities within the soil. As such, it is also a useful tool in making management decisions concerning the type of crops suitable for cultivation, the possible need to modify soil pH, and a rough indicator of the availability of nutrients for the plants in the soil. Soil pH affects nutrient availability, nutrient toxicity, and microbial activity, as well as has a direct effect on the protoplasm of plant root cells (Alam *et al*., 2020).

Soil pH is defined as the negative logarithm of the hydrogen ion concentration in soil. Soil pH also refers to the measurement of the soil solution's acidity and alkalinity (McCauley *et al*., 2017).

Soil pH directly affects the activity of nitrogen-fixing microbes and the solubility of many of the nutrients in the soil needed for proper plant growth and development. Some elements, like potassium, magnesium, calcium, and phosphorus, are likely to be unavailable to plants in acidic soil, and in basic soil, elements like copper, zinc, boron, manganese, and iron are not easily absorbed by plants (Neina, 2019).

Texture

Soil texture is a qualitative classification tool used in both the field and laboratory to determine the classes for agricultural soils based on their physical texture. The soil in different regions exhibits varying textures, which are primarily determined by the size of the particles. Soil texture shows its effect on aeration and root penetration. It also affects the nutritional status of the soil. Soil texture can be expressed significantly by its electrical conductivity (Mahajan, & Billore, 2014).

Moisture

Water content or moisture content is the quantity of water contained in a material, such as soil, called soil moisture. Moisture is one of the most important properties of soil. Absorption of nutrients by soil largely depends on the moisture content of the soil moisture of soil also shows its effect on the texture of the soil (Kekane *et al*., 2015).

Soil temperature

Soil temperature depends on the ratio of the energy absorbed to that lost. Soil has a temperature range between -20 to 60 °C. The temperature of the soil is the most important property because it shows its effect on the chemical, physical, and biological processes related to the growth of plants. Soil temperature changes with season, time of day, and local conditions of climate (Mahajan, & Billore, 2014).

Nitrogen

Nitrogen is the most critical element obtained by plants from the soil and is a bottleneck in plant growth. About 80% of the atmosphere is nitrogen gas. Nitrogen gas diffuses into water, where it can be "fixed" (converted) by blue-green algae to ammonia for algal use. Nitrogen can also enter lakes and streams as inorganic nitrogen and ammonia. Because nitrogen can enter aquatic systems in many forms, there is an abundant supply of available nitrogen in these systems (Chaudhari, 2013).

Phosphorus

Phosphorus is the most important element present in every living cell (Kekane *et al*., 2015). It is one of the most important micronutrients essential for plant growth. Phosphorus most often limits nutrients that remain present in plant nuclei and acts as an energy storage (Solanki & Chavda, 2012).

Potassium

Potassium plays an important role in different physiological processes of plants, it is one of the important elements for the development of the plant (Shivanna & Nagendrappa, 2014). It is involved in many plant metabolism reactions, ranging from lignin and cellulose used for the formation of cellular structural components, for the regulation of photosynthesis, and the production of plant sugars that are used for various plant metabolic needs (Solanki & Chavda, 2012).

Soil Organic Matter

It is also a valuable property of soil. If the soil is poor in organic matter, then it enhances the process of soil erosion (Kekane *et al*., 2015). If the soil organic matter is present in the soil, then this soil is useful for agricultural practices. Organic matter may be added to the soil in the form of animal manure, compost, etc. The presence of a higher content of organic matter in the soil can be another possible reason for the lowering of the pH. Soil organic matter content has decreased from surface to subsoil due to leveling (Shivanna & Nagendrappa, 2014).

Soil Fungi and Bacteria

Bacteria and fungi, among soil organisms, actively participate in organic matter decomposition, liberating chemical nutrients and furthering plant growth. Microorganism numbers vary in and between different soil types and conditions, with bacteria being the most numerous (Vieira & Nahas, 2005).

Fungi are present and prominent in all soils. At broad phylogenetic scales, the saying "everything is everywhere" does seem to apply to fungi: beyond soils, they are also found in nearly every other habitat on Earth, including deep-sea hydrothermal vents and sediments, subglacial sediments, ancient permafrost, sea ice, hot and cold deserts, salterns, and soils of the Dry Valleys of Antarctica (Cantrell *et al*., 2011).

Fungi generally dominate microbial biomass and activity, including respiration, in soil organic horizons, particularly in forests (Joergensen and Wichern, 2008). Bacterial-to-fungal ratios tend to be lower in acidic, low-nutrient soils with recalcitrant litter and high C-to-N ratios (Fierer *et al*., 2009). In contrast, bacteria are increasingly prominent in high N + P, saline, alkaline, and anaerobic waterlogged soils (Joergensen & Wichern, 2008). Although fungal abundance and ratios of fungal to bacterial biomass tend to increase as soil pH decreases (Rousk *et al*., 2009), other studies suggest that fungal distributions are more influenced by N and P availability than pH per se (Lauber *et al*., 2009).

Fungi and bacteria are the dominant members of soil microbial communities worldwide in terms of diversity, abundance, and biomass (Bahram *et al*., 2018). Representing distinct kingdoms of life, bacteria and fungi systematically differ in a multitude of physiological and life-history traits with direct implications for global soil biogeochemical cycles (Wieder *et al*., 2015).

Temperature, precipitation, soil pH, and soil C: N have all been linked to the balance of fungi vs. bacteria within soil communities across different spatial scales (Bahram *et al*., 2018). Relative to fungi, bacteria tend to dominate in locations with high soil nutrient contents or in frequently disturbed soils that limit the growth of fungal hyphae or make N more available (Fierer *et al*., 2009). A recent analysis suggested that the relative soil bacterial abundance is high in tropical latitudes and decreases in abundance towards the high-latitude boreal regions, where fungi tend to dominate (Bahram *et al*., 2018).

Bacteria and fungi are by far the key living components in soils in terms of biodiversity, biomass, and their impacts on biogeochemical processes (Wang, & Kuzyakov, 2024). They always coexist with each other in soils and form complex interactions (Cao *et al*., 2024) that are crucial for their survival, adaptation, establishment, maintenance, and functions (Pierce *et al*., 2021).

