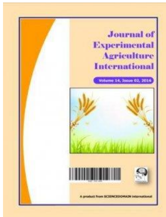

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Hydraulic Conductivity and Penetration Resistance of a Tropical Rainforest Alfisol under Different Land Uses in Akure, Southwestern Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Effects of different land use (Arable land; Teak forest/plantation; Natural forest; Banana plantation; and Construction site) on hydraulic conductivity, penetration resistance and hydrological changes of soils was investigated in Akure, southwestern Nigeria. The field experiment was conducted during the rainy season of 2013 in five (5) different locations based on land use pattern. Six points (approximately 60 m apart) were randomly selected from each location for the collection of soil samples following a grid sampling pattern. Soil infiltration rates, penetration resistance, soil moisture content, bulk density and porosity of the sites were measured. Cone penetration resistance was determined at depths 7.5, 15, 22.5 and 30 cm, while the soil moisture content and bulk density were determined at depths of 5, 10, 15 and 20 cm. Construction site demonstrated higher bulk density, higher penetration resistance and lower unsaturated hydraulic conductivity when compared with soils of other locations. Highest bulk density (1.88±0.06 g/cm^3) was obtained

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at the soil surface layer of the construction corresponding to the highest penetration resistance value of 3.47 MPa. Strong and positive correlation was recorded between soil penetration resistance and bulk density within different land uses. The highest hydraulic conductivity was recorded under Natural forest with a mean value of 5.74×10^{-4} cms^{-1} and lowest (1.42×10^{-4} cms^{-1}) in the Construction site. Results of the experiment provided the basis for proper selection, planning and implementation of land use schemes in the study area.

Keywords: Hydraulic conductivity; penetration resistance; bulk density; land use; porosity.

1. INTRODUCTION

Land is categorized largely on the basis of the pattern of utilisation. This utilisation could be agricultural, industrial, or structural land use. It is agricultural if it refers to the activities of man on land which are directly related to the growing of crops on fields [1,2,3,4]; industrial in that land is the solid part of the earth surface: the soil together with the vegetation, minerals, rivers, streams, lakes, ponds, hills, mountains, valleys and airspace immediately above the land [5] and to the engineers who use land for structural support, it is the weathered material in the upper layers of the earth crust which serves as support and in building all sort of structures: houses, roads, bridges, etcetera. Land has different functions that can change over time with different land uses. Rapidly increasing human populations and expanding agricultural and industrial activities have brought about extensive land use changes throughout the world. The demands for arable land, grazing, forestry, wildlife, tourism and urban development are greater than the land resources available, hence land has become a scarce resource. The land use pattern of a region is an outcome of natural and socio –economic factors and their utilization by man in time and space [6]. Land uses in Akure are predominantly for agricultural and structural purposes. Agricultural practices, such as soil tillage, fertilization and irrigation, have impacted on soil structure; causing soil compaction and degrade field drainage.

Land is becoming a scarce resource due to immense agricultural, industrial, structural and demographic pressures. The rapidly increasing human populations and the demands for land for agricultural, structural and industrial activities have brought serious pressures on the available land spaces and consequently land use changes throughout the world [7]. The extensive land uses portends varying impacts on physical and hydraulic properties of the soil, which are of key importance to soil hydrology. Since soil physical and hydraulic properties play a central role in transport and reaction of water, solutes and gases in soils, their knowledge is very important in understanding soil behaviour to applied stresses, transport phenomena in soils, hence for soil conservation and planning of appropriate agricultural and industrial practices.

Over the years, physical properties of the soil that control water movement and retention in the soils are largely affected due to human, animal activities as well as use of heavy duty machineries for soil tillage purposes. The ability of a soil to generate some products or perform some functions may decline with certain land uses. Consequently, many studies have examined changes in topsoil structure [8]. Recently, the importance of persistent subsoil compaction for soil structure change has been reported [9,10,11,12]. When soils are purposely compacted for construction, or collaterally compacted around infrastructures, greater square meter of soil particle surfaces are present per unit volume, and pore space declines. This process provides more frictional, adhesive and cohesive forces, which hold the soil together and consequently, greater soil strength. Water movement and aeration pathways are constrained and as water content declines in soil, strength increases and root elongation declines [13].

