Volume 4, Issue 2, pp 33-44, March, 2023

ACHIEVERS JOURNAL OF SCIENTIFIC RESEARCH

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EFFECT OF BITUMEN DEPOSITS ON THE PHYSICAL PROPERTIES AND HYDRAULIC CONDUCTIVITY OF SANDY LOAM SOIL IN ONDO STATE, SOUTHWEST NIGERIA.

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Submitted: December 10, 2022; Revised: January 25, 2023; Accepted: February, 20, 2023; Published: March, 20, 2023

Abstract

The effects of bitumen deposits was investigated on soil samples from three locations in Irele area of Ondo state (Loda, Lofo and Legbogbo sites) where Loda and Lofo are bituminous soils while Legbogbo is bitumen free. Soil samples were collected at 0 – 15 cm depth from five points for the experiment. Loda had the lowest moisture content (MC) (12.65 %) at 0-10cm depth and legbogbo had the highest at 40 -50 cm depth (18.39 %). The moisture content values for Legbogbo increases down the soil profile at a consistent soil moisture depth from the least to the highest. It was observed that Loda had the highest MC due to hard deposits of bitumen. The soil bulk density (BD) was significantly affected by soil depth ($p \leq 0.001$). In Legbogbo, there was increase in the BD down the soil depths. Loda had the lowest BD (1.54 gcm^{-3}) at 40-50 cm depth while Lofo had the highest BD (1.68 gcm^{-3}) at 30-40 cm. Legbogbo had the highest mean of 9.02 cm/s while the mean hydraulic conductivity for Loda was 6.41 cm/s and Lofo had 5.61 cm/s showing that Legbogbo is significantly different. Tukey pairwise comparisons at 95% confidence level shows that mean of hydraulic conductivity for Loda - Legbogbo and Lofo – Legbogbo are statistically and significantly different while the mean of hydraulic conductivity values of Lofo – Loda is not significantly different, which may be due to bitumen deposits and the compaction which affects infiltration or permeability.

Keywords: Bitumen Deposits; Bulk Density; Hydraulic Conductivity; Moisture Content; Sandy Loam

1.0 Introduction

Bitumen is a dark brown to black cement like viscous liquid or semi- solid or solid, which plays a significant role in asphalt production as it acts as a binder to the aggregates (Itodo *et al.,* 2018 and Strausz *et al.,* 2010). It occurs both on the surface and sub-surface of the earth. It is a black viscous mixture of hydrocarbons which is obtained naturally or as a residue from petroleum distillation (Donev *et al.*,2018). Bitumen has a low-grade of crude oil, which is composed of complex, heavy hydrocarbons. Donev *et al.,* 2018 and Ogiriki *et al.,* 2018 described bitumen as a sticky, tar like form of petroleum, which is thick and heavy that it must be heated or diluted before it will flow. Bitumen originated from fossil deposit, which represents the product of reservoir transformation of convectional oil by microorganism (Ogedengbe and Akinbile, 2009).

Agarry and Oghenejoboh (2014) reported that bitumen exhibits thermoplastic behavior, softening when heated and becoming mobile liquid on further heating while returning to their original state on cooling. This will result into seepage of the liquid bitumen into the soil and cause great depletion in the soil and the heavy metals can cause deterioration in the soil profile, thereby causing reduction in the plant yield. The plant yield in the bitumen deposit area will definitely be affected hence; the water and the soil with which the plant will grow must be considered for investigation to enhance good productivity in the study area.

Bitumen is a naturally occurring material that is found in deposits where the permeability is low and passage of fluids through the deposit can only be achieved by prior application of fracturing techniques. Alagbe (2020) reported that the world's largest bitumen deposits were found in Venezuela, Canada, and Saudi Arabia respectively. It was also observed that Nigeria has a reserve estimate of 30-40 billion barrels (bbls) bitumen with potential recovery of 3654 × 106bbls (Alagbe, 2020). Alagbe (2020) also said that, the seepage, and other deposit over the Okitipupa especially the Dahomey basin paved way for exploration in Nigeria (Odunaike *et al*., 2010).