Electrical Conductivity

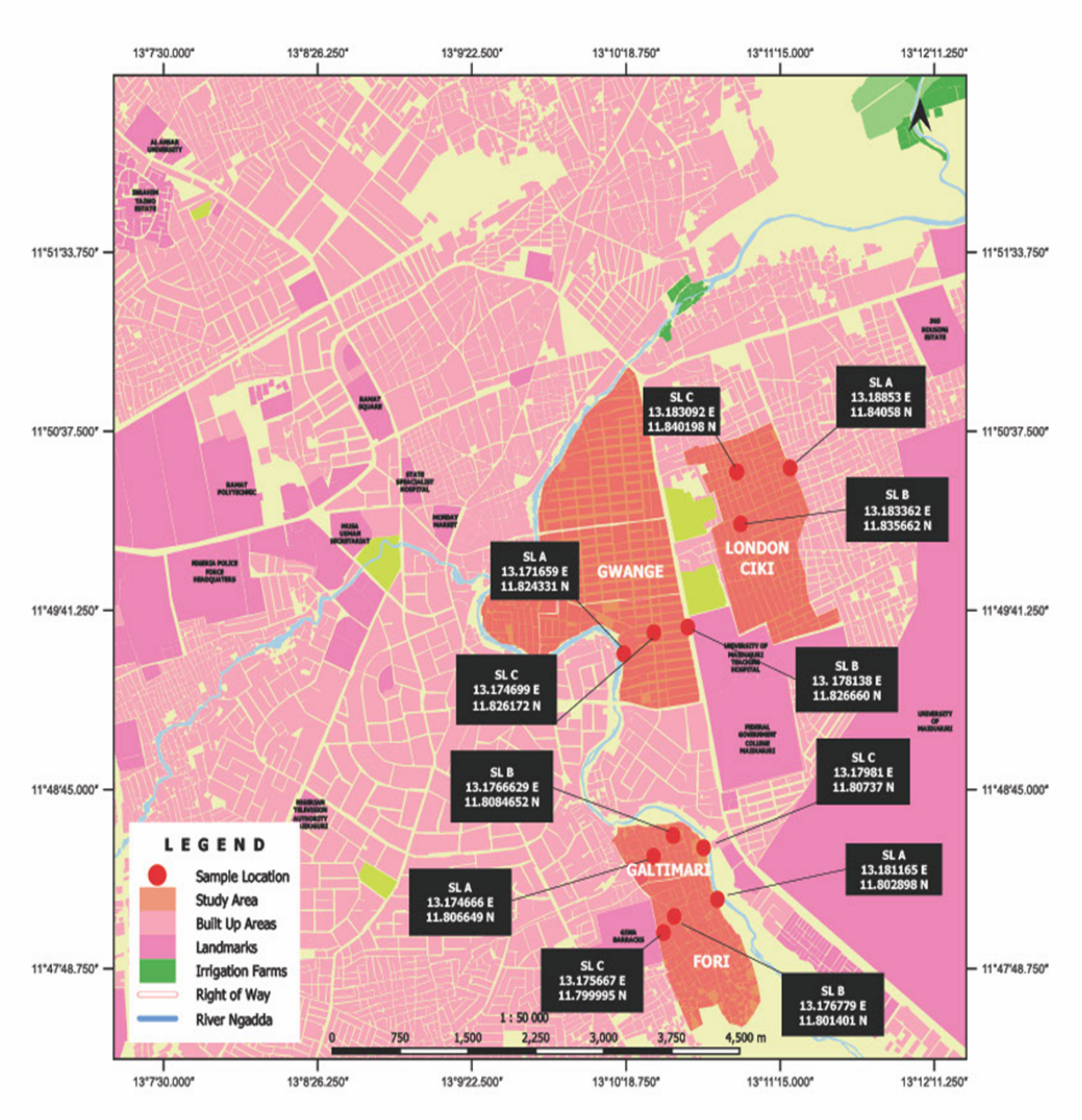
Soil EC is a useful indicator in managing agricultural systems, and the interpretation of EC of a soil or media must be made considering the plant(s) to be grown (Arnold *et al*., 2005). The EC of the soil has little direct detrimental effect on sandy mineral soils or media. However, EC directly affects plant growth in the soil or media (Alam *et al*., 2020).

III. Methodology

Study Area

The study was carried out in Maiduguri Metropolis, the capital of Borno State. Administratively, it constitutes MMC and parts of Jere, Konduga, and Mafa LGAs. It is situated between longitudes 12°58'35.625"E to 13°15'28.125"E and 11°45'28.125"N to 11°55'46.875"N. Maiduguri experiences a semi-arid climate with high temperatures and low rainfall. The climate condition of the State is hot and dry for most of the year. It has low rainfall, which ranges from 500mm to 1000mm annually, and a low relative humidity ranging from 42% to 49% (Mayomi and Jimme, 2014). It is the headquarters of Maiduguri Metropolitan Council, bounded in the North by Jere LGA, in the west, south, and south-west by the Konduga local government area, and in the northwest by Mafa Local government.

Map of Maiduguri showing the study area



Map of Maiduguri

Soil Sampling

Four soil samples were taken from each selected site and homogenized to form a composite sample. These were repeated in all four sites selected at each study area. The soil samples were taken using a soil corer, from a depth of 0-15cm and 15-30cm, placed in individual plastic bags, and transported to the laboratory for physicochemical and microbial analysis. The plastic bags were labelled with name, sampling date, location, and soil depth. The samples were air-dried to remove excess moisture. The samples were mashed up using a pestle, mortar, and grinder to obtain a uniform state, and then passed through a 2mm sieve of aluminum foil. Any gravel, stones, and plant fragments found in the samples were removed to obtain a homogenous sample (Akoto *et al*., 2022). The soil samples were transported to the soil chemistry laboratory, Department of Soil Science, University of Maiduguri, for physicochemical parameter analysis.

pH and EC Determination in the Supernatant Suspension of 1:2-5 Soil H_2O ratio

10g of soil sample was weighed into a 50 ml beaker, and 25 ml of distilled water was added. The suspension was allowed to stand for one hour with occasional stirring using a glass rod (stirrer). The pH meter was calibrated using buffer solutions of pH 4 and pH 7.0, before being immersed in the supernatant of the suspension. The reading was taken when it was stable without further stirring. The reading was then recorded as "soil pH measured in 1:2:5 soil water ratio. The electrodes of the pH meter were then rinsed with distilled water and wiped dry with a clean tissue before being immersed in distilled water before each subsequent measurement. The suspension was then stored for EC determination, which was taken in the same manner with the use of an EC meter. The results were recorded in ds/m^{-1} (Thomas, 2020).

Determination of Exchangeable Cation (Ca^{2+}, Mg^{2+}, Na^{2+} and k^{+})

10g of air-dried soil sample was weighed into a 150mls plastic bottle and 30mls of 1N NH_4OAC (pH 7.O) was added and shaken for 2 hrs. The extract was filtered into a clean 100ml volumetric flask, and 30mls of 1N NH_4 OAC was added to the residue and shaken for 30 minutes, it was then filtered into the same volumetric flask. Another 30 mL 1N NH_4 OAC was added and shaken for 30 minutes, which was filtered into the same volumetric flask. The extract was made up to 100ml with the extracting solution of 1N NH_4OAC (Sparks, 2019).

Titrimetric Determination of Ca^{2+} and Mg^{2+}

10mls of the extract above was pipetted into a clean 250ml conical flask and 1000mls of distilled water was added. Fifteen (15mls) of NH_4 buffer and 10mls each of KCN, NH_4 OH HCL. $K_4Fe(CN)_6$ and TEA were also added. A few minutes were allowed for the reaction to take place, after which 5 drops of EBT indicator were added and the solution was titrated with 0.01N Na_2 EDTA to a permanent blue color (APHA, 2020).