Hydraulic conductivity, (*k*) is a property of soil, which describes the ease with which water can move through pore spaces or fractures. It depends on the intrinsic permeability of the material and on the degree of saturation, the type of soil, porosity and the configuration of the soil pores [14]. According to Kirkham [15], hydraulic conductivity is defined as “the metres per day of water seeping into the soil under the pull of gravity or under a unit hydraulic gradient”. The hydraulic conductivity of water in soil can be measured by both field and laboratory experiments. The field technique is known to be generally more reliable than laboratory techniques [16,17]. Measurement of hydraulic conductivity is very challenging considering that parameters can differ over several orders of magnitude across the spectrum of sediments and rock types [18]. The parameters can also vary widely in space due to the fact that hydraulic conductivity depends on soil texture and structure [19], which is a function of the land use pattern, dynamics of plant canopy and roots, tillage operations, activity of soil organisms [20]. This variability has appreciable effects on infiltration process and its related parameters [21]. Hydraulic conductivity is the single most important hydraulic parameter for flow and transport-related phenomena in soil and is an important feature of water infiltration [22].

Over the years, there has been a growing concern about soil compaction. Soil compaction can be associated with a majority of field operations that are often performed when soils are wet and more susceptible to compaction. Soil compaction is an increase in the density of soil and reduction in porosity, associated with an increase in strength and a reduction in hydraulic conductivity [23]. Soil structure is important and must not be damaged because it determines the ability of a soil to hold and conduct water, nutrients, and air necessary for plant root activity. Some of the problems caused by soil compaction include poor aeration, excessive soil strength limiting root growth, drainage, excessive runoff and erosion [23]. Increase in soil compaction increases the soil penetration resistance or cone index. Some of the factors influencing cone index or penetration resistance are matrix potential (or water content), bulk density, soil compressibility or soil strength parameters such as soil structure and others [24]. Soil compaction, as well as changes in soil physical properties, is a major factor that causes high mechanical impedance or excessive soil strength [25,26,27]. Soil compaction is the main form of soil degradation, which affects 11% of the land area in the surveyed countries of the world [28,29]. Compaction also reduces total air-filled (non-capillary) pore space and reduces average pore size, increases mechanical resistance to root penetration, and can increase or decrease water holding capacity, depending on the amount of compaction, and initial bulk density and pore size distribution [30]. Many studies have been conducted to understand the influence of bulk density and water content on penetration resistance in the laboratory [31,32] and field [33,34,35].

Land is one of the most precious resources and it has been reported by several researchers that land-use practices is of key importance to soil hydrology, attributed to the effects of tillage, erosion, compaction, and pore structure evolution [36,37]. However, information on soil physical properties under different land uses is very scarce especially in the humid tropical region of sub-Saharan Africa. This research was therefore aimed at assessing land-use impacts on soil physical properties such as hydraulic conductivity, bulk density, penetration resistance under the tropical climate of Akure, Ondo state, Nigeria.

2. MATERIALS AND METHODS

2.1 Experimental Site and Procedure

2.1.1 Experimental site

This study was carried out within FUTA community in Akure, Nigeria. Akure, (latitude 7°14'N and longitude 5°08'E) is located within the humid region of Nigeria. Akure lies in the rain forest zone with mean annual rainfall of between 1300 – 1600 mm and average annual temperature of 27°C. The relative humidity ranges between 85 and 100% during the rainy season and less than 60% during the dry season period. Akure is about 351 m above the mean sea level. Akure has an area of about 2,303 sq km and situated within the western upland area [38]. The map of Nigeria showing Ondo state is presented in Map. 1.

2.1.2 Experimental procedure

The field experiments was conducted in five (5) different locations based on the land use pattern and six points per location, 60 m apart were randomly selected for soil sampling and field data collection following a grid sampling system. A 2 × 2 m^2 area of the various locations was used for the experimentation. Field measurements were conducted to determine soil penetration resistance and hydraulic conductivity. The five (5) locations include Arable land, Teak forest/Plantation, Natural forest, Banana Plantation, and Building/Construction site. The arable land (2.5 hectares) has been put under conventional tillage with cassava and maize cultivation for about seven consecutive years, while the Teak forest (5.7 hectares), also within the study environment (Federal University of Technology, Akure) has grown to full maturity with dried leaves falling off the plant stands. The natural forest is an unopened land with growing shrubs and deciduous trees and Banana plantation (120 m × 90 m), located in the University Research and Training Farm has been under cultivation for over nine years. The construction site is an existing earthen road almost 1.2 km, presently under construction by the municipal authority.

