ASSESSMENT OF SOIL INFILTRATION CHARACTERISTICS OF LAND USES IN URBANIZING WETLANDS IN PORT HARCOURT METROPOLIS SOUTH-SOUTH NIGERIA

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ABSTRACT

The capability of certain spatial activities to trigger a cycle of environmental problems in a reactor (like soil) necessitated the assessment of soil infiltration characteristics of land uses in urbanizing wetlands in Port Harcourt metropolis, South-South Nigeria. The study adopted the experimental design that warranted laboratory analysis of the physical properties such as porosity, bulk density, moisture content, and permeability that determines infiltration characteristics. 21 soil samples was collected from 4 land uses (agricultural, residential, commercial and artisanal) in each of the 5 selected wetlands and Control in the study area. The result of the physical properties of the soil samples was subjected to statistical analysis of mean and standard deviation. The study revealed mean Porosity of 0.36%, moisture content of 14.51%, and Permeability of 128.10 cm/h in the land uses that falls within the ≤ 0.99%, 10%-40% and 120-250 cm/h USDA classification of Low Porosity (LP), Normal Moisture (NMC), and Rapid Permeability Index (RPI) respectively for soil samples. Also, the study found that mean bulk density of 2.45 g/cm3 in the land uses fit into the USDA classification of soil with bulk density of ≥ 2.00 gcm-3 as High Bulk Density (HBD) that predispose soil to high infiltration rate. While the values of 1.09 g/cm3, 0.33%, 10.33%, and 91.95% for bulk density, porosity, moisture and permeability respectively obtained at Rumuekini (Control) fits into the USDA classification of such soil as Low Bulk Density (LBD), Low Porosity (LP), Normal Moisture Content (NMC), Slow Permeability Index (SPI) respectively. The study mathematically expressed that HBD = LIR while LBD = HIR. The study recommended that developers prior to the approval of their land use applications should be made to understand and attest their compliance and vicarious liability to wastes or effluents discharge laws in order to forestall the intrusion or incursion of contaminants into the soil.

KEY WORDS: Soil, infiltration characteristics, land uses, urbanizing wetlands

INTRODUCTION

Soils literally provide food, fodder and fuel for meeting the basic human and animal needs (Schoonover & Crim, 2015), including facilitating the proper functioning of ecosystem processes and services in that area (Finlayson et al., 2017). This understanding will eliminate actions that gives rise to unethical use of earth's resources (like soil) that can influence the infiltration capacity or maximum rate of infiltration (*Kirkham, 2014)*. Infiltration is the movement of water from the surface due to gravitational flow into the soil (Thompson et al., 2010). Osuji et al. (2010) stated that infiltration rate is determined by the characteristics of the soil. This Eludoyin and Akinola (2015) stated is anchored on the land use patterns (via built-up, vegetation, wetland, industrial, and water bodies), which influenced the current material depositions and toxins linked to the productivity and survival of the flora (plant abundance) and fauna species (animals) in that soil.

Huot et al. (2015) assert that land uses could result in the formation of technosols (i.e. soils having more than 20% artefacts, relics, pebbles, sediments and debris) with comparatively poor aeration, high leaching levels and different infiltration characteristics when assessed with that of the original soil. Conversely, having erroneous view of soil has the propensity to induce the engagement in negative and unsustainable actions (like waste littering, indiscriminate allotment of land, etc.) and activities (agricultural practices, zoos, park and gardens, etc.) in wrong areas. Implicitly, forestalling unethical and unsustainable use of soil through tillage, effluent discharge, fertilizer application and developments (like construction of roads, industrial estates, residential buildings, health facilities, and educational institutions etc.) underscores the essence of assessment.

Soil assessment and classification schemes can sometime be difficult to communicate to all persons due to the complexities in reliably ascertaining and interpreting their nature, size and composition (Hartemink, 2015). This could beget inapt application of organic and inorganic manure in especially saline soils that in 5 consecutive years results in the increase of that soil bulk density and moisture content and decreases the infiltration rate (Imadi & Ahmad, 2016). In reality, both properly and improperly regulated urbanization activities in wetlands inevitably inundates soil with alien materials. However, inadequate regulation of land uses could lead to that land crossing its ecological threshold in such a way that the ecosystem quality, services and health may no longer return to its inherent, characteristic or natural resilience state (Oku, 2017). Hence, Onugha (2021) assert that increased knowledge and understanding of soil properties would be beneficial to resource management, soil stability, biodiversity conservation, and sustainability.

Chen et al. (2016) reiterate that adequate knowledge and proper management technique begets appropriate land uses that will promote ecological rehabilitation and restoration of soil properties which otherwise would have been lost or altered due to wrong spatial developments. Besides, assessing soil infiltration characteristics in urbanizing wetlands (conceptualized as wetlands inundated by developments up to the river banks) is predicated on the understanding that soil is a slowly naturally formed (i.e. 178 years for 1 cm soil), quickly pedogenic, and slowly renewable dynamic natural resource that activities therein can ultimately influence the sustainability of land uses (Schoonover & Crim, 2015). However, Ezekwe (2017) stated that the slowly formed soils can be shortly destroyed within 8 years by wrong spatial activities like construction, farming method, exploration, etc. Alluding to this, Imadi and Ahmad (2016) assert that parent materials of soil may be altered by anthropogenic activities. Hence, Fekadua et al. (2018) advocated assessing soils properties in order to provide adequate reference point and information for quick understanding and deduction that culminates to sustainable land use.

Furthermore, assessing the soil infiltration characteristics according to Ezekwe (2017) is extremely important since regions or areas with soft rocks are easily broken down into soil particles that results into a higher frequency of soil formation. This implies that an area like Port Harcourt metropolis that is resting on an elevation of about 13m above sea level (Wali, 2015), with its soils described by Chiadikobi et al. (2011) as being ferrallic and saline soil, but low in mineral reserve and fertility. Huot et al. (2014) stated that soil dissimilarity may constrain the growth of organisms which aerate, regenerate and enrich or nourish soils especially those to be used for agricultural purposes. Accordingly, Onugha (2021) found that extremely polluted soils of Port Harcourt metropolis was induced by soils inundated by unethical land uses that predispose them to regularity of human aided soil formation with high spatial heterogeneity in deposition, hydrogeology, pollutants, structuration, leaching, fertility, aeration, infiltration rate, among other soil properties.

Statement of the Problem

Every space belongs to a distinctive specific soil property with varying level of aeration, leaching, infiltration, compaction, fertility, mineralogy and quality that would influence the land use types (agriculture, residential, artisanal, commercial, etc.) in a wetland environment. In specificity, understanding the infiltration characteristics of soil enhances accurate measurement, making valid pollutants assessment, and adopting appropriate management technique (like conservation, technology, etc.) in varying land uses. Although, whether aptly or not; interactions in the soil via construction, excavation, tillage including land reclamation or sand-filling of wetlands located in swampy, depressed or burrow-pits landscapes results in the creation of Technosols (i.e. soils with more than 20% artefacts, stones, garbage, etc.) with tiny pores, low aeration, and permeability rate that could induce infiltration, leaching and high pollution effects.