Titrimetric Determination of Ca^{2+}

10mls of extract was pipetted into a clean 250ml conical flask and 100ml of distilled water was added. Ten (10) drops each of KCN, NH_2OH. HCL, $K_4Fe(CN)_6$, and TEA were also added, followed by 10mls of 10% NaOH to raise the P^H to 12 or slightly higher.

A pinch of murexide indicator was added, and the solution was titrated to reddish violet with 0.01N Na_2 EDTA (APHA, 2020).

Determination of Sodium and Potassium

The determination was by flame photometric methods, and the concentration of potassium and sodium (in PPM) of each was directly found from the standard curve. The amount of potassium in the sample (meq) was calculated using the following formulae (APHA, 2020).

$$\text{Meq } K^+/100g \text{ soil} = \frac{\text{ppm from graph} \times d.f \times 100 \times 100}{1000 \times w \times \text{eq. wE of } K^+}$$

$$\text{Meq } Na^+/100g \text{ soil} = \frac{\text{ppm from graph} \times d.f \times 100 \times 100}{1000 \times W \times \text{eq. wE of } Na^+}$$

Where: - w= weight of sample used
d.f = dilution factor
v = total volume of the sample made

Determination of Organic Carbon (Wet Oxidation)

1g of air-dried (passed through a 0.5 mm sieve) soil sample was weighed into a 250 mL conical flask. 10ml of 1N potassium dichromate was added with the help of a clean pipette, using a clean measuring cylinder. 20mls concentrated sulphuric acid was added. After cooling, 100ml of distilled water was added, followed by 10mls of ortho-phosphoric acid (H_3PO_4) and 0.2g of sodium fluoride (NaF). Five (5) drops of diphenylamine indicator were added, which turned the color to deep violet (Nelson & Sommers, 2019).

The excess chromic acid was then titrated with 0.5N ferrous sulphate (1N $FeSO_4$). The endpoint was recorded as the color changed from deep violet to deep green. The same procedure was repeated on the blank (without a soil sample). The amount of soil sample was then recorded, and the strength of FeSO4 was finally determined. The % O.C. oxidised by potassium dichromate ($K_2Cr_2O_7$) was calculated using the formulae below (Nelson & Sommers, 2019).

$$\% \text{ O.C} = \frac{B - T \times F}{W} \times 0.39$$

Where: - B= amount of 0.5N $FeSO_4$ solution required in black titration
T= amount of 0.5 N $FeSO_4$ solution required in the titration of sample.
F= normality of $FeSO_4$
W= weight of soil sample used

Microbiological Analyses of the Soil Samples
Digestion of Samples

The soil samples were spread on a clean Whatman filter paper on a flat surface and air-dried in the open air in the laboratory under room conditions for 24 hours. Afterwards, the soil was sieved on a 2 mm sieve, and a 1g sample was taken from the sieved soil and put in a beaker. 10 ml of nitric acid was added to the sample. The samples were digested at 105°C. HCl and distilled water in a ratio of 1:1 were added to the digested sample, and the mixture was transferred to the digester again for 30 min. The digestate was then removed from the digester and allowed to cool to room temperature. The cooled digestate was washed into a standard volumetric flask and made up to the mark with distilled water (Akintokun and Taiwo, 2016). The research was conducted at the soil chemistry laboratory, Department of Soil Science, University of Maiduguri, for microbial analysis.

Total Heterotrophic Bacterial Count:

The total Heterotrophic Bacterial Count (THBC) of the soil samples was determined using the method suggested by Akintokun and Taiwo. The TVC was determined by the standard pour plate method, using dilutions of 10^{10}. One milliliter each of serially diluted samples was inoculated on a sterile Plate Count Agar using the pour plate method and incubated invertedly at 37 ºC for 24 h. Colonies were counted and reported after 24 hours as colony-forming units (CFU/g) (Akintokun and Taiwo, 2016).

Total Fungal Count:

The Total Fungal Count (TFC) was determined by inoculating 1 mL each of serially diluted (10^{10}) samples on sterile Potato Dextrose Agar incorporated with 1 % (v/v) Chloramphenicol using the pour plate method and then incubated at 28 ºC for 72 h. The 1% chloramphenicol was added to Potato Dextrose Agar to inhibit bacterial growth. Colonies were counted and reported as colony-forming units per gram (Akintokun and Taiwo, 2016). All media were prepared as directed by the manufacturers.

Data Analyses

Multivariate Analysis of Variance (MANOVA) and Pearson Product-Moment Correlation were used to test for significant differences and relationships in the physical and chemical properties of soils from the study areas. The means were compared using the Least Significant Difference (LSD) test.

IV. Result

The results of the physical and chemical properties of flooded and control soils are presented in Table 1.

The pH levels of all the soils of the study areas (topsoil and subsoil) ranged from 7.4 to 7.7, with an average value of 7.56, indicating slightly alkaline to neutral soil conditions. The average pH of the control site (Fori) is 7.7 (0-15cm) and 7.5 (15-30cm). The highest pH was recorded in Fori (7.7, 0-15cm) and Gwange (7.7, 0-15cm), while the lowest pH was recorded in Galtimari (7.4, 0-15cm). The results agree with the findings of Jenkwe (2023) and those of Talbot *et al*. (2018). The pH values of the areas were significantly different regarding depths and sites ($P>0.05$).

The electrical conductivities (EC) for the soil samples of the selected areas at different depths (0-15 to 15-30cm) ranged from 0.10 to 0.41 (dsm^{-1}) with a mean value of 0.225 (dsm^{-1}). The lowest EC was recorded in the control site Fori 0.10 (dsm^{-1}) at the depth of 0-15cm, while the highest EC was recorded in the London Ciki area 0.41 (dsm^{-1}) at the depth of 0-15cm. Significant differences were observed among the mean EC values of all the areas compared to the control site (Fori) mean EC values at ($P<0.05$). It was also observed that the mean of EC decreases from topsoil to subsoil in some of the study areas. The result of EC is mainly affected by different environmental factors such as climate, geology, local biota, and anthropogenic activities that change soil characteristics (Narshimha *et al*., 2013).

The calcium (Ca^{2+}) concentration of the location's topsoil and subsoil ranges from 11. 4 to 28, with an average of 17.38. The highest calcium concentration was recorded in London Ciki at 28 (0-15cm), and the lowest concentration was recorded in the Galtimari at 11.4 (15-30 cm), while the control site had 22.6 (0-15cm) and 14 (15-30cm). Significant differences were observed among the mean concentration of calcium values of all the areas compared to the control site (Fori) at ($P<0.05$). There were no significant differences between Fori (control site) at 0-15cm and London Ciki at 15-30cm.