2.2 Measurements

2.2.1 Hydraulic conductivity (*k*)

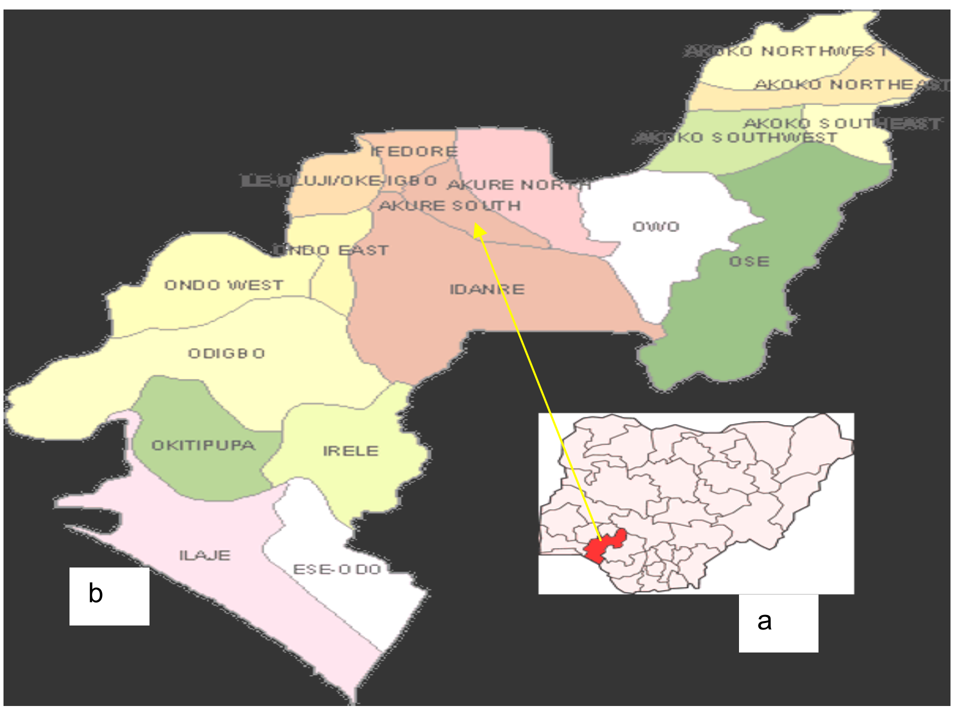
The hydraulic conductivity measurement was conducted on the field using the mini disk infiltrometer, Decagon Devices (Pullman, Washington). The mini disk infiltrometer consists of a plastic tube; 22.5 cm long and 3.1 cm in outside diameter marked with milliliter gradation (0 to 100 mL) with set suctions of 0.5 cm and 7.0 cm and have a radius of 1.55 cm. An adjustable steel tube is installed above the sample chamber to regulate the suction rate. The suction rate can be adjusted to accommodate measurement of any soil type. Measurements were recorded at regular time intervals of 30 seconds. The data collected were then used to calculate the infiltration rates of the soil and consequently the hydraulic conductivity using the method of [39].

2.2.2 Penetration Resistance (PR) and soil moisture content

Soil penetration resistance (PR) was determined using cone penetrometer, HYPEN1 model with 30° cone angle and 2 threaded extension rods 300 mm long graduated every 75 mm. Penetration resistance data were recorded at an interval of 75 mm down the soil profile to a depth of 300 mm. Soil moisture content (MC) was recorded during infiltration using a hand-held digital soil moisture meter - Lutron PMS-714; IP-65 water resistance, heavy duty and capable of measuring moisture content ranging from 0-50% with a 7.9" SS probe. Measurements were taken within the 0 – 7.5 cm, 7.5 – 15 cm, 15 – 22.5 cm and 22.5 – 30 cm depths from the five locations.