The use of land for different purposes shows that the impacts will lie on the physical and hydraulic properties of the soil and this is very important in hydrology. Hydraulic conductivity (k) can be described as a measure or the ease with which water can move through pore spaces in the soil or a medium. It can also be said to be a measure of the rate of flow for a particular fluid through a porous medium and which the value varies as function of the fluid and the porous medium. Hydraulic conductivity helps to control seepage and the rate of consolidation. It can also be defined as a coefficient of proportionality of Darcy's law, and this links the discharge velocity with the hydraulic gradient. According to Fasinmirin *et al*., 2018, hydraulic conductivity depends on some factors which are; the intrinsic permeability of the material, the degree of saturation, the type of soil, porosity and the configuration of the soil pores. Hydraulic conductivity is one of the most important properties of soil that have the ability to transmit water through the pore spaces through a medium between particles.

Hydraulic conductivity increases with increasing moisture content until reaching a maximum rate in saturated conditions. Hydraulic conductivity can be measured by both field and laboratory experiments. The laboratory experiment is done in the laboratory while the field experiment is done on the field and more reliable (Fasinmirin *et al*., 2018). Bituminous soil can be used as a stabilizer to improve the properties of locally available cohesion less soil (Kumar and Bansal, 2017). Bituminous stabilization helps to increase the shear strength and also decreases the permeability of sandy soil.

The bitumen deposit in the soil can create hard surface on both surface and subsurface of the soil resulting to soil hydrophobicity. Bitumen deposit is a source of pollution in the soil can prevent normal oxygen exchange between soil and the atmosphere as a result of the hydrophobic properties of oil (Okoh, 2003, Agele *et al*., 2017). Oil sand from the region where there are bitumen deposits is composed of relatively recalcitrant and insoluble petroleum hydrocarbons and with this, hydrophobicity may be present (Leskiw *et al*., 2006; Fleming, 2012) and these can make the affected soils to act as a zone of low hydraulic conductivity, thereby slowing down the flow of water through the soil profile and increasing the residence time of water in the overlying soils (Neil, 2018).

Some compounds like the hydrophobic compounds present in the soil like the bitumen deposits have the potential of producing water repellency soil which prevents the absorption of water into the soil and this can affect the hydraulic conductivity of the soil (Dang-Vu *et al*., 2009; Neil, 2018).

The hydraulic conductivity was described by Mingyue, 2017 as one of the most important physical properties of geomaterials because it can control seepage and the rate of consolidation in the soil. Neil (2018) reported that during infiltration, when the wetting front reaches the layer interface, the hydraulic conductivity decreases to that of the limiting (fine-textured; highly compacted) layer. Hydrophobic substances or deposits like bitumen deposits in soils such as organically derived oils usually produce soil water repellency thereby producing a surface property that reduces or prevents the infiltration into the soil (Dang-Vu *et al*., 2009, Diehl, 2013). In some locations, the hydrophobic compounds may either enhance or diminish the soil water retaining capacity and the hydraulic conductivity of the affected soil, and thereby affecting the ecosystem (Diehl, 2013).

The bitumen deposits in the Southern part of Ondo State, has been of concern or threat to agricultural production in terms of low crop yields on crops. Bitumen deposits, has due to its mass deposit in the area of study affected not only the water but the agronomy soil (Ogedengbe and Akinbile, 2009. However, a lot of researchers had worked on how bitumen affects soil, water and plant in the research area (Ogedengbe and Akinbile, 2009; Agarry and Oghenejoboh, 2014; Fagbote and Olanipekun, 2010) but much work has not been done on how bitumen deposits affect the soil properties and the hydraulic conductivity of the area of study.

This study aims at determining the effects of the bitumen deposits in southwestern part of Ondo state on the physical properties of the soil and the hydraulic conductivity on the texture of the soil in the study area.