The organic matter (OM) for the soil samples of the selected areas at different depths (0-15 to 15-30cm) ranged from 1.28 to 4.17 with an average mean value of 1.90. The highest mean was recorded at the Galimari area, 4.17 at 0-15cm, and the lowest at London Ciki, 1.28 at 0-15cm. Significant differences were observed among the mean OM values of all the areas compared to the sites ($P<0.05$). However, there were no significant differences between Galtimari and London Ciki at the depth of 15-30cm. The result agrees with those of Dan *et al*. (2018). The organic matter contents of the samples in the studied sites were also found to decrease with soil depth, which agrees with the findings of Dan *et al*. (2018).

The organic carbon (OC) for soil samples of the selected areas at different depths (0-15 to 15-30cm) ranged from 0.03 to 2.42 with an average of 0.98. The highest mean was recorded at Galimari area 2.42 at 0-15cm, and the lowest was recorded in London Ciki 0.03 at 0-15cm. Significant differences were observed among the mean OC values of all the areas compared to the sites (P<0.05). However, there were no significant differences between Galtimari and London Ciki at the depth of 15-30cm. The study is consistent with the results of (Wells *et al*., 2011).

The ratio of carbon to nitrogen (C: N) for soil samples of the selected areas at different depths (0-15 to 15-30cm) ranged from 3.17 to 4.26, with an average of 3.67. The highest mean was recorded at Galimari area, 4.26 at 0-15cm, and the lowest was recorded at Gwange, 3.17 at 0-15cm. Significant differences were observed among the mean C: N values of all the sites and depths (P<0.05). The C: N decreases with depth. The samples had larger values at 0–15 cm than the 15–30 cm soil layer, which agrees with the findings of (Radoˇcaj *et al*., 2021).

The phosphorus (P) concentration of the location's topsoil and subsoil ranges from 5.95 to 30.8 with an average of 20.69. The highest calcium concentration was recorded in Fori at 30.8 at the depth of 15-30cm, and the lowest concentration was recorded in the Galtimari at 5.95 at the depth of 15-30cm. Significant differences were observed among the mean concentration of phosphorus values of all the areas compared to the control site (Fori) at (P<0.05). However, there were no significant differences between Fori (control site) at 0-15cm and London Ciki at 15-30cm. As flooding increases the solubility of mineral elements, dissolution and dilution may contribute to low calcium concentrations in the study areas (Kelly *et al*., 2020).

The magnesium (Mg^{2+}) concentration of the location's topsoil and subsoil ranges from 11.6 to 35, with an average of 21.33. The highest magnesium concentration was recorded in London Ciki at 35 at the depth of 0-15cm, and the lowest concentration was recorded in London Ciki at 11.6 at the depth of 15-30cm. Significant differences were observed among the mean concentration of magnesium of all the sites compared to the control area (P<0.05). However, there were no significant differences between Galtimari and Gwange at the depth of 0-15cm.

The potassium (K^+) concentration of the location's topsoil and subsoil ranges from 0.10 to 0.17, with an average of 0.13. The highest magnesium concentration was recorded in London Ciki at 0.17 at the depth of 15-30cm, and the lowest concentration was recorded in Galtimari at 0.10 at the depth of 15-30cm. Significant differences were observed among the mean concentration of potassium of the control site (Fori) and Galtimari and London Ciki at a depth of 0-15cm (P<0.05). However, there were no significant differences between the control site and Galtiamri, Gwange, and London Ciki at a depth of 15-30cm. The levels of K^+ in this study were higher than those reported by Akodu *et al*. (2023), but consistent with values reported by Mofor *et al*. (2017).

The sodium (Na^+) concentration of the location's topsoil and subsoil ranges from 0.50 to 0.160 with an average of 0.11. The highest sodium concentration was recorded in Fori at a depth of 15-30cm and London Ciki at a depth of 0-15cm, and the lowest concentration was recorded in Galtimari at a depth of 15-30cm. Significant differences were observed among the mean concentration of sodium of the control site (Fori) and Galtimari and London Ciki at a depth of 0-15cm, and also between the control site and Galtimari, Gwange, and London Ciki at a depth of 15-30cm at (P<0.05). However, there were no significant differences between the control site and Gwange at 0-15cm and Galtimari and London Ciki at 15-30cm.

The highest and lowest TEB values of (London Ciki) 63.59 Cmolkg-^{1} and (Fori) 29.48 Cmolkg^{-1} were recorded at 0-15cm and 15-30cm, respectively, with an average mean of 38.59. Significant differences were observed among the mean TEB of the control site (Fori) and Galtimari, Gwange, and London Ciki at a depth of 0-15cm and between the control site and Galtimari, Gwange, and London Ciki at a depth of 15-30cm (P<0.05). However, there were no significant differences between the depths of 0-15cm and 15-30cm of Gwange.

The highest and lowest ECEC values of (London Ciki) 63.51 Cmolkg^{-1} and (Fori) 29.78 Cmolkg^{-1} were recorded at 0-15cm and 15-30cm, respectively, with an average mean of 39.24. Significant differences were observed among the mean ECEC of the control site (Fori) and Galtimari, Gwange, and London Ciki at a depth of 0-15cm, also between the control site and Galtimari, Gwange, and London Ciki at the depth of 15-30cm at (P<0.05).

The highest and the lowest PBS values of (London Ciki) 99.7% and (Fori) 98.9 % were recorded at 0-15cm depth with an average mean of 99.2. No significant differences were observed in the mean PBS between the control and other sites at different depths (P<0.05).

The nitrogen (N) concentration of the location's topsoil and subsoil ranges from 0.20 to 0.57, with an average of 0.29. The highest sodium concentration was recorded in Fori at a depth of 0-15cm, and the lowest concentration was recorded in Galtimari at a depth of 0-15cm. Significant differences were observed among the mean concentration of sodium of the control site (Fori) and Galtimari and London Ciki at a depth of 0-15cm, and also between the control site and Galtimari, Gwange, and London Ciki at the depth of 15-30cm at (P<0.05). However, there were no significant differences between the concentrations of nitrogen in London Ciki at the depths of 0-15cm and 15-30cm. The levels of N in this study were higher than those reported by Akodu *et al*. (2023), but consistent with values reported by Mofor *et al*. (2017).

The highest and the lowest Total Exchangeable Acidity (TEA) values of (Fori and Gwange) 0.4 Cmolkg-1 and (London Ciki and Gwange) 0.2 Cmolkg-1 were recorded at 0-15cm and 15-30cm, respectively, with an average mean of 0.29. No significant differences were observed in the mean TEA between the control and other sites at different depths ($P<0.05$).

The results of the physical properties of the flooded and controlled soils.

The highest clay contents were recorded in Galtimari (29.70%) at a depth of 0-15cm, while the lowest were recorded in Gwange and London Ciki (9.70%) at the depths of 0-15 and 15-30cm. The highest sand contents were recorded in Fori (82.80%) at a depth of 15-30cm, and the least was recorded at Galtimari (35.30%) at a depth of 0-15cm. The highest silt contents were recorded in Gwange (37.50%) at a depth of 0-15cm, and the least was reported in Fori (7.50%) at the depths of 0-15 and 15-30cm.