2.3 Soil Sampling and Analysis

Soil samples were collected in soil profiles at depth up to 20 cm, from the 5 different locations. Samples were collected from horizon A in each location, packed in plastic bags, and transferred to the laboratory. The samples were allowed to dry in the open air. The chemical characterization of the various soil sample collected from all the locations includes the analysis of organic matter



Map 1. Map of Nigeria (a), and map of Ondo State showing Akure (b)

content, organic carbon and soil pH whereas the physical characterization consisted of particle size analysis, water holding capacity, bulk density and total porosity determination. Soil particle sizes were determined using the method described in [40]. The organic carbon was determined using the Walkley - Black wet oxidation procedure and the soil organic matter content was determined from the organic carbon [41]. Soil pH was determined in distilled water using the pH meter with water ratio of 1:2.

2.3.1 Bulk Density (BD) and Total Porosity (PT)

Soil bulk density was determined using the method described by Vogelmann et al. [42]. Soil samples were collected in segments at depths 0 – 5 cm, 5 – 10 cm, 10 – 15 cm and 15 – 20 cm from the five locations using ring cylinders with height 5 cm and diameter 4.2 cm. The total porosity (PT) was calculated from BD and PD using the equation and relationship developed by Danielson and Sutherland [43].

$$Total\ Porosity\ (PT) = 1 - \frac{BD}{PD} \quad (1)$$

where; BD and PD are soil bulk density and particle density, respectively. The particle density of the study area was assumed 2.65 g cm^{-3} [44,45,46]. The default value of 2.65 g cm^{-3} is used as a rule of thumb based on the average bulk density of rock with no pore space (USDA-NRCS).

2.4 Data Analysis

The slope of the curve of the cumulative infiltration vs. the square root of time was calculated and analyzed using a basic Microsoft Excel spreadsheet macro created by Decagon Devices. Hydraulic conductivity and Penetration resistance were subjected to statistical analysis to determine the mean, standard deviation, coefficient of variation, linear and non linear regressions using Microsoft Excel and SPSS 17.0.

3. RESULTS AND DISCUSSION

3.1 Soil Physical Properties

The sand, silt, and clay percentages of the soil samples (average of 0 – 15 cm samples) ranged from 57.24% to 75.40%, 5.76% to 20.00%, and 10.80% to 36.96%, respectively in all the sites. The result of the particle size distribution of the collected soil samples is presented in Table 1. The particle size distribution shows that natural forest and banana plantation have characteristically high percentage of sand (75.40%), while arable land and teak forest have a percentage sand of 58.80% and 57.28%, respectively. The textural classification of the sample soils of Banana plantation and Natural forest are sandy loam, while the soils of Construction sites and Arable land are sandy clay loam and Teak plantation falls in the sandy clay class of the USDA classification. Teak forest has the highest percentage clay content of 36.69%, followed closely by construction site (26.60%) while Banana plantation and natural forest jointly share the least clay percentage (10.80%). The silt content is generally low in the sampled soils except in arable land with percentage silt content of 20.00%.

Means of organic matter content/organic carbon, soil pH and water holding capacity of the experimental sites are shown in Table 2. The percentage organic matter of the different land uses ranged from 1.29% to 4.64% and the percentage organic carbon from 0.75% to 2.69%. The soil pH values showed that the construction site has the highest value of 8.19 while the arable land has the least value of 5.42. Teak forest has the highest water holding capacity of 62.73%; this is primarily due to the high clay contents of the sampled soil. Arable land with percentage clay content of 21.20% (Table 1) followed with a water holding capacity of 56.73% while construction site has the least water holding capacity (45.00%). This agrees with [47] who observed that as the soil organic matter decrease, the water retention and available water capacities of the soil decrease. Also, a soil's available water capacity is also affected by compaction. Compaction increases bulk density and reduces total pore volume, consequently reducing available water holding capacity.

3.2 Soil Moisture Content

The soil moisture content values at different soil depths and the trend showing their variations from one location to another is presented in Table 3. It is a very important soil properties which relates with other soil properties such as the infiltration, hydraulic conductivity etc [48]. The soil moisture content ranges from 4.57 to 10.84% in the 0– 5 cm depth in the uppermost layer and from 10.78 to 15.36% in the 15 – 20 cm soil depth. In all the experimental sites, the moisture content values increases down the soil profile. This observation is in line with the works of [49] and [14].