This therefore, implies that urban growth is seemingly becoming not only a necessary activity but inevitable soil formation and change venture. In the midst of such significant process, retaining somewhat the viability and endowments of the original soil properties needed for biodiversity and developmental support (like buildings, drainage, roads, telecommunication facilities, amongst other infrastructures) in the newly formed soil in an urban inundated wetland, is indeed a major research concern for sustainable urban environmental management. Hence, it is succinctly articulated herein that cautiously undertaking the ensuing land uses (like agricultural, residential, industrial, infrastructural, etc.) in a way that the likely inevitable pedogenic soils does not entirely destroy the natural resources. It is based on this premise that this study assesses the soil infiltration characteristics of land uses in urbanizing wetlands in Port Harcourt metropolis, South-South Nigeria.

Objectives of the Study

The objectives of the study are to:

1. Examine the soil infiltration characteristics of the soil in the residential land use in the selected wetlands in the study area.
2. Ascertain the soil infiltration characteristics of the soil in the agricultural land use in the selected wetlands in the study area.
3. Determine the soil infiltration characteristics of the soil in the commercial land use in the selected wetlands in the study area.
4. Find out the soil infiltration characteristics of the soil in the artisanal land use in the selected wetlands in the study area.

Research Questions

The following research questions guided the study'

1. What is the soil infiltration characteristics of the soil in the residential land use in the selected wetlands in the study area?
2. What is the soil infiltration characteristics of the soil in the agricultural land use in the selected wetlands in the study area?
3. What is the soil infiltration characteristics of the soil in the commercial land use in the selected wetlands in the study area?

4. What is the soil infiltration characteristics of the soil in the artisanal land use in the selected wetlands in the study area?

Scope of the Study

The study would be limited to the assessment of soil infiltration characteristics of land uses in urbanizing wetlands. The study in terms of geographic scope was centred in Port Harcourt metropolis (covering Port Harcourt City and Obio-Akpor Local Government Areas) in South-South Nigeria. While in terms of content scope, the study focused on all the identified freshwater and saltwater urbanizing wetlands (conceptualized as wetlands inundated by changes in the form of developments such as commercial, artisanal, industrial, residential, defense, institutional, and pipeline routes, including transportation (like road, rail and seaport) and communication (like masks, cables, interchange, etc.) infrastructures down to the river) with varied levels of land uses that can influence the infiltration characteristics and associated impacts in the study area.

Study Area

In terms of location and extent, the study was **s**pecifically carried out in Port Harcourt metropolis, which comprises Port Harcourt City and Obio-Akpor Local Government Areas of Rivers State. The study area is bounded in the East by Emohua Local Government Area (LGA), in the West by Eleme LGA, in the South by Okrika LGA, while in the North by Ikwerre and Etche LGAs. In terms of size, Uwalaka (2014) states that Port Harcourt metropolis is 369 km^2, out of this, land covers 360 km^2, water covers 9 km^2, while built-up area is 158 km^2. Also, Geographically, Port Harcourt metropolis is located within Latitudes 4◦ 42′ N, and 4◦ 55′ N and Longitudes 6◦ 53′ E and 7◦ 08′ E (Eludoyin & Akinola, 2015), and located 25.6 km from the Atlantic Ocean (Wali, 2015). In terms of climate, the study area features a tropical monsoon climate with double maxima rainfall regime spanning from March to November, and a very short dry season mainly around the months of December and January.

In addition, the soil of Port Harcourt metropolis are majorly saline and consists of Deltaic plain soils which are found in wetland and upland areas. Surface soil colours in the study area is mainly brown or very dark grayish brown and are well drained having no mottles (Chiadikobi et al., 2011). The relief of the study area is low-lying and the rivers are influenced by tidal fluctuation. Port Harcourt metropolis lies at an average altitude of about 12m above mean sea level that falls within the coastal belt dominated by Low-Lying coastal plains which structurally belongs to the sedimentary formation of the recent Niger Delta (Arokoyu & Ukpere, 2014). The study area is drained by many rivers (both salt and fresh water) such as Ntawogba, New Calabar, Amadi Creek, Woji River, Mini Apalugbo, Mini Ekere, Mini Ndai, Primose River, Rumuoparali River,
Mgbuodohia River, etc.

Instructively, Ntawogba River drain Rumuokwuta, Ikwerre Road, G.R.A. Phases III and IV (Rumueme Community) and Amadi Flats (Rumuoparali and Ogbunabali Communities). Also the Ntawogba River drains the Bonny River to the West and Amadi Creek to the East, Dockyard lies to the south of Port Harcourt Township and Borikiri; an area where it makes a unique network with swamps and several creeks including Isaka River and Dick Fiberesima Creek (Chiadikobi et al., 2011; Weli & Ideki, 2014). However, recent developments in this area that is projected at 3, 861 349 as at 2016 (NPC, 2016) accounts for the populace engagement in oil exploration, manufacturing, trading, merchandizing, food processing, and civil service. Including health care, housing, petrochemicals, bulk cement production, construction, administrative, commercial, financial, artisanal, and printing activities and centres that are uncontrollably extending
and invading into conserved areas, wetlands and water bodies. This unregulated invasion through unethical land use accentuates the shrinking of wetlands and its ecosystem services including the narrowing river channels, flow, morphometric characteristics, and discharge capabilities in the study area. This corroborates with the findings by Onugha (2021) that water body in Port Harcourt metropolis reduced from its

17.37% size in 1990 to 5.57% size in 2020 (see Figure 1 for the map of the study area).