Texture classes of the flooded and the control soils

The results of the texture classes for the flooded and the control areas show that in all locations and across depths, the soil texture classes were dominated by loamy, sandy clay, and clay. In summary, the soils of London Ciki and Gwange were sandy loamy at all depths, Galtiamari were clay loamy at 0-15cm and sandy loamy at 15-30cm, while Fori was sandy loamy at 0-15cm and loamy sandy at 15-30cm.

Table 1: Physicochemical parameters of soil collected from some flooded areas and a control area in Maiduguri

	Site										
	FR	GL	GW	LC		FR	GL	GW	LC		
	Depth (0-15 cm)					Depth (15-30 cm)					
Parameter										±SEM	LSD(p<0.5)
pH	7.7±0.01^{a}	7.4±0.01^{c}	7.7±0.01^{a}	7.5±0.1^{b}		7.5±0.01^{b}	7.6±0.006^{a}	7.5±0.01^{b}	7.6±0.02^{a}	0.0151	0.0452
EC	0.10±0.09^{f}	0.18±0.01^{de}	0.32±0.01^{b}	0.41±0.0^{a}		0.13±0.0^{ef}	0.24±0.0^{cb}	0.28±0.0^{bc}	0.14±0.0^{ef}	0.0142	0.0426
TEA	0.4±0.1	0.3±0.1	0.4±0.1	0.2±0.1		0.3±0.1	0.3±0.1	0.2±0.1	0.2±0.1	0.0408	0.1224
Ca^{2+}	22.6±0.1^{b}	12.8±0.1^{e}	15.6±0.1^{c}	28±1^{a}		14±1^{d}	11.4±0.1^{f}	12±1^{ef}	22.6±0.1^{b}	0.2521	0.7557
Mg^{2+}	12.6±0.1^{f}	22.2±0.1^{d}	21.8±0.1^{d}	35±1^{a}		15.2±0.1^{e}	25.6±0.1^{c}	26.6±0.1^{b}	11.6±0.1^{g}	0.1493	0.4476
K^{2+}	0.13±0.0^{bc}	0.13±0.01^{bc}	0.14±0.01^{b}	0.15±0.0^{b}		0.12±0.0^{e}	0.10±0.09^{ef}	0.12±0.01^{e}	0.17±01^{a}	0.0142	0.0427
Na^{2+}	0103±0.09^{ab}	0.070±0.01^{b}	0.103±0.09^{ab}	0.160±0.01^{a}		0.160±0.01^{a}	0.050±0.01^{b}	0.080±0.01^{ab}	0.130±0.01^{ab}	0.0197	0.0591
TEB	35.43±0.09^{cd}	32.43±1.01^{e}	37.64±1.01^{b}	63.31±1.01^{a}		29.48±1.01^{f}	37.15±1.01^{bc}	38.77±0.95^{b}	34.50±1.1^{d}	0.4127	1.2373
ECEC	35.83±1.01^{cd}	35.5±1.1^{d}	38.04±1.01^{b}	63.51±1.01^{a}		29.78±1.01^{e}	37.45±1.01^{bc}	39.1±1.01^{b}	34.7±1.1^{d}	0.4218	1.2646
PBS	98.9±1.01	99.2±1.01	99.0±1.01	99.7±1.01		99.0±1.01	99.2±1.1	99.2±1.01	99.4±1.01	0.4168	1.2497
N	0.25±0.01^{bcd}	0.57±0.01^{a}	0.28±0.01^{bc}	0.2±0.1^{d}		0.28±0.01^{bc}	0.31±0.01^{b}	0.24±0.01^{cd}	0.21±0.01^{d}	0.0149	0.0447
OC	0.94±0.01^{d}	2.42±0.01^{a}	0.03±0.01^{c}	0.74±0.01^{g}		0.92±0.01^{e}	1.29±0.01^{b}	0.76±0.01^{f}	0.76±0.01^{f}	0.0041	0.0122
O.M	1.62±0.01^{d}	4.17±0.01^{a}	1.78±0.01^{c}	1.28±0.01^{g}		1.59±0.01^{e}	2.05±0.01^{b}	1.34±0.01^{f}	1.34±0.01^{f}	0.0041	0.0122
C: N	3.76±0.01^{c}	4.26±0.01^{a}	3.68±0.01^{dc}	3.7±0.1^{cd}		3.29±0.01^{f}	3.84±0.01^{b}	3.17±0.01^{g}	3.62±0.01^{e}	0.0149	0.0448
P	29.05±0.01^{b}	9.45±0.01^{f}	23.45±0.01^{d}	10.15±0.01^{e}		30.8±0.1^{a}	5.95±0.1^{g}	28±1^{c}	28.7±0.1^{b}	0.1458	0.4371
Soil class	Sandy loam	Clay loam	Sandy loam	Sandy loam		Loamy sandy	Sandy loam	Sandy loam	Sandy loam		

EC= Electrical Conductivity, OM= Organic Matter, TN= Total Nitrogen, ECEC= Effective Cation Exchange Capacity, PBS= Percentage Base Saturation, TEA=Total Exchangeable Acidity, TEB= Total Exchangeable Bases, FR=Fori, GL=Galtiamri, GW=Gwange, LC=London Ciki.

Mean values with the same superscripts (a, b, c) in the same column are not significant at $P>0.05$

Correlation of Physicochemical Parameters of Soil Collected from Some Flooded Areas in Maiduguri

The correlation among the chemical properties of the flooded soils and the Control soils revealed that chemical properties such as EC and Mg^{2+} (0.87) show a strong relationship at ($P<0.05$). The Mg^{2+} and electrical conductivity are strongly related, indicating that as EC increases, Mg^{2+} also tends to increase. Electrical conductivity and magnesium concentration are strongly related, suggesting that high EC values may be associated with magnesium availability.

The EC and Total Exchangeable Base (TEB) (0.78) show a strong positive relationship at ($P<0.05$). The EC and TEB are almost completely correlated, suggesting that EC is a good indicator of TEB.

The effective cation exchange capacity (ECEC) and EC (0.79) show a strong relationship at ($P<0.05$). The ECEC and electrical conductivity are strongly related, indicating that as EC increases, ECEC also manages to increases.

The effective cation exchange capacity (ECEC) and total exchangeable base (TEB) (0.99) show a strong relationship at ($P<0.05$). The ECEC and TEB are strongly positively related.

The calcium (Ca^{2+}) and total exchangeable base (TEB) (0.65) show a strong relationship at ($P<0.05$). The Ca^{2+} and TEB are strongly related, indicating that as Ca^{2+} increases, TEB also increases.

The magnesium (Mg^{2+}) and total exchangeable base (TEB) (0.77) display a strong relationship at ($P<0.05$). The Mg^{2+} and TEB are strongly related, indicating that as Mg^{2+} increases, TEB also increases.