Table 1. Mean±STD of textural classes of soil of the experimental sites

Land use types	Sand %	Silt %	Clay %	USDA textural class
Arable land	58.80±4.03	20.0±1.32	21.20±2.64	Sandy clay loam
Construction site	67.40±3.92	6.00±2.87	26.60±3.89	Sandy clay loam
Banana Plantation	75.40±1.98	13.80±4.66	10.80±1.78	Sandy loam
Natural Forest	75.40±3.78	13.80±3.04	10.80±0.35	Sandy loam
Teak Forest	57.28±4.74	5.76±2.10	36.96±2.14	Sandy clay

Table 2. Means±STD of organic matter content, soil pH, organic carbon and water holding capacity of the experimental sites

Land use types	OMC (%)	pH	OC (%)	WHC (%)
Arable land	4.06±0.14	7.14±1.25	2.35±0.12	56.73±4.32
Construction site	3.29±0.18	6.34±2.10	1.91±0.17	45.00±2.10
Banana Plantation	4.13±0.07	7.57±0.89	2.39±0.08	48.07±3.65
Natural Forest	4.33±0.26	7.58±0.66	2.51±0.22	54.98±3.89
Teak Forest	4.64±0.32	7.32±1.04	2.69±0.28	62.73±5.76

3.3 Bulk Density and Total Porosity

In this study, the bulk density of Arable land, Natural forest and Teak forest showed a regular increase with depth (Table 4 and Fig. 1), whereas the BD of Banana plantation decreased slightly from the 5 - 10 cm soil layer, though the general trend of increase in BD was observed in others layers. Siltecho [50] noticed similar trends under a young rubber tree plantation and a ruzi grass but observed a slight decreased at 40 cm depth under natural forest in Thailand. Price [46] also discovered that the mean bulk density of the upper cores was significantly smaller than the lower cores (1.10 vs. 1.30 g cm^{-3}, T = 6349.0, $p < 0.001$) in their study to characterize soil physical properties under three land-use classes (forest, pasture, and managed lawn) in the southern Blue Ridge Mountains of southwestern North Carolina. The construction sites which has the highest bulk density values at each layer decreased slightly from 5 – 10 cm and 10 – 15 cm as compacted soils tends to decrease with increasing soil depth as shown in Fig. 1.

The high BD values at the construction sites are probably due to the effects of compaction on the soil and this agrees with the findings of [51] and [52]. It is noteworthy that bulk density is an indirect measure of compaction and primarily it is affected by soil texture [53] since well graded soils containing both fine and coarse particles results in a higher number of contact points than in a poorly graded soil [54]. Likewise, the bulk density values at the different depth in the Teak forest are slightly higher than the others (even though the organic matter content is high). This may be due to the high gravel content found in the site. In all, the natural forest has the least bulk density and increase with depth, this may be due to findings that soils underlying native vegetation (e.g., undisturbed forest) generally feature low bulk density and high saturated hydraulic conductivity, total porosity, and macroporosity, as a result of ample litter cover, organic inputs, root growth and decay, and abundant burrowing fauna [55].

The variation of the total porosity with depth at the various experimental sites is presented in Table 5. This is inversely related to the values of the bulk density. This observation agrees with the works of [14,42,56,57,58]. The Banana plantation and natural forest had the highest total porosity (0.55 cm^3/cm^3) at 0 – 5 cm soil surface layer, while the construction site had the least value (0.29 cm^3/cm^3) and this showed considerable influence of compaction on physical properties, such as total porosity. Fasinmirin and Adesigbin [59] reported that porosity decreased in the order of soil compaction i.e. increased soil compaction reduces the number of soil pores.

The physical characterizations of the locations showed clear and strong variations with respect to land uses and soil types. Construction site demonstrated higher bulk density, higher penetration resistance and lower unsaturated hydraulic conductivity when compared with soils of other locations as shown in Fig. 1. The hydraulic conductivity of Teak plantation was low comparatively with the natural forest and Banana plantation and this may have been caused by the high clay content (36.96%) of the Teak plantation. Soils with high clay mineral are low in porosity, and the pores have the tendency to expand rather than giving room for moisture infiltration (Table 1).