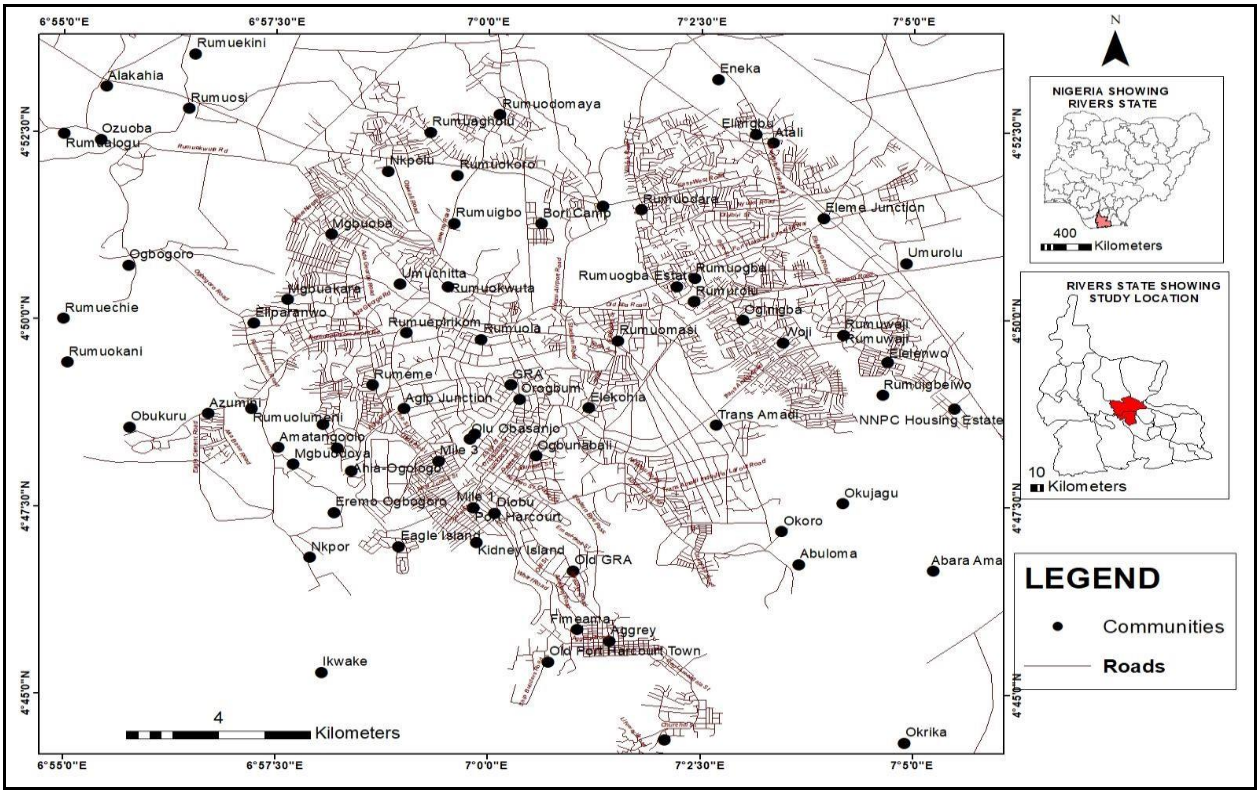

Figure 1: **Port Harcourt metropolis showing major roads, layouts and drainage (Insert showing Nigeria and Rivers State)**

Source: ***Rivers State Ministry of Lands and Survey (2021)***

MATERIALS AND METHODS

Research Design: This study adopted the true-experimental design. Nwankwo (2013) stated that the true-experimental design is applied in studies where all the threats to validity can be controlled.

Population of the Study: The population of the study comprised all the forty (40) wetlands that were identified in their clusters in Port Harcourt metropolis (i.e. Port Harcourt and Obio-Akpor Local Government Areas) measuring about 369 km^2 (Uwalaka, 2014). Also, the wetlands in the study area covers a total size of 43,475 ha comprising 19, 170.58 ha with 15 wetlands in Port Harcourt Local Government and 24, 304.34 ha with 25 wetlands in Obio-Akpor Local Government Area (Onugha, 2018).

Sample and Sampling Technique: A sample of six (6) wetland locations (representing approximately 15% of the total of 40 wetlands) comprising five (5) fully urbanized wetlands and one (1) partially urbanized wetland (i.e. control) that are drained by water bodies (i.e. oceans, rivers, streams, estuaries and canals) were selected for this study. This selected percentage according to Nwankwo (2013) constitute a fair representation of the study's population that was scientifically drawn. In order to achieve this, a three-phased multistage sampling was utilized. Firstly, purposive sampling technique was used in selecting one partially urbanized wetland in Rumuekini area (i.e. the control). In the second phase, random sampling technique was used or employed in the selection of two (2) urbanized wetlands (i.e. approximately 13% of the 15 wetlands) and three (3) urbanized wetlands (i.e. approximately 12% of the 25 wetlands) in Port Harcourt and Obio-Akpor Local Government Areas respectively. This process led to the selection of wetland locations such as; Ogbunabali and Nkpogu wetlands in Port Harcourt Local Government Area that are drained by the Amadi Creek and Nwaja River respectively. While Rumuagholu, Rumueme, and Minikpeti wetlands that are drained by Apalugbo stream, Rumueme River, and Mini Ndai respectively were selected in
Obio-Akpor Local Government Area.

Secondly, purposive sampling technique was used in the selection of four (4) land uses (via residential, artisanal, agricultural, and commercial) where soil samples was collected from each of the 5 urbanized wetlands and the 1 partially urbanized wetland (serving as the control). In the third and final phase, 40 soil samples (comprising 4 topsoil soil samples and 4 subsoil samples totaling 8 soil samples (i.e. 2 each) from each of the 4 land uses) was collected in each urbanized wetland located in Ogunabali, Nkpogu, Rumuagholu, Rumueme and Minikpeti communities, and 2 soil samples (via 1 topsoil and 1 subsoil) at the Control located in Rumuekini community. Government Area). This constituted a sample of 42 soil samples (via 21 topsoil soil samples, and 21 subsoil samples) from the 21 selected sampling points in the 6 urbanized wetland locations.

Instrumentation: The instruments used for this study included: Global Positioning System (GPS), Ziploc, aluminum foil, masking tape, and hand auger. The GPS was used for determining the coordinates of the sampling points, while an instrument like hand auger was used in the random collection of the triplicate soil samples at two depths via 0-15cm depth (top soil), and 15-30cm depth (sub-soil) in all the 6 randomly selected wetlands (i.e. 5 urbanized wetlands and 1 partially urbanized wetland).

Method of Data Collection: The top and sub soil samples was collected from the four (4) land uses in each of the 5 randomly selected urbanized wetlands (experimental), and 1 partially urbanized wetland site (i.e. the control). This implied that 8 soil samples were collected from each of the sampling points accumulating to 40 soil samples across the 5 sampling points, and 2 soil samples from the control, thereby totaling 42 soil samples. Also, the multiple processes of data collection began with the use of the hand augar for random collection of triplicate soil samples and then composite (i.e. collection of related top or sub-soil samples at different point and then merged or mixed together into one sample) to form each soil sample (i.e. representative sample) at both 0-15cm depth (top soil), and 15-30cm depth (sub-soil) for all the forty-two (42) sampling.

In specificity, each of the 42 representative soil samples that were collected across the 5 wetland locations and the control were wrapped in a labelled aluminum foil that was then packed into sealed or air tight Ziploc. This was based on the procedure and precautionary measures for collecting soil sample for determining physical properties such as porosity, bulk density, moisture content, and permeability that are determining the infiltration characteristics. In addition, the coordinate (i.e. Northings, Easthings, and

Elevation) of the 20 sampling points were taken prior to the collection of soil samples in respect to their land uses (via residential, artisanal, agricultural, and commercial) and the control. Hence, the validation of the coordinates (see Figure 2) and observance of precautionary measures was to enhance the reliability and accuracy of the sampling process devoid of any form of manipulation and contamination of the soil samples respectively.