The effective cation exchange capacity (ECEC) and Ca^{2+} (0.63) show a strong relationship at ($P<0.05$). ECEC tends to increase as Ca^{2+} increases. Mg also shows a similar pattern with ECEC.

The Organic Carbon (OC) and nitrogen (N) (0.95) show a strong relationship at ($P<0.05$). OC increases as nitrogen increases. The Organic Matter (OC) and nitrogen (N) (0.96) also show a strong relationship at ($P<0.05$). OM increases as nitrogen increases. The Carbon-to-nitrogen (C: N) ratio and nitrogen (0.66) show a strong relationship at ($P<0.05$). The C: N increases as nitrogen increases. The Organic Carbon (OC) and Organic Matter (OM) (1.00) show a strong relationship at ($P<0.05$). Organic carbon and organic matter are strongly related, indicating that they are interchangeable measures of soil organic content. The relationship is higher than all the parameters and suggests that OC increases as OM increases. The C: N and OC (0.76) and C: N and OM (0.78) show a strong relationship at ($P<0.05$).

On the other hand, the magnesium Mg^{2+} and phosphorus (P) (-0.68) show a strong negative relationship at ($P<0.05$). The magnesium ion concentration is strongly negatively related, implying that as Mg^{2+} increases, P tends to decrease. The C: N also decreases as P increases.

The OM, OC, and N increase as pH decreases and vice versa at ($P>0.05$), which indicates a strong negative relationship, indicating that pH affects OM, OC, and N availability. The OM, OC, and ECEC also increase as P decreases and vice versa at ($P>0.05$), which indicates a strong negative relationship.

These results show that soil pH plays a crucial role in determining the availability of various nutrients, such as calcium, nitrogen, organic matter, and organic carbon. Electrical conductivity is a good indicator of soil fertility, as it is strongly related to ECEC and moderately related to Ca^{2+} and K^{+}. Organic carbon and organic matter are interchangeable measures of soil organic content. Phosphorus availability may be limited in soil with high ECEC.

Correlation matrix of Physicochemical Parameters of Soil collected from Some Flooded Areas in Maiduguri

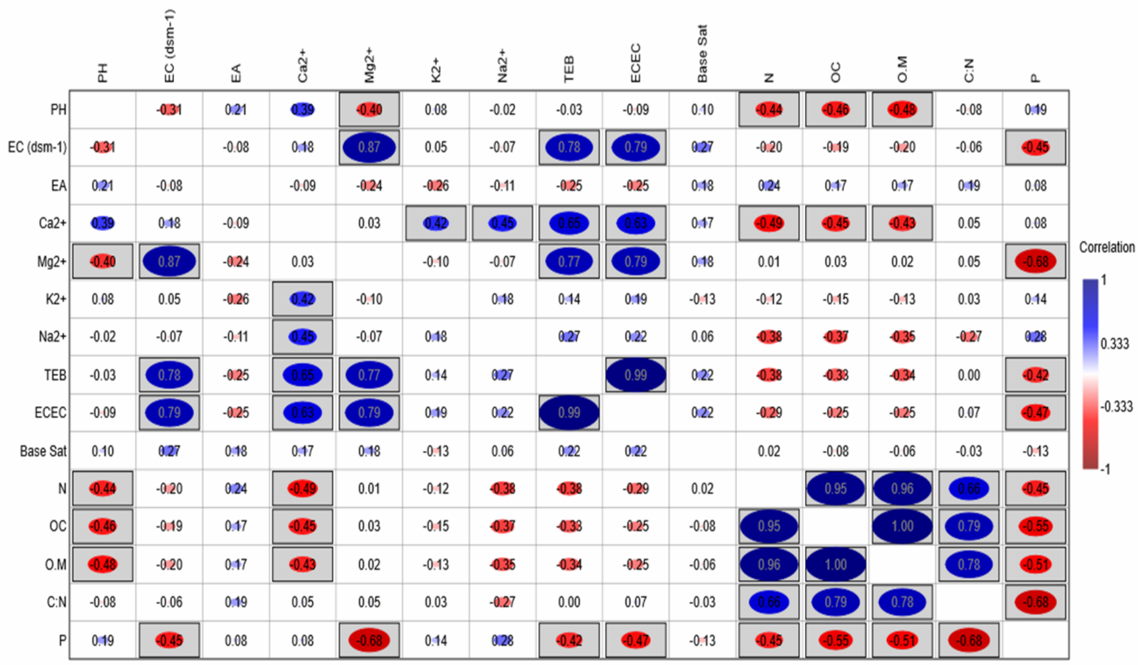


Fig. 1: Correlation matrix of physicochemical parameters of soils collected from some flooded areas in Maiduguri. NB: Grey box implies significant at (p>0.05). Blue implies a positive correlation, while red indicates a negative correlation.

The microbial analysis of the soil of the study areas: soil samples collected from three locations and the control soil were analyzed for bacteria and fungi.

Table 2 showed that the bacterial count was significantly different across the sites. The highest bacterial count was recorded in Gwange ($82{\pm}1^b$ cfu/g), and the lowest count was recorded in London Ciki ($2.8{\pm}0.01^a$ cfu/g) at dilution 10^{10}.

The bacterial count was higher in the flooded area compared to the control area, which agrees with the findings of Ito, & Uhunoma (2014). It showed that prolonged flooding had a greater effect than nutrient loading in that flooding altered both the composition as well as functional components of the microbial community.

Table 2 showed that the fungal count was significantly different across the sites. The highest fungal count was recorded in Galtimari ($12{\pm}1^c$ cfu/g), and the lowest count was recorded in London Ciki ($2.4{\pm}0.01^a$ cfu/g) at dilution 10^{10}. The fungal count was higher in the flooded area.

Microbial results

Table 2. Microbial parameters of soil collected from some flooded areas in Maiduguri

	London Ciki	Gwange	Galtimari	Fori
TBC (10^{10})	$2.8{\pm}0.01^a$	$82{\pm}1^b$	$40.5{\pm}0.1^c$	$43.43{\pm}0.21^d$
TMC (10^{10})	$2.4{\pm}0.01^a$	$4.3{\pm}0.1^b$	$12{\pm}1^c$	$10{\pm}1^d$

Mean values with the same superscripts (a, b, c) in the same column are not significant at (p>0.05). TBC = Total Bacteria Count, TMC = Total Mould Count.

V. Discussion, Recommendation, And Conclusion

Discussion

The higher value of pH observed in the flooding area in this study may not be unconnected with the effects of the flood, which makes the pH value approach neutrality. The high pH value could also influence micronutrients, which thrived at the expense of soil wetness. The most substantial property of soil is its pH level and its effects on all other parameters of soil. Therefore, pH is considered while analyzing any kind of soil. If the pH is less than 6, then it is said to be acidic soil; the pH ranges from 6-8.5, its normal soil, and greater than 8.5, then it is said to be alkaline soil (Chaudhari, 2013).