3.4 Penetration Resistance of the Experimental Sites

The variation of penetration resistance with depth at the various locations is presented in Table 6. Penetration resistance increased with depths at the various sites. The construction site has the highest penetration resistance value of 3.47 MPa at 0 – 7.5 cm and 4.21 MPa at 7.5 – 15 cm depths respectively until reaching an impenetrable layer in the soil as compaction is common on construction sites [60,61] due to the use of heavy machinery. The natural forest has the least penetration resistance value of 1.06 MPa at the 0 – 7.5 cm depth while the arable land with little variation down the soil profile has the least value of 2.31 MPa at 22.5 – 30 cm depth. The one-way ANOVA of the mean penetration resistance at the various depths (0 – 7.5 cm, 7.5 – 15 cm, 15 – 22.5 cm, 22.5 – 30 cm) showed statistically significant differences among the group means: 0 – 7.5 cm ($F (4, 25) = 54.18$, $p < .001$); 7.5 – 15 cm ($F (4, 25) = 42.70$, $p < .001$); 15 – 22.5 cm ($F (3, 20) = 148.88$, $p < .001$) and 22.5 – 30 cm ($F (3, 20) = 180.74$, $p < .001$) indicating that not all five groups of the land uses resulted in the same penetration resistance value with depths. Specific analysis using Tukey pairwise comparisons was done between group means at different depth to determine which pairs of the five land uses means differed. At 0 – 7.5 cm depth, there was no significant difference between the corresponding means of Arable land, Banana plantation and natural forest while mean penetration resistance of Construction site and Teak plantation are significantly higher than that of the other land uses. At 7.5 – 15 cm depth, Tukey pairwise comparison shows that mean penetration resistance of Construction site is significantly higher than the other land uses. There are no significant differences between the other land uses. At 15 – 22.5 cm, there was no significant difference between the corresponding means of Arable land, Banana plantation and natural forest, while mean penetration resistance of Teak plantation was significantly higher ($p<0.001$) than that of the other land uses excluding the Construction site. At 22.5 – 30 cm depth, there were significant differences in the corresponding means of all the land uses excluding the Construction site, where there are hard core within the 15 – 22.5 cm and 22.5 – 30 cm.

Table 3. Mean±STD of moisture contents (%) of the experimental sites

Depths (cm)	Arable land	Construction site	Banana plantation	Natural forest	Teak forest
0 – 5	7.66±1.20	4.57±1.12	10.84±2.47	9.86±2.38	10.67±3.82
5 –10	9.49±1.05	8.12±2.30	11.68±2.08	10.17±2.04	10.95±2.98
10 –15	10.55±2.20	10.36±3.32	13.07±1.46	10.35±1.86	11.33±4.48
15 – 20	15.36±1.84	11.32±2.58	13.37±3.28	10.78±3.18	12.74±2.96

Table 4. Mean±STD of bulk density (g/cm^3) of the experimental sites

Depths (Cm)	Arable land	Construction site	Banana plantation	Natural forest	Teak forest
0 – 5	1.28±0.14	1.88±0.06	1.20±0.04	1.19±0.06	1.34±0.10
5 –10	1.30±0.09	1.72±0.08	1.19±0.07	1.27±0.12	1.34±0.09
10 –15	1.38±0.07	1.55±0.12	1.33±0.05	1.31±0.08	1.49±0.15
15 – 20	1.49±0.19	1.64±0.11	1.50±0.10	1.35±0.11	1.52±0.07

Table 5. Mean±STD of total porosity (cm^3/cm^3) of the experimental sites

Depths (cm)	Arable land	Construction site	Banana plantation	Natural forest	Teak forest
0 – 5	0.52±0.09	0.29±0.03	0.55±0.06	0.55±0.08	0.49±0.04
5 – 10	0.51±0.06	0.35±0.02	0.55±0.04	0.52±0.05	0.49±0.03
10 – 15	0.48±0.08	0.42±0.07	0.51±0.06	0.51±0.07	0.44±0.07
15 – 20	0.44±0.08	0.38±0.02	0.43±0.03	0.49±0.06	0.43±0.05