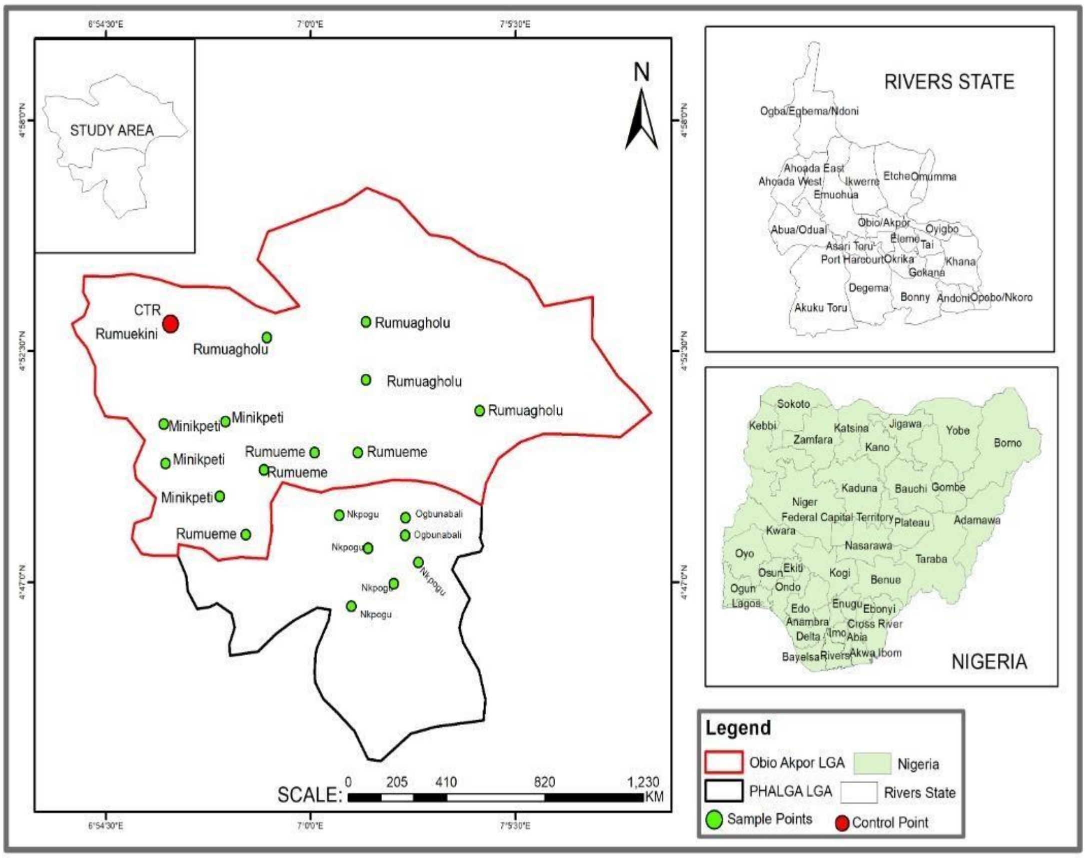

Figure 2: Geographic and Validation Coordinates of the Sample Points in the Study Area

Source: Field Work Summary, 2021

Methods of Data Analysis: The laboratory analysis of soil samples and statistical analysis of data generated from the soil tests were discussed under two sub-headings:

Laboratory Analysis of Soil Samples: The laboratory analysis began with either oven drying and chemically digested soil samples (where applicable), followed by crushing and then sieving it in order to determine the physical parameters. In specificity, the moisture content of the soil samples were determined gravimetrically after drying the soils in an oven to a constant weight (Gallenkamp OV-330) at 105°C until a constant weight was obtained (Maiti, 2003). Similarly, the bulk densities were carried out using the gravimetric method (Olofunmi & Alli, 2016). While, the porosity of the soil samples was determined or calculated from the bulk density.

3.7.2 Statistical Analysis of Data Generated from Soil Test: Generally, the statistical analysis adopted upon completion of data entry was addressed using tables, mean and standard deviation.

RESULTS

Research Question 1: What is the soil infiltration characteristics of the soil in the residential land use in the selected wetlands in the study area?

Table 1: Infiltration Characteristics of the Soil in the Residential Land Use in Wetlands in the Study Area

SP	Bulk Density cm/h	Porosity %	Moisture %	Permeability g/cm^3
	$\bar{x}$±SD	$\bar{x}$±SD	$\bar{x}$±SD	$\bar{x}$±SD
SP1	1.03± 0.01	0.37± 0.01	11.49± 0.45	123.85± 5.02
SP 6	2.97± 0.01	0.37± 0.01	15.81± 3.67	131.25± 6.44
SP 10	2.28± 0.10	0.37± 0.02	13.36± 0.08	104.45± 0.92
SP 14	2.70± 0.02	0.37± 0.00	12.53± 0.18	129.45± 2.62
SP 20	2.93± 0.01	0.38± 0.01	12.83± 0.30	115.85± 9.41
Grand $\bar{x}$±SD	**2.38± 0.03**	**0.37± 0.01**	**15.83± 0.81**	**120.97± 4.88**
USDA (2016) Classification	**HBD**	**LP**	**NMC**	**RPI**

Infiltration Rate	**High Infiltrate Rate**			
Control	1.09± 0.01	0.33± 0.01	10.33± 1.00	91.95± 6.15
USDA (2016) Classification	**LBD**	**LP**	**NMC**	**SPI**
Infiltration Rate	**Low Infiltration Rate**			

Source: Authors Computation, 2021
NOTE: HRD = High Bulk Density, LBD = Low Bulk Density, NP = Normal Porosity, LP = Low Porosity, NMC = Normal Moisture Content, LMC = Low Moisture Content, RPI = Rapid Permeability Index, SPI = Slow Permeability Index.
USDA (2016) Classification- HBD = ≥ 2.00, LBD = < 1.99, NP = 1%-40%, LP = ≤ 0.99, NMC = 10%-40%, LMC = ≤ 9.99%, RPI = 12.70%-25% (120-250 cm/h).