1.2 Precautionary Measures

These are behavioral non-pharmaceutical interventions that are prescribed by World Health Organization (WHO, 2020). These include the followings**:**

2.0 Materials and Methods

2.1 Experimental Site and Procedure

2.1.1 Experimental site

The study was carried out within Irele local government area of Ondo State, Nigeria. The total land coverage falls between latitudes $6^0 16^1$N to $6^0 47^1$ N and longitudes 4^0 45^1 E to 5^0 10^1 E. Irele is about 25 miles (40.2 km) west of Okitipupa on the Benin/ Ore road in the Southern part of Ondo State. The area falls within the tropical rainforest ecological zone with well-defined rain and dry seasons. The area is well drained. It has smaller settlements like Loda, Lofo, Kajola, Loya, Lotito, Legbogbo etc. it is located on a hill 135 feet above sea level. The climate type is tropical savanna. The geologic region of Irele is sedimentary, that is the study area falls in sedimentary terrain. The sedimentary basin of Ondo State is underlain by coastal alluvium at the extreme south and along major river flood plain. The terrain is flat with gentle undulating topography. The annual rainfall is about 180 cm, average temperature is about 25^0C. The residents are predominantly small scale farmers with farming and fishing as the principal economic activities which are feasible in the community. The population census of Irele local government area in 2006 was 144,136, while the projection in 2016 was 194,600; the area is 963km^2 with density 202.1 of people/km^2 National population Commission of Nigeria (web), National Bureau of Statistics (web), 2017. The map of Ondo state showing Irele local government area is presented in Figure. 1 below;

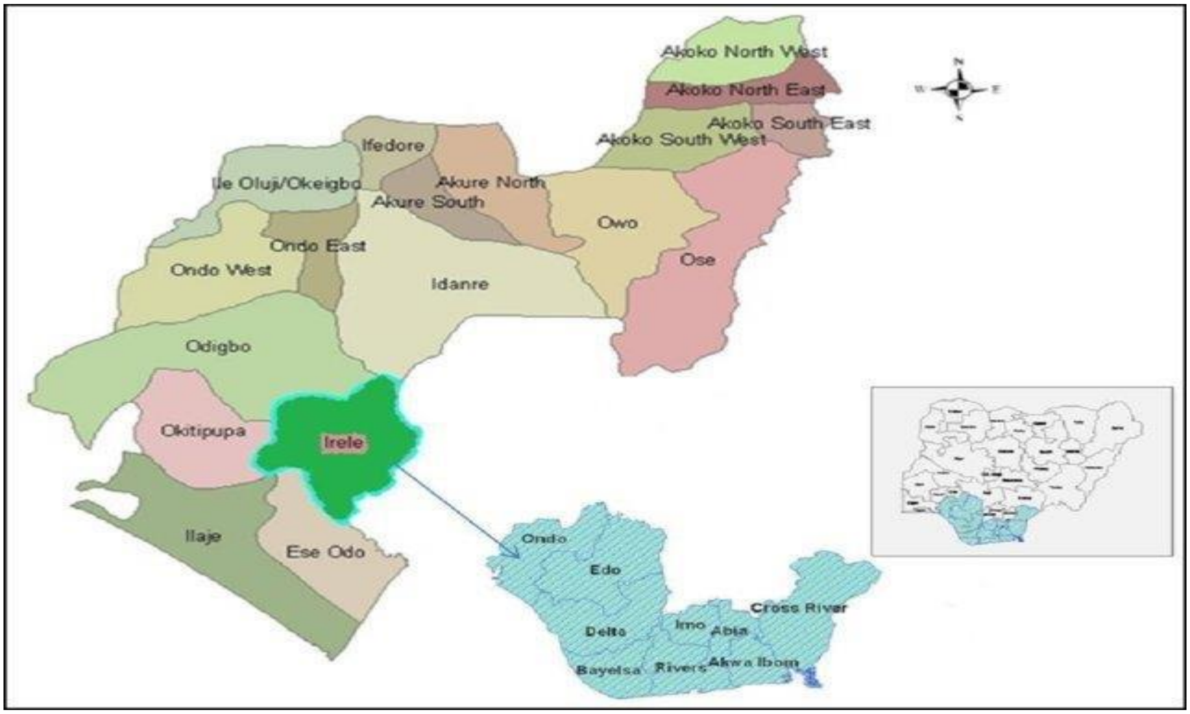


Figure 1: Map of Irele Town

2.1.2 Experimental procedure

The design plot was divided into three parts; the field experiment was conducted in three (3) different locations in the study area. Two of the locations contain bitumen deposits (Loda and Lofo) while the third location (Legbogbo) was a control site without bitumen deposit in Irele community. The field measurement was conducted to determine the hydraulic conductivity of each location. Some physical properties of soil in the study area such as particle size distribution, moisture content, bulk density and porosity, organic matter and water holding capacity were determined in the laboratory using standard procedures as expressed by Agbede and Ojeniyi (2009) and Fasinmirin *et al*. (2009).