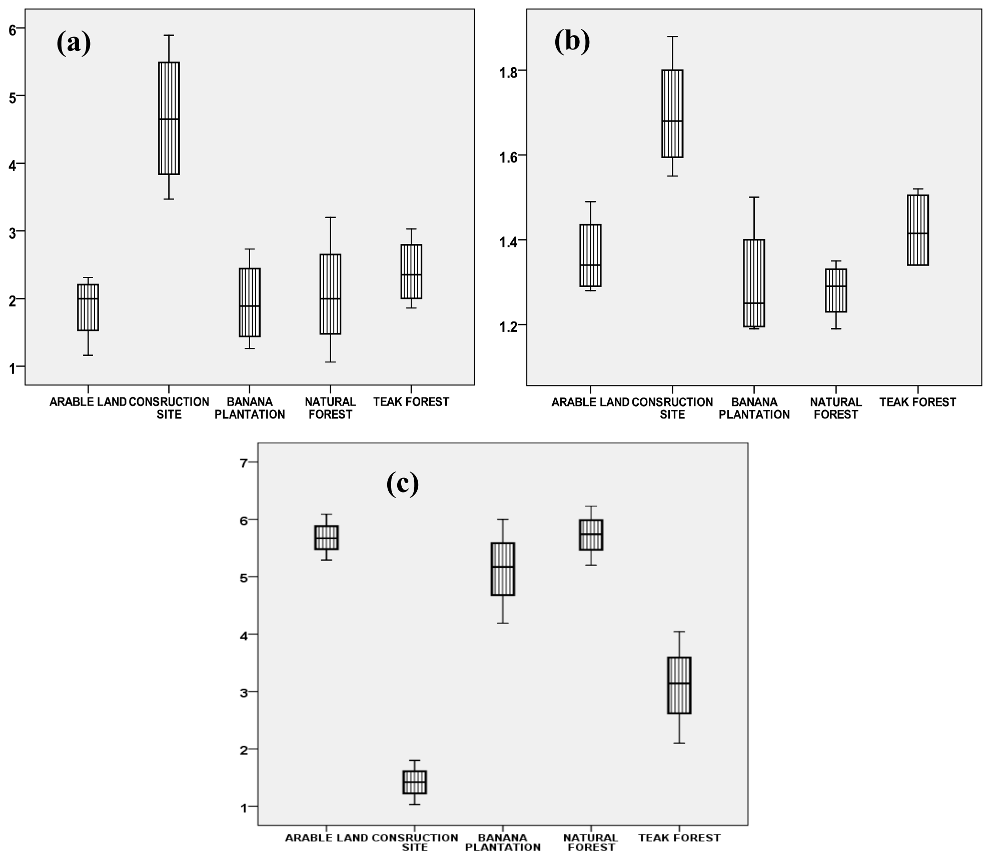


Fig. 1. Soil physical and hydraulic characteristics by the different land uses (a) penetration resistance (MPa), (b) bulk density (g cm^{-3}), (c) hydraulic conductivity ×10^{-4} (cm s^{-1}). the boxes correspond to the inter–quartile range while the black line across each box denote the values of their median

According to Braford [24], soil factors that influence penetration resistance include water content, bulk density, soil compressibility (susceptibility to decrease in bulk volume when subjected to a load), soil strength parameters, and soil structure. Although soil strength is most easily affected by changes in soil water content and bulk density, other factors including texture, and organic matter content also affect soil penetration resistance [62,63]. Wet soils generally are more easily penetrated; but as the soils become dryer, both penetration resistance and bulk density in soils with clay types and organic matter increases [63]. Penetration resistance was greater at greater soil depth in all experimental sites (Table 6). This is expected because some resistance depends on the weight of soil (overburden) above the depth of measurement [64]. Thus, lateral forces on the penetrometer cone increase with increasing depth; therefore, more force is needed for the cone to displace soil. Resistance also can increase with depth because of changes in soil texture, gravel content, and structure, but also because biological activity in surface soils (with high organic matter content) reduces penetration resistance. Penetration resistance and bulk density increase with depth. This agrees with the findings of [64] and [65], who reported that resistance to penetration has direct relationship with soil bulk density. Soil bulk density increases primarily due to the effect of soil tillage with heavy machinery causing compaction and consolidation of the soils. Compaction reduces the soil pores by expelling air from the soil voids while consolidation expels the soil moisture.

In summary, Land use and management practice influence bulk density, total pores and penetration resistance Construction sites generally experience even more compaction during giving rise to a generally higher bulk density, lower total pores and high penetration resistance (Tables 4 - 6).