Table 1 shows the infiltration characteristics of soil in the residential land use and control in the selected wetland soil in Port Harcourt metropolis. It further shows that apart from Sample Point 1 (Rumuagholu) with bulk density of 1.03 g/cm^3 that is classified into the Low Bulk Density (LBD i.e. soil with bulk density of **<** 1.99 g/cm^3). Other Sample Points among the sampled soils such as SP 6 (Minikpeti) with 2.97 g/cm^3, SP 10 (Rumueme) with 2.28 g/cm^3, SP 14 (Ogbunabali) with 2.70 g/cm^3, and SP 20 (Nkpogu) with 2.93 g/cm^3 as well as the mean Bulk Density of 2.38 g/cm^3 for the residential land use soil, all fit into the USDA (2016) Classification of soil with bulk density of ≥ 2.00 g/cm^3 as High Bulk Density (HBD) that could predispose soil to low infiltration rate. Also, the mean Porosity of 0.37%, mean Moisture content of 15.83%, and mean Permeability of 120.97 cm/h in all the selected wetlands in the residential land use fits into the USDA (2016) Classification of soil with Porosity of ≤ 0.99% as Low Porosity (LP), Moisture level of 10%-40% as Normal Moisture (NMC), and Permeability range of 12.70%-25% (120-250 cm/h) as Rapid Permeability Index (RPI) for soil samples.

Furthermore, cataloguing of soils in Sample Points (1, 6, 10, 14 and 20) in the residential land use in selected wetlands in Port Harcourt metropolis based on their mean bulk density, porosity, moisture and permeability that aligns with the USDA (2016) Classification of such soil meeting the requirement for High Bulk Density (HBD), Low

Porosity (LP), Normal Moisture Content (NMC), Rapid Permeability Index (RPI) respectively. However, the value of 1.09 g/cm^3 for bulk density, 0.33% for Porosity, 10.33% for moisture, and 91.95 cm/h for permeability in the Control fits into the USDA (2016) Classification of such soil as Low Bulk Density (LBD), Low Porosity (LP), Normal Moisture Content (NMC), Slow Permeability Index (RPI) respectively is indeed at variance with the classification of the result in the sampled soils in the residential land use in selected wetlands in Port Harcourt metropolis. Comparatively, the HBD categorization of the soils in the residential land use induces such soils to low infiltration rate while the LBD of the Control soil predispose it to high infiltration rate.

Research Question 2: What is the soil infiltration characteristics of the soil in the agricultural land use in the selected wetlands in the study area?

Table 2: Infiltration Characteristics of the Soil in the Agricultural Land Use in Wetlands in the Study Area

SP	Bulk Density g/cm^3	Porosity %	Moisture %	Permeability cm/h
	$\bar{x}$±SD	$\bar{x}$±SD	$\bar{x}$±SD	$\bar{x}$±SD
SP 4	1.98± 0.03	0.37± 0.01	11.64± 0.23	125.05± 10.68
SP 5	1.79± 0.24	0.36± 0.01	12.46± 0.07	125.20± 5.66
SP 9	2.63± 0.01	0.37± 0.01	12.45± 0.07	117.50± 5.23
SP 16	2.75± 0.01	0.38± 0.00	13.78± 0.04	118.20± 7.78
SP 19	2.82± 0.04	0.38± 0.01	12.25± 0.34	273.50± 23.40
Grand $\bar{x}$±SD	**2.39± 0.07**	**0.37± 0.008**	**15.14± 0.15**	**151.89± 10.55**
USDA (2016) Classification	**HBD**	**LP**	**NMC**	**RPI**
Infiltration Rate		**High Infiltrate Rate**		
Control	1.09± 0.01	0.33± 0.01	10.33± 1.00	91.95± 6.15

USDA (2016)
LBD LP NMC SPI
Classification Infiltration Rate Low Infiltration Rate Source: Authors Computation, 2021

Table 2 shows the infiltration characteristics of soil in the agricultural land use and control in the selected wetland soil in Port Harcourt metropolis. It further shows that apart from Sample Points 4 (Rumuagholu) and 5 (Minikpeti) with bulk density of 1.98 g/cm^3 and 2.97 g/cm^3 respectively that is classified into the Low Bulk Density (LBD i.e. soil with bulk density of **<** 1.99 g/cm^3). Other Sample Points among the sampled soils such as, SP 9 (Rumueme) with 2.63 g/cm^3, SP 16 (Ogbunabali) with 2.75 g/cm^3, and SP 19 (Nkpogu) with 2.82 g/cm^3 as well as the mean Bulk Density of 2.39 g/cm^3 for the agricultural land use soil, all fit into the USDA (2016) Classification of soil with bulk density of ≥ 2.00 g/cm^3 as High Bulk Density (HBD) that could predispose soil to low infiltration rate. Also, the mean Porosity of 0.37%, mean Moisture of 15.14% and mean Permeability of 151.89 cm/h in all the selected wetlands in the agricultural land use fits into the USDA (2016) Classification of soil with Porosity of ≤ 0.99% as Low Porosity (LP), Moisture level of 10%-40% as Normal Moisture (NMC), and Permeability range of
12.70%-25% (120-250 cm/h) as Rapid Permeability Index (RPI) for soil samples.

Furthermore, cataloguing of soils in Sample Points (4, 5, 9, 16 and 19) in the agricultural land use in selected wetlands in Port Harcourt metropolis based on their mean bulk density, porosity, moisture and permeability that aligns with the USDA (2016) Classification of such soil meeting the requirement for High Bulk Density (HBD), Low Porosity (LP), Normal Moisture Content (NMC), Rapid Permeability Index (RPI) respectively. However, the value of 1.09 g/cm^3 for bulk density, 0.33% for Porosity, 10.33% for moisture, and 91.95 cm/h for permeability in the Control fits into the USDA (2016) Classification of such soil as Low Bulk Density (LBD), Low Porosity (LP), Normal Moisture Content (NMC), Slow Permeability Index (SPI) respectively is indeed at variance with the classification of the result in the sampled soils in the agricultural land use in selected wetlands in Port Harcourt metropolis. Comparatively, the HBD categorization of the soils in the agricultural land use induces such soils to low infiltration rate while the LBD of the Control soil predispose it to high infiltration rate despite the similarity in porosity level and moisture content.

Research Question 3: What is the soil infiltration characteristics of the soil in the commercial land use in the selected wetlands in the study area?