2.2 Measurements

2.2.1 Hydraulic conductivity (*k*)

The field experiment was conducted using the mini disk infiltrometer (Decagon Devices, Inc., Pullman, WA) for the measurement of the hydraulic conductivity. It is a hand-held field instrument which is used to rapidly assess soil infiltration capacity of the soil and also be used to measure the soil hydraulic conductivity, water sorptivity and ethanol sorptivity as described by Olorunfemi and Fasinmirin (2017).

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. The measurements taken at a time intervals of 30 seconds were recorded for each location.

The data that was collected was used to calculate the water infiltration rates of the soil. The hydraulic conductivity of soil was calculated using the method of Zhang (1997), that requires measuring cumulative infiltration versus time and fitting the results with the infiltration function.

(a) (b)

Plate 1: (a) Measurement of hydraulic conductivity on a bitumen deposit soil (LODA)

(b) Measurement of hydraulic conductivity on a the control site (Legbogbo)

2.3 Soil Sampling and Analysis

2.3.1 Particle Size Determination

Soil samples were collected in soil profiles at depth up to 20 cm, from the 5 different locations. Soil samples were collected at a depth of 0 -15 cm from five (5) different locations in each bitumen deposit area (bulked together making 25 soil samples). The samples were collected from each layer and bulked per location into one composite sample, thoroughly mixed and air-dried in the laboratory, sieved with a 2-mm sieve and analyzed. The particle size distribution of the samples from different locations was determined using the hydrometer method (Agbede and Ojeniyi, 2009). According to Fasinmirin *et al.* (2018), the particle density was assumed 2.65 gcm-^{3} (Price *et al*., 2019).

2.3.2 Determination of Soil Moisture Content, Bulk Density and Porosity

Soil samples were collected from each location 0 – 10, 10 – 20, 20-30 and 40-50 cm depths using a soil sampler (10 cm long X 4.8 cm in diameter) at five different locations on bitumen deposit areas and the control site. Soil cores were used to measure the bulk density (BD) as mass of oven dried soil per volume of core in Mgm^{-3} (Fasinmirin *et al*., 2018 and Volgelmann *et al*., 2010) and gravimetric water content (ϴW) as mass of water in the soil sample per mass of the oven dried soil. The unit for the gravimetric water content is $kgkg^{-1}$.

2.4 Data Analysis

The data collected from the field using the mini disk infiltrometer was analyzed and the slope of the curve of the cumulative infiltration versus the square root of time was calculated and analyzed using a basic Microsoft Excel spreadsheet macro that the Decagon Devices created for the calculation. Statistical analysis of the moisture content and the hydraulic conductivity were used to determine the mean, standard deviation, coefficient of variation, linear and non- linear regressions using Microsoft Excel and SPSS 17

3.0 Results and Discussion

3.1 Physical Properties of soil

The percentages of sand, silt and clay of the soil samples collected from the three sites ranged from 48.88 % to 58.88 %, 12.00 % to 20.00 % and 29.20 % to 31.20 % respectively. The textural classes for all the sites are sandy loam class from the USDA classification. The particle size distribution in Table 1 below indicates that Lofo site has the highest percentage of sand (58.88 %) while Loda had the least percentage (48.88 %). Lofo and Legbogbo sites shared the same silt content (12.00 %) while Loda which had the largest bitumen deposit out of the three sites in the study area has silt content of 20 %. The clay content for Lofo and Legbogbo are also the same (29.20 %) while Loda had 31.20 % clay. The bitumen deposits in Lofo is not as much as the ones in Loda, it now behaves like legbogbo particle size distribution.