Soil pH directly affects the activity of nitrogen-fixing microbes and the solubility of many of the nutrients in the soil needed for proper plant growth and development. Some elements, like potassium, magnesium, calcium, and phosphorus, are likely to be unavailable to plants in acidic soil, and in basic soil, elements like copper, zinc, boron, manganese, and iron are not easily absorbed by plants (Neina, 2019).

The results agree with the findings of Jenkwe (2023) and those of Talbot *et al.* (2018). The pH values of the areas were significantly different regarding depths and sites (P>0.05). The decrease/fluctuation in pH levels that follows flooding demonstrates that floods affect the flooded soil. Thus, the soil becomes more acidic. When organic acid is fermented in a highly saturated soil, the pH level of the soil decreases. With increasing alkalinity, the pH of acidic soils increases, while the pH of alkaline soils falls. The soil's pH is a significant determinant of which elements are available for plant absorption (Neina, 2019).

The results of the electrical conductivity (EC) in the study area showed that the electrical conductivity of the flooded soils was slightly higher than the control soils, though the result of the analysis of variance showed a significant difference (p>0.05). Thus, the slight rise in the electrical conductivity of the soils could be ascribed to the occurrence of floodwater. The rise in the EC of the flooded soils could also be a result of more moisture content in the control soils. A soil's electrical conductivity (EC) is a measure of soil salinity that directly influences crop growth and development in the soil. When ions (salts) are present, the EC of the solution increases.

The EC is low if no salts are present, indicating that the soil solution does not conduct electricity well. Salts are influenced by various factors such as rainfall amount and timing, internal soil drainage, and irrigation practices. Usually, rainfall contains low amounts of salts and acts to dilute salts that are present in the soil. During drying, water is lost from the soil due to evaporation, and salts are effectively concentrated. The utility of soil and water electrical conductivity (EC) is immense as an indicator of the condition and stewardship of farmlands and water resources (Alam *et al.*, 2020).

The values that decreased down the soil profile could be attributed to deposition after the flood, which may raise the values in topsoil than the layers beneath (Olayimka *et al.*, 2017). It was also found that the older the dumpsite, the higher the decomposition rate of its constituents comprising the waste soil (Sani *et al.*, 2012).

The apparent soil EC is influenced by various factors such as soil porosity, the concentration of dissolved electrolytes, texture, quantity, and composition of colloids, organic matter, and water content in the soil. The EC of soils varies depending on the amount of moisture held by soil particles. Sands have a low conductivity, silts have a medium conductivity, and clays have a high conductivity (Corwin & Lesch, 2018).

TEA established that there is a high rate of acidity in the flooded area, matching that in the control area. This means that there is a high rate of negative changes in organic matter in flooded soils.

The results of the calcium (Ca^{2+}) value in the study area proved that the calcium reduced significantly ($p>0.05$). However, the slight rise in the value of magnesium can be attributed to the effect of flooding. The increase in the value of magnesium because of flooding showed that flooding plays a part in healthy development, since magnesium is among the essential micronutrients required in the soil for improved soil productivity. As flooding increases the solubility of mineral elements, dissolution and dilution may contribute to low calcium concentrations in the study areas (Kelly *et al*., 2020). During a significant flood, when water permeates the soil and flushes away dissolved compounds via leaching, it is normal to anticipate a larger loss of soil nutrients (Jenkwe, 2023).

The findings from this study show that the levels of potassium (K^+) found in the flooded area compared to the control area are significantly different ($p>0.05$**)**. Thus, the reduction in the value of potassium could be attributed to the effect of flooding water. However, potassium is among the macronutrients that are not only required for healthy plant growth in the soil but also for proper microbial performance.

The results of the level of sodium (Na^+) showed that the control area had a higher sodium value than those found in the flooded area and were significantly different ($p>0.05$). It could be expected that during a high flood, more soil nutrients would be lost because of erosion and runoff.

The results on Total Exchangeable Base (TEB) were found in the flooded area to be higher, compared to the control area, with a significant difference at ($p>0.05$).

The results of the Effective Cation Exchange Capacity (ECEC) showed that ECEC values from flooded areas and control areas were significantly different ($p>0.05$). However, the ECEC in the flooded area was generally higher than that control area, and this could be a result of a reduction in the organic matter, usually experienced in the flood-affected soil. The fact that a decline in cation exchange capacity levels during the flood is likely to affect the soil.

The results of the Percentage Base Saturation (PBS) found from the flooded areas were slightly less than those in the control soils. Nevertheless, the difference was not significant ($p>0.05$). This result shows that there was a loss in percentage-based saturation during flooding. The moderate values obtained could be attributed to deposition by the flood as well as nitrogen introduced to the soil by natural processes such as lightning and decayed plant tissues (Akodu *et al*., 2023). Nitrogen is essential to plants for the formation of living tissues as it is a necessary component of proteins such as DNA and RNA, as well as vitamins, hormones, and enzymes (Akodu *et al*., 2023).

The result of OM agrees with those of Dan *et al*. (2018). The organic matter contents of the samples in the studied sites were also found to decrease with soil depth, which agrees with the findings of Dan *et al*. (2018). The values may be attributed to the fact that topsoil usually contains more plant residue and vegetables (Ojo *et al*., 2017). Soil organic matter enhances the usefulness of soils for agricultural purposes. It supplies essential nutrients. It also functions as a source of food for soil microbes and thereby helps enhance and control their activities (Okeke *et al*., 2020). Soil organic matter usually acts as a storehouse or reservoir for most metals and hence can influence their bioavailability in the soil (Dan *et al*., 2018). Organic matter is a key characteristic of soil and environmental quality because it is an essential sink and source of main plant and microbial nutrients, and additionally exerts a profound influence on physical, chemical, and biological functions (King *et al*., 2020).

The values may be attributed to the fact that topsoil usually contains more plant residue and vegetables (Ojo *et al*., 2017). Soil organic matter enhances the usefulness of soils for agricultural purposes. It supplies essential nutrients. It also functions as a source of food for soil microbes and thereby helps enhance and control their activities (Okeke *et al*., 2020).

The results of Organic Carbon (OC) in the control areas were slightly lower than those of the control area and showed a significant difference ($p>0.05$). The reduction in Organic Carbon in the flooded area could be a result of bacterial decomposition or the ratio that took place after the flooding effects in the study area. In a nutshell, the decreased Organic Carbon content of soil could adversely affect soil quality and fertility since Organic Carbon is required to stimulate microbial respiration and activities. The study is consistent with the results of (Wells *et al*., 2011). The organic carbon contents of the soil samples from the studied sites were found to decrease with soil depth, which is consistent with the findings of Okeke *et al*. (2020). Many studies state that the majority of OC is found primarily between 0 to 30 cm because it is the most biologically active (Wells *et al*., 2011); however, according to Wiesmeier *et al*. (2012), OC content is greater than 50% in the subsoils of most ecosystems. Plant growth and carbon are interlinked. Soil organic carbon influences soil features such as color, nutrient turnover, nutrient holding capacity, and stability, which affect the water relation, workability, and aeration (Chaudhari *et al*.,2013). The organic carbon contents of the soil samples from the studied sites were found to decrease with soil depth, which is consistent with the findings of Okeke *et al*. (2020). Many studies state that the majority of OC is found primarily between 0 to 30 cm because it is the most biologically active (Wells *et al*., 2011); however, according to Wiesmeier *et al*. (2012), OC content is greater than 50% in the subsoils of most ecosystems.