Table 3: Infiltration Characteristics of the Soil in the Commercial Land Use in Wetlands in the Study Area

SP	Bulk Density cm/h	Porosity %	Moisture %	Permeability g/cm^3
	$\bar{x}$±SD	$\bar{x}$±SD	$\bar{x}$±SD	$\bar{x}$±SD
SP 3	2.02± 0.01	0.39± 0.01	12.34± 0.09	122.55± 6.01
SP 8	2.68± 0.00	0.31± 0.00	12.45± 0.07	102.35± 6.01
SP 12	2.75± 0.07	0.36± 0.01	20.20± 3.78	101.60± 2.69
SP 15	2.80± 0.01	0.36± 0.00	11.52± 0.16	108.35± 5.73
SP 18	3.02± 0.18	0.37± 0.00	12.46± 0.08	134.95± 7.99
Grand $\bar{x}$±SD	**2.65± 0.05**	**0.34± 0.00**	**13.79± 0.84**	**113.96± 5.69**
USDA (2016) Classification	**HBD**	**LP**	**NMC**	**RPI**
Infiltration Rate		**High Infiltrate Rate**		
Control	1.09± 0.01	0.33± 0.01	10.33± 1.00	91.95± 6.15
USDA (2016) Classification	**LBD**	**LP**	**NMC**	**SPI**
Infiltration Rate		**Low Infiltration Rate**		

Source: Authors Computation, 2021

Table 3 shows the infiltration characteristics of soil in the commercial land use and control in the selected wetland soil in Port Harcourt metropolis. It further shows that SP 3 (Rumuagholu) with bulk density of 2.02 g/cm^3, SP 8 (Minikpeti) with bulk density of 2.68 g/cm^3, SP 12 (Rumueme) with 2.75 g/cm^3, SP 15 (Ogbunabali) with 2.80 g/cm^3, and SP 18 (Nkpogu) with 3.02 g/cm^3 including the mean Bulk Density of 2.65 g/cm^3 for the commercial land use soil, all fit into the USDA (2016) Classification of soil with bulk density of ≥ 2.00 g/cm^3 as High Bulk Density (HBD) that could predispose soil to low infiltration rate. Also, the mean Porosity of 0.34%, mean Moisture of 13.79% and mean Permeability of 113.96 cm/h in all the selected wetlands in the commercial land use fits into the USDA (2016) Classification of soil with Porosity of ≤ 0.99% as Low Porosity (LP), Moisture level of 10%-40% as Normal Moisture (NMC), and Permeability range of 12.70%-25% (120-250 cm/h) as Rapid Permeability Index (RPI) for soil samples.

Cataloguing of soils in Sample Points (3, 8, 12, 15 and 18) in the commercial land use in selected wetlands in Port Harcourt metropolis based on their mean bulk density, porosity, moisture and permeability that aligns with the USDA (2016) Classification of such soil meeting the requirement for High Bulk Density (HBD), Low Porosity (LP), Normal Moisture Content (NMC), Rapid Permeability Index (RPI) respectively. However, the value of 1.09 g/cm^3 for bulk density, 0.33% for Porosity, 10.33% for moisture, and 91.95% for permeability in the Control fits into the USDA (2016) Classification of such soil as Low Bulk Density (LBD), Low Porosity (LP), Normal Moisture Content (NMC), Slow Permeability Index (RPI) respectively is indeed at variance with the classification of the result in the sampled soils in the commercial land use in the study area. Comparatively, the HBD categorization of the soils in the commercial land use induces such soils to low infiltration rate while the LBD of the Control soil predispose it to high infiltration rate.

Research Question 4: What is the soil infiltration characteristics of the soil in the artisanal land use in the selected wetlands in the study area?

Table 4: Infiltration Rate in the Soil in the Artisanal Land Use in Wetlands in the Study Area

SP	Bulk Density	Porosity %	Moisture %	Permeability g/cm³ cm/h
	$\bar{x}$±SD	$\bar{x}$±SD	$\bar{x}$±SD	$\bar{x}$±SD
SP 2	2.09± 0.06	0.37± 0.01	9.82± 0.82	129.85± 6.58
SP 7	2.88± 0.01	0.31± 0.10	13.56±1.05	136.30± 4.38
SP 11	1.52± 0.01	0.37± 0.01	13.96± 0.20	116.90± 5.37
SP 13	2.59± 0.02	0.37± 0.01	15.18± 0.18	126.70± 2.55
SP 17	2.75± 0.01	0.38± 0.00	13.78± 0.04	118.20± 7.78
Grand $\bar{x}$±SD	**2.37± 0.02**	**0.36± 0.03**	**13.26± 2.46**	**125.59± 5.33**
USDA (2016) Classification	**HBD**	**LP**	**NMC**	**RPI**
Infiltration Rate		**High Infiltrate Rate**		
Control	1.09± 0.01	0.33± 0.01	10.33± 1.00	91.95± 6.15
USDA (2016) Classification	**LBD**	**LP**	**NMC**	**SPI**
Infiltration Rate		**Low Infiltration Rate**		

Source: Authors Computation, 2021

Table 4 shows the infiltration characteristics of soil in the artisanal land use and control in the selected wetland soil in Port Harcourt metropolis. It further shows that apart from SP 11 (Rumueme) with bulk density of 1.52 g/cm³ that is classified into the Low Bulk Density (LBD i.e. soil with bulk density of < 1.99 g/cm³).Other Sample Points among the selected wetland soils such as SP 2 (Rumuagholu) with bulk density of 2.09 g/cm³, SP 11 (Minikpeti) with bulk density of 2.88 g/cm³, SP 13 (Rumueme) with 2.59 g/cm³, and SP 17 (Ogbunabali) with 2.75 g/cm³, including the mean Bulk Density of 2.37 g/cm³ in the artisanal land use soil, all fit into the USDA (2016) Classification of soil with bulk density of ≥ 2.00 g/cm^3 as High Bulk Density (HBD) that could predispose soil to low infiltration rate. Also, the mean Porosity of 0.36%, mean Moisture of 13.26% and mean Permeability of 125.59 cm/h (equivalent to 11.39%) in all the selected wetlands in the artisanal land use fits into the USDA (2016) Classification of soil with Porosity of ≤ 0.99% as Low Porosity (LP), Moisture level of 10%-40% as Normal Moisture (NMC), and Permeability range of 12.70%-25% (120-250 cm/h) as Rapid Permeability Index (RPI) for soil samples.

Furthermore, cataloguing of soils in Sample Points (2, 7, 11, 13 and 17) in the artisanal land use in selected wetlands in Port Harcourt metropolis based on their mean bulk density, porosity, moisture and permeability that aligns with the USDA (2016) Classification of such soil meeting the requirement for High Bulk Density (HBD), Low Porosity (LP), Normal Moisture Content (NMC), Rapid Permeability Index (RPI) respectively. However, the value of 1.09 g/cm^3 for bulk density, 0.33% for Porosity, 10.33% for moisture, and 91.95% for permeability in the Control fits into the USDA (2016) Classification of such soil as Low Bulk Density (LBD), Low Porosity (LP), Normal Moisture Content (NMC), Slow Permeability Index (RPI) respectively is indeed at variance with the classification of the result in the sampled soils in the artisanal land use in selected wetlands in Port Harcourt metropolis. Comparatively, the HBD categorization of the soils in the artisanal land use induces such soils to low infiltration characteristics while the LBD of the Control soil predispose it to high infiltration rate.