3.2 Moisture Content (MC)

The result for the moisture content (MC) of the soil at different locations and depth is presented below in Table 2 and Figure 1(a). Moisture content is a very important property of soil which determines the amount of water or moisture in the soil, it relates with infiltration, hydraulic conductivity and other soil properties (Fasinmirin *et al*., 2018). The moisture content for the experiment was significantly affected by soil depth ($\rho = 0.001$) and the interaction of bitumen deposits in the soil of different locations and depths ($\rho = 0.01$). There was increase in the moisture content down the depth of the soil in Legbogbo. In Loda, the lowest moisture content is 12.65 % at 0-10 cm depth and the highest at 10-20 cm depth was 15.92 %. The lowest MC at Lofo was 13.53 % at 0-10 cm depth and highest (15.84 %) at 10-20 cm depth. At Legbogbo, the lowest MC was 14.43 % at 0-10 cm depth and highest at 40-50 cm depth was 18.39 %. It was observed that the moisture content values for the control site (Legbogbo) increases down the soil profile which is in line with Halfmann, 2005 and Fasinmirin *et al*., 2018. Also, Legbogbo, had a consistent soil moisture depth from the least to the highest in the experiments, but it was observed that Loda and Lofo at 10-20 cm depth had their highest MC which may be due to hard deposits of bitumen which cannot allow the passage of water freely into the soil.

The fluctuation in moisture content of Loda and Lofo sites is as a result of the bitumen deposits in the soil which resulted into clogs. The clogs do not pave way for infiltration of water into the soil at some depth and trapped moisture in some regions therefore the water was been held by the bitumen deposits and did not allow easy infiltration process (Neil, 2018, Diehl, 2013, Okoh, 2003).

Table 1: Mean ± Standard Deviation of the Textural Classes of Soil at different Site

Soil Parameters	**Significance of the difference between Locations**			**MS**	**Error**	**F – Value**	***Sig.***
	LODA (LD)	**LOFO (LF)**	**LEGBOGBO (LG)**				
Sand (%)	48.88^{b} (± 1.75)	58.88^{a} (± 0.94)	58.80^{a} (± 2.00)	99.27	2.65	37.52	$p \leq .001$
Silt (%)	20.00^{a} (± 1.00)	12.00^{b} (± 1.73)	12.00^{b} (± 2.65)	64.00	3.67	17.45	$p \leq 0.01$
Clay (%)	31.20^{a} (± 0.95)	29.20^{a} (± 1.00)	29.20^{a} (± 0.85)	4.00	0.88	4.55	ns
Textural classes	Sandy Loam	Sandy Loam	Sandy Loam				

3.3 Bulk Density (BD)

Table 2 shows the result of bitumen concentration in soils of the different locations and soil depths on soil bulk density (BD). The soil bulk density was significantly affected by soil depth ($p \leq 0.001$) and the interaction of bitumen concentration in soils of the different locations and soil depths ($p \leq 0.01$). In

Legbogbo, there was increase in the BD down the soil depths. In Loda, lowest (1.54 gcm^{-3}) and highest (1.62 gcm^{-3}) BD was observed at 40-50 cm and 20-30 cm depth, respectively. Highest BD (1.68 gcm^{-3}) was found at 30-40 cm under Lofo while the lowest BD (1.60 gcm^{-3}) at 20-30 cm soil depth. At the superficial layer (0-10 cm), Legbogbo had the least BD (1.55 g cm^{-3}) while Lofo had the highest BD (1.64 gcm^{-3}).