Table 6. Means±STD of soil penetration resistance (MPa) of the experimental sites

Depths	Arable (No-Till) land	Consruction site	Banana plantation	Natural forest	Teak forest
0 – 7.5	1.16 (±0.24)	3.47 (±0.44)	1.26 (±0.55)	1.06 (±0.08)	1.86 (±0.21)
7.5 – 15	1.90 (±0.04)	4.21 (±0.26)	1.62 (±0.90)	1.90 (±0.04)	2.15 (±0.21)
15 – 22.5	2.10 (±0.04)	HP	2.16 (±0.49)	2.10 (±0.05)	2.56 (±0.35)
22.5 – 30	2.31 (±0.17)	HP	2.73 (±0.18)	3.20 (±0.04)	3.43 (±0.18)

HP – Hard Pan

Table 7. Means±STD of soil hydraulic conductivity of sampled soils of the experimental sites

Location	Mean (STD) of hydraulic conductivity $\times 10^{-4}$ (cm s^{-1})
Arable land	5.67 (±0.40)
Construction site	1.42 (±0.39)
Banana plantation	5.17 (±0.91)
Natural forest	5.74 (±0.52)
Teak plantation	3.14 (±0.98)

3.5 Hydraulic Conductivity of the Experimental Sites

The hydraulic conductivity of the experimental sites is presented in Table 7. The hydraulic conductivity value showed a general increasing trend from the construction site to Teak Plantation, Banana Plantation, Arable land and natural forest (1.42 ±0.39, 3.14 ±0.98, 5.17 ±0.91, 5.67 ±0.4 and 5.74 ±0.52 respectively). There was a statiscally significant differences among the group means as determined by One way ANOVA ($F(4, 25) = 92.01$, $p < 0.001$). Post hoc comparisons using Tukey procedures was done to determine which pairs of the five group means differed. Tukey pairwise comparisons at 95% confidence interval shows that mean hydraulic conductivity values of Arable land, Banana plantation and Natural forest are not significantly different, while the mean hydraulic conductivity values of Construction site and Teak plantation are significantly different from each other and from the other groups' means. Little variation was observed in hydraulic conductivity values of banana plantation, arable land and natural forest. Among all, Natural forest had the highest hydraulic conductivity value (5.74×10^{-4} cms^{-1}), while the construction site was least (1.42×10^{-4} cms^{-1}). Compaction of the construction site resulted to the death and decline in the number of trees and this reduced root and microbial activities in the soil. Compaction reduces total air-filled (non-capillary) pore space and reduces average pore size, which increases mechanical resistance of the soil to root penetration. With the loss of macropores, water infiltration and hydraulic conductivity was reduced. Compaction has a significant influence on soil hydraulic properties such as soil water retention, soil water diffusivity, unsaturated hydraulic conductivity and saturated hydraulic conductivity, which in turn govern infiltration rates [66]. Furthermore, the exposure of the soil in the construction site to human impact has stripped it of organic-rich upper horizons and subsequent compaction by heavy equipment increased its bulk density (Table 2) and reduced infiltration rates [23,45].

In contrast, soils of the natural forest are rich in organic matter (4.33 %) and as a result had lower bulk density and high total number of pores (Tables 2 and 4), and consequently high soil infiltration capacities and hydraulic conductivity (5.74×10^{-4} cms^{-1}). Similar observation was reported by Buytaert et al. [67] and Gol [68].

4. CONCLUSION

In this research, we showed that soil hydraulic and mechanical properties (hydraulic conductivity and soil penetration resistance) were impacted by the differences in land uses and management practices. Soil particle size distributions did not show significant variation among the land uses, and soil hydraulic conductivity did not differ significantly between Arable land, Banana plantation and Natural forest. Construction site shows significantly lower hydraulic conductivity than soils of other locations. Also construction site had reduced water holding capacities compared to other land uses sites. This is apparently related to the differences in texture. In all, Natural forest had higher hydraulic conductivities, lower bulk density and higher total porosity values. These results explained the effects of land use on soil physical and hydraulic properties such as hydraulic conductivity, bulk density, penetration resistance and moisture retention with a view towards giving a full understanding of soils hydrologic response to human impacts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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