Table 5: Summary of Infiltration Characteristics of the Soil in the Land Uses (Residential, Agricultural, Commercial and Artisanal) in Wetlands in the Study Area

Land Use	Bulk Density	Porosity %	Moisture %	Permeability g/cm^3 cm/h
	$\bar{x}$±SD	$\bar{x}$±SD	$\bar{x}$±SD	$\bar{x}$±SD

Residential	2.38± 0.03	0.37± 0.01	15.83± 0.81	120.97± 4.88
Agricultural	2.39± 0.07	0.37± 0.01	15.14± 0.15	151.89± 10.55
Commercial	2.65± 0.05	0.34± 0.00	13.79± 0.84	113.96± 5.69
Artisanal	2.37± 0.02	0.36± 0.03	13.26± 2.46	125.59± 5.33
USDA (2016) Classification	**HBD** (= $\bar{x}$ 2.45± 0.04)	**LP** (= $\bar{x}$ 0.36± 0.01)	**NMC** (= $\bar{x}$ 14.51± 1.07)	**RPI** (= $\bar{x}$ 128.10± 6.61)
Infiltration Rate	**High Infiltrate Rate**			
Control	1.09± 0.01	0.33± 0.01	10.33± 1.00	91.95± 6.15
USDA (2016) Classification	**LBD**	**LP**	**NMC**	**SPI**
Infiltration Rate	**Low Infiltration Rate**			

Source: Authors Computation, 2021

Table 5 shows the summary of infiltration characteristics of soil in the land uses (residential, agricultural, commercial and artisanal) and control in the selected wetlands in Port Harcourt metropolis. It further shows that the commercial land use had bulk density of 2.65 g/cm^3, agricultural land use had 2.39 g/cm^3, residential land use soil had bulk density of 2.89 g/cm^3, and artisanal land use had bulk density of 2.37 g/cm^3. These mean bulk density of 2.45 g/cm^3 obtained in all the land uses (residential, agricultural, commercial and artisanal) fit into the USDA (2016) Classification of soil with bulk density of ≥ 2.00 g/cm^{3}as High Bulk Density (HBD). Also, the mean Porosity of 0.36% fits the USDA (2016) Classification of soil with Porosity of ≤ 0.99% as Low Porosity (LP), the mean Moisture content of 14.51% obtained in all the land use fit into the USDA (2016) Classification of soil with Moisture level of 10%-40% as Normal Moisture (NMC). While the mean Permeability of 128.10 cm/h for the land uses fit into the USDA (2016) Classification of soil with Permeability range of 120-250 cm/h as Rapid Permeability Index (RPI).

In addition, the value of 1.09 g/cm^3 for bulk density, 0.33% for Porosity, 10.33% for moisture, and 91.95 cm/h for permeability in the Control fits into the USDA (2016) Classification of such soil as Low Bulk Density (LBD), Low Porosity (LP), Normal Moisture Content (NMC), Slow Permeability Index (RPI) respectively is indeed at variance with the classification of the result in the sampled soils in the agricultural land use in selected wetlands in Port Harcourt metropolis. Hence, comparatively, the HBD categorization of the soils in the land uses (residential, agricultural, commercial and artisanal) inundates such soils to low infiltration rate while the LBD of the Control soil predispose the Control soil to high infiltration characteristics despite the similarity in porosity level and moisture content.

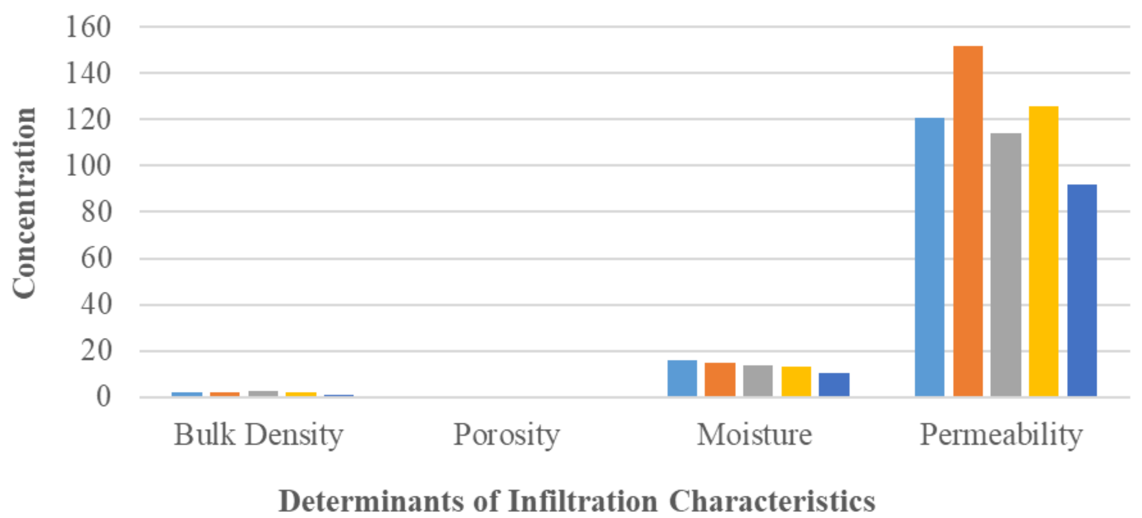

Figure 3: Summary of Infiltration Characteristics of the Soil in the Land Uses (Residential, Agricultural, Commercial and Artisanal) in Wetlands in the Study Area

Figure 3 shows the column chart for the summary of the mean of the physical properties determining infiltration rate in the soil in the different land uses (residential, agricultural, commercial and artisanal) and Control in the selected wetlands in Port Harcourt metropolis. It vividly or clearly shows that the commercial land use had the highest mean bulk density, residential and agricultural land uses had the highest mean porosity. Also, residential land use had the highest mean porosity content while agricultural land use had the highest mean permeability value among the selected wetland soils in Port Harcourt metropolis.

DISCUSSION

The result in Table 1 revealed that Rumuagholu had Low bulk density, with Minikpeti, Rumueme, Ogbunabali and Nkpogu wetlands had High Bulk Density. All the wetlands had Low Porosity and Normal Moisture Content, while apart from Rumueme and Nkpogu wetlands with Slow Permeability Index (SPI), Rumuagholu, Rumueme and Ogbunabali wetlands had Rapid Permeability Index (RPI). However, the mean infiltration characteristics indicated that the selected wetlands (Rumuagholu, Minikpeti, Rumueme, Ogbunabali and Nkpogu) in the residential land use had High Bulk Density, Low Porosity, Normal Moisture Content, and Rapid Permeability Index. While the soil sample in the Control had Low Bulk Density (LBD), Low Porosity (LP), Normal Moisture Content (NMC), and Slow Permeability Index (RPI). This finding is consistent with Imadi and Ahmad (2016) that the increasing or high bulk density due to land use activities in a saline soil could result in decreased or low infiltration rate in that area. This aligned with the position of Ashok and Kotha (2020) that high soil bulk density determines the low rate of infiltration of soils. Hence, the researchers reiterated that the upsurge of urban developments in Port Harcourt metropolis with saline soils accounted for the High Bulk Density, Low Porosity, Normal Moisture Content, and Rapid Permeability that give rise to low rate of infiltration.