Table 2: Main and Interaction effects of locations on soil physical properties at different depths

Depths (cm)	Locations	BD (g cm^{-3})	MC (%)
0-10	LODA	1.59^{a} (± 0.08)	12.65^{b} (± 0.73)
	LOFO	1.64^{a} (± 0.05)	13.53^{ab} (± 0.31)
	LEGBOGBO	1.55^{a} (± 0.04)	14.43^{a} (± 0.20)
10-20	LODA	1.60^{a} (± 0.02)	15.92^{a} (± 1.84)
	LOFO	1.62^{a} (± 0.05)	15.84^{a} (± 0.89)
	LEGBOGBO	1.66^{a} (± 0.03)	15.66^{a} (± 0.76)
20-30	LODA	1.62^{a} (± 0.06)	13.86^{b} (± 0.51)
	LOFO	1.60^{a} (± 0.09)	15.18^{ab} (± 0.82)
	LEGBOGBO	1.74^{a} (± 0.05)	16.48^{a} (± 0.83)
30-40	LODA	1.57^{a} (± 0.05)	15.49^{a} (± 0.67)
	LOFO	1.68^{a} (± 0.12)	15.50^{a} (± 0.80)
	LEGBOGBO	1.76^{a} (± 0.04)	17.46^{a} (± 1.09)
40-50	LODA	1.54^{b} (± 0.01)	14.11^{b} (± 0.19)
	LOFO	1.67^{ab} (± 0.06)	14.86^{b} (± 1.10)
	LEGBOGBO	1.79^{a} (± 0.09)	18.39^{a} (± 1.75)

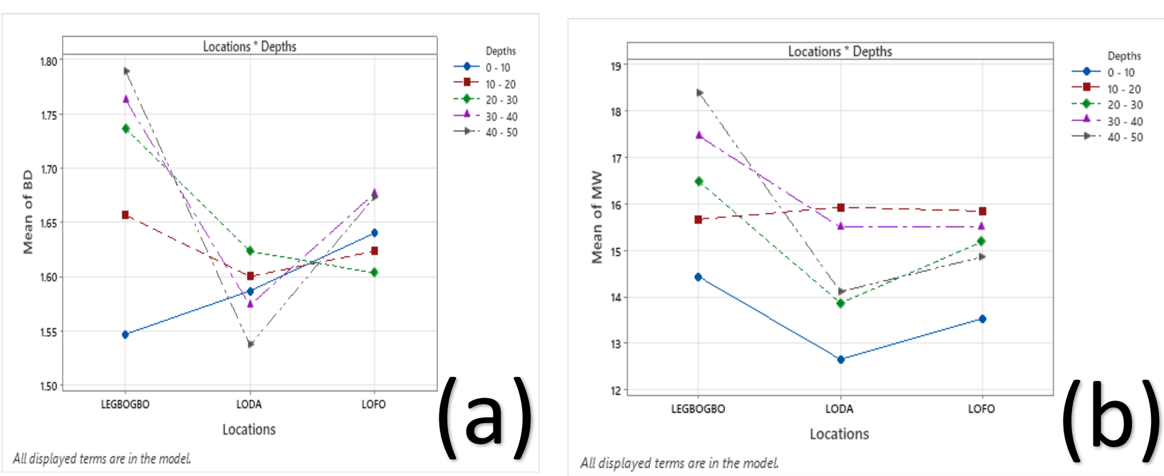


Figure 1(a) Interaction plot for Moisture Content (MC) (b) Interaction plot for Bulk Density (BD)

At 40-50 cm, the lowest BD (1.54 gcm^{-3}) was found in LODA while the highest (1.79 gcm^{-3}) was observed

in Legbogbo. It was observed that the soil bulk density in each of the locations follow the same trend.

Also, Figure 1 shows the main effects plot for bulk density showing the locations and the various depths. From the Figure 1, it was observed that Legbogbo which is the control site had the lowest bulk density (1.55 gcm^{-3}) but recorded higher bulk densities in the location than other site which may be due to compaction (Al-Ghazal, 2002 and Cassel *et al*., 1995). The bulk densities at Loda site are lower than other sites which may be as a result of the undisturbed forest though filled with bitumen deposits but generally have the characteristics of low bulk density and high saturated hydraulic conductivity, total porosity, and macro porosity in accordance with Lee and Foster, 1991.