The C: N decreases with depth. The samples had larger values at 0–15 cm than the 15–30 cm soil layer, which agrees with the findings of (Radoˇcaj *et al*., 2021). The determination of the actual C: N ratio is very important because this ratio affects both the mineralization and immobilization of soil nitrogen and hence its availability to plants (Gaffer, 2015). Carbon-to-nitrogen (C: N) ratio is often used as a determinant for the health of soil (Xu *et al*., 2016). Soil microorganisms (fungi, bacteria, protozoa, nematodes, etc.) are directly affected by the C: N ratio. Nitrogen is essential for microbial growth; therefore, a higher C/N ratio results in lower decomposition activities by soil microorganisms (Brady and Weil, 2002; Laurence *et al*., 2015). The determination of the actual C: N ratio is very important because this ratio affects both the mineralization and immobilization of soil nitrogen and hence its availability to plants (Gaffer, 2015).

The levels of K^+ in this study were higher than those reported by Akodu *et al*. (2023), but consistent with values reported by Mofor *et al*. (2017). The low concentration of both K^+ and Na^+ could be attributed to the fact that elements often bond to the soil macroparticles, thereby reducing their availability in the soil. It could also be a result of their higher ionic charge, which makes them bond more to the exchangeable sites than ions of lower ionic charge (Osakwe 2014).

The results of the physical properties of the flooded and controlled soils.

The highest clay contents were recorded in Galtimari (29.70%) at a depth of 0-15cm, while the lowest were recorded in Gwange and London Ciki (9.70%) at the depths of 0-15 and 15-30cm. The highest sand contents were recorded in Fori (82.80%) at a depth of 15-30cm, and the least was recorded at Galtimari (35.30%) at a depth of 0-15cm. The highest silt contents were recorded in Gwange (37.50%) at a depth of 0-15cm, and the least was reported in Fori (7.50%) at the depths of 0-15 and 15-30cm.

Texture classes of the flooded and the control soils

The results of the texture classes for the flooded and the control areas show that in all locations and across depths, the sand texture classes were dominated by loamy, sandy clay, and clay. In summary, the soils of London Ciki and Gwange were sandy loamy at all depths, Galtiamari were clay loamy at 0-15cm and sandy loamy at 15-30cm, while Fori was sandy loamy at 0-15cm and loamy sandy at 15-30cm.

Microbial counts of flooded and controlled soils

The microbial count of soil samples from this study varied in response to flood disturbances. Samples from the experiment showed a change in microbial count with flooding. However, the field study showed a greater influence of location. It agrees with Ito & Uhunoma (2014), suggesting that prolonged flooding had a greater effect than nutrient loading in that flooding altered both the composition and functional components of the microbial community. It is also consistent with Mentzer *et al*. (2006) reported that flooding increases gram-negative bacterial, anaerobic bacterial, and Gram-positive bacterial markers.

The findings suggest that flooded soil exhibits higher bacterial and fungal counts compared to non-flooded soil. This is consistent with existing Ito & Uhunoma (2014), which indicates that flooding can alter the soil microbiome, leading to increased microbial activity and diversity.

Flooding can lead to an influx of nutrients, such as organic matter and nutrients from sediment and runoff, which support microbial growth. And it has higher moisture content, creating an ideal environment for microbial growth and activity.

Conclusion

The findings of this study concluded that some nutrient levels in both the control and flooded soils of the study areas are significantly different some are not, which suggests that some nutrients are leached during flooding, some are added through deposits from rivers and streams, and some are unaffected by the flood. The level of depletion and addition of such soil properties may perhaps be connected to the level and duration of flooding and the slope of the affected areas. This makes the effect of flood on the flooded and control soils, and indeed any other soil, unpredictable.

The results showed that flooding affects soil pH, electrical conductivity, and nutrient availability. The study highlights the importance of considering the impact of flooding on soil chemical properties and its potential effects on plant growth and nutrient availability.

Flooding can lead to an influx of nutrients, such as organic matter and nutrients from sediment and runoff, which support microbial growth. And it has higher moisture content, creating an ideal environment for microbial growth and activity.

Recommendation

Based on the findings of this study, the following recommendations are made: regular soil testing should be conducted to monitor the chemical properties of soils in flood-prone areas soil management practices, such as liming and fertilization, should be implemented to mitigate the effects of flooding on soil chemical properties. Conservation measures, such as terracing and contour farming, should be implemented to reduce soil erosion and nutrient loss due to flooding.

Further research should be conducted to investigate the long-term effects of flooding on soil chemical properties and to develop strategies for mitigating these effects.

Regularly monitor soil microbial communities and nutrient levels to better understand the impacts of flooding and inform management decisions. Further studies are encouraged to explore the long-term effects of flooding on soil microbiology and ecosystem functioning.

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Appendix

Fig 1

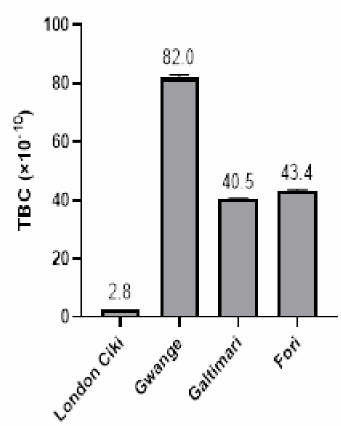
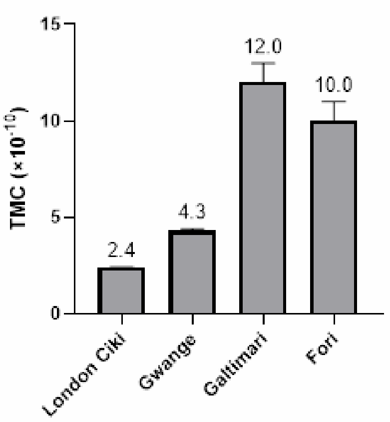
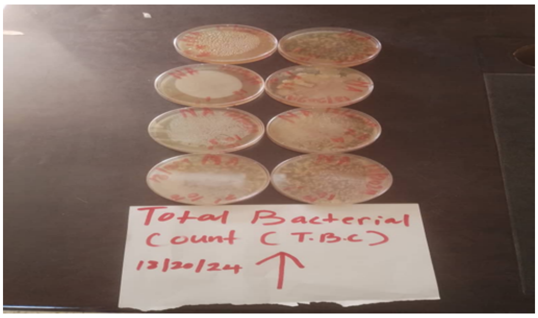


Fig 3




Total Bacterial
Count (T.B.C)
13/20/24