The result in Table 2 revealed that Rumuagholu and Minikpeti had Low bulk density, with Rumueme, Ogbunabali and Nkpogu wetlands had High Bulk Density. All the wetlands had Low Porosity and Normal Moisture Content, while apart from Rumueme and Ogbunabali wetlands with Slow Permeability Index (SPI), Rumuagholu, Minikpeti and Nkpogu wetlands had Rapid Permeability Index (RPI). However, the mean infiltration characteristics indicated that the selected wetlands (Rumuagholu, Minikpeti, Rumueme, Ogbunabali and Nkpogu) in the agricultural land use had High Bulk Density, Low Porosity, Normal Moisture Content, and Rapid Permeability Index. While the soil sample in the Control had Low Bulk Density (LBD), Low Porosity (LP), Normal Moisture Content (NMC), and Slow Permeability Index (RPI). This finding is in agreement with Kirkham (2014) that the normalcy in soil moisture content with low porosity level including what Bi et al. (2014) ascribed as rapidly permeable soils altogether account for the decreased or low soil infiltration capacity. Thus, the low soil infiltration rate could affect the agricultural land use in terms of soil fertility and crop productivity in wetlands in the study area.

The result in Table 3 revealed that Rumuagholu, Minikpeti Rumueme, Ogbunabali and Nkpogu wetlands had High Bulk Density. All the wetlands had Low Porosity and Normal Moisture Content, while apart from Minikpeti, Rumueme and Ogbunabali wetlands with Slow Permeability Index (SPI), Rumuagholu, and Nkpogu wetlands had Rapid Permeability Index (RPI). However, the mean infiltration characteristics indicated that the selected wetlands (Rumuagholu, Minikpeti, Rumueme, Ogbunabali and Nkpogu) in the commercial land use had High Bulk Density, Low Porosity, Normal Moisture Content, and Rapid Permeability Index. While the soil sample in the Control had Low Bulk Density (LBD), Low Porosity (LP), Normal Moisture Content (NMC), and Slow Permeability Index (RPI). This finding is consistent with the position of Osuji et al. (2010) that the soil infiltration rate mainly depends on the characteristics of the soil. Alluding to this finding Williams et al. (2020) reiterated that increased bulk density and moisture content from land use activities (like commercial, dumpsites, construction, telecommunication infrastructure, etc.) could lead to low infiltration rate in soils.

The result in Table 4 revealed that Rumueme had Low bulk density, with Rumuagholu, Minikpeti, Ogbunabali and Nkpogu wetlands had High Bulk Density. All the wetlands had Low Porosity, Rumuagholu wetland had Low Moisture Content with the rest wetlands having Normal Moisture Content, while apart from Rumueme and Nkpogu wetlands with Slow Permeability Index (SPI), Rumuagholu, Minikpeti and Ogbunabali wetlands had Rapid Permeability Index (RPI). However, the mean infiltration characteristics indicated that the selected wetlands (Rumuagholu, Minikpeti, Rumueme, Ogbunabali and Nkpogu) in the artisanal land use had High Bulk Density, Low Porosity, Normal Moisture Content, and Rapid Permeability Index. While the soil sample in the Control had Low Bulk Density (LBD), Low Porosity (LP), Normal Moisture Content (NMC), and Slow Permeability Index (RPI). This finding is in agreement with the earlier position of Osuji et al. (2010) that the time under which a soil was left undisturbed reflected different infiltration rate whereas Kirkham (2014) stated that land use activities has the propensity to influence the bulk density, porosity, moisture content and permeability index of soil that culminates to a different infiltration rate and capacity when compared to the undisturbed soil.

The result in Table 5 revealed that the Residential, Agricultural, Commercial, and Artisanal land uses had High Bulk Density, Low Porosity and Normal Moisture Content while apart from the Commercial land use with Slow Permeability Index, the rest land uses had Rapid Permeability Index (RPI). This finding is consistent with Osuji et al. (2010) that the high bulk density and low porosity in soils results in a decrease in soil infiltration rate. Alluding to this finding, Youdeowei and Nwankwoala (2010) stated that low infiltration rate will promote high run-off in areas with certain elevations or slopes. The finding of the study conforms to Kirkham (2019) assertion that the addition of organic and inorganic materials in the soil could lead to high bulk density, rapid permeability index and low moisture content that culminates to a decrease in the soil infiltration rate and capacity. In addition, the soil sample in the Control had Low Bulk Density (LBD), Low Porosity (LP), Normal Moisture Content (NMC), and Slow Permeability Index (RPI). This finding is consistent with the previous finding by Bi et al. (2014) that the presence of vegetation amidst the land use results in low soil bulk density and low porosity that leads to high soil infiltration rate. Thus, the researchers aligns with the findings of this study as all the land uses showed high bulk density, low porosity, normal moisture content and rapid permeability index that culminates to low infiltration rate of the soils in the selected wetlands in Port Harcourt metropolis.

CONCLUSION

The study concludes that the activities in the examined land uses such as residential (RE), agricultural (AG), commercial (CO), and artisanal (AR) inundated the soils to High Bulk Density (HBD) as determinant to Low Infiltration Rate (HIR). While the soil in the Control had Low Bulk Density (LBD) that predispose it the of the Control soil (CS) to High Infiltration Rate (HIR). Hence, the study mathematically expressed that HBD = LIR while LBD = HIR. Furthermore, the low infiltration rate predispose soils to high runoff, rapid permeability, and increased leaching could seriously impact on the agricultural land use more than other land uses in terms of low soil fertility and crop productivity in the selected wetlands in Port Harcourt metropolis. Conclusively, land uses accentuated high soil bulk density, low porosity, normal moisture content, and rapid permeability that culminated to low soil infiltration rate in wetlands in Port Harcourt metropolis.

RECOMMENDATIONS

Based on the finding of the study, the following recommendations were proffered.

1. Land use activities should be properly regulated in order to tackle the incidents of increased water channelization including sewage and substances discharge into the soils in Port Harcourt metropolis.
2. Developers prior to the approval of their land use applications should be made to understand and attest their compliance and vicarious liability to wastes or effluents

discharge laws in order to forestall the intrusion or incursion of contaminants into the soil.

3. The Rivers State government is encouraged to institute a legislatively backed law that would require an assessment of the environmental and social impacts of every developments on wetlands with a view at choosing the best and sustainable option for spatial developments.
4. Physical barriers such as hedges, drains, tanks, and reservoirs should be constructed in order to prevent increasing runoff or overflow and leaching that is common in soils with low infiltration rate and capacity.

Trees and vegetative cover should be planted despite the land use in order to attain low soil bulk density and high soil infiltration rate that predispose soils to increased flooding and leaching as well as poor aeration and low fertility that affects soils in the agricultural land use

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