For the experiment, soil bulk density increased with depth increment in the control site (Legbogbo) due to low organic matter content and compaction from the pressure of the upper layers (Datta *et al.,* 2015). Legbogbo had the lowest BD at the surface soil, which might be attributed to greater aboveground biomass intake in the form of leaf, plant residues, and decomposed plant components. The lowest BD was likewise reported at 40-50 cm depth under Loda, most likely due to the presence of a bitumen deposit. The bulk density at Loda increases with depth from depth 0 to 30 cm and decreases from depth 30 cm to 50 cm. Bulk density can decrease if the clay and organic matter contents increase and sand content decreases down the depth. Also, as aggregation and clay content increases, bulk density decreases. In line with Eric and Seth, (2015), bulk density of compacted soils tended to decrease with increasing depth. From Figure 1, Lofo site bulk density decreases at the surface layer from depth of 0 to 30 cm and increases from 30 cm to 50 cm which indicates that the bitumen deposit from 0 to 30 cm depth was not united and can be due to that it is undisturbed.

3.4 Hydraulic Properties of the Experimental Sites

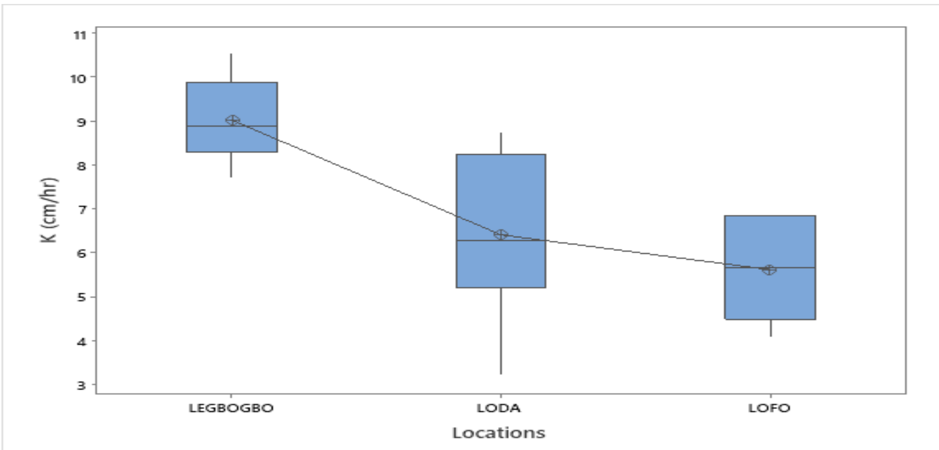
The results of the concentration of bitumen in soils at different locations and soil depth on soil hydraulic conductivity (K) were presented in Table 3 below. The value of the hydraulic conductivity showed an increasing trend from Lofo to Loda and to Legbogbo (5.61 ± 1.15, 6.41 ± 1.94 and 9.02 ± 0.98 respectively). As presented in Figure 2(a), the box plot is drawn to show the variability of data in each location. Legbogbo which is the control site has the highest mean of 9.02 cm/s while the mean hydraulic conductivity for Loda is 6.41 cm/s and Lofo had 5.61 cm/s showing that Legbogbo is significantly different from the others. Figure 2(b) shows the Post hoc comparisons using Tukey procedure. Tukey pairwise comparisons at 95 % confidence level show that mean of hydraulic conductivity values of Loda -Legbogbo and Lofo – Legbogbo are statistically significant and significantly different while the mean of hydraulic conductivity values of Lofo – Loda is not statistically different compared to others, this may be because of the bitumen deposits and the compaction of the deposits in Lofo and Loda which makes infiltration or permeability to be reduced since soil hydraulic conductivity properties can be influenced significantly by compaction and this is inconformity with Fasinmirin *et al* (2018), Aboufoul and Garcia (2017).

The control site (Legbogbo) has no bitumen deposit; the hydraulic conductivity was 9.02 X 10^{-4} cm/s^{1} and this is in conformity with Buytaert *et al* (2007) and Gol (2009).

Table 3: Soil hydraulic properties

Soil Parameters	Significance of the difference between Locations			MS	Error	F – Value	*Sig.*
	LODA (LD)	LOFO (LF)	LEGBOGBO (LG)				
K	6.41^{b} (± 1.94)	5.61^{b} (± 1.15)	9.02^{a} (± 0.98)	19.04	2.10	9.46	$p \leq 0.01$

(a)



(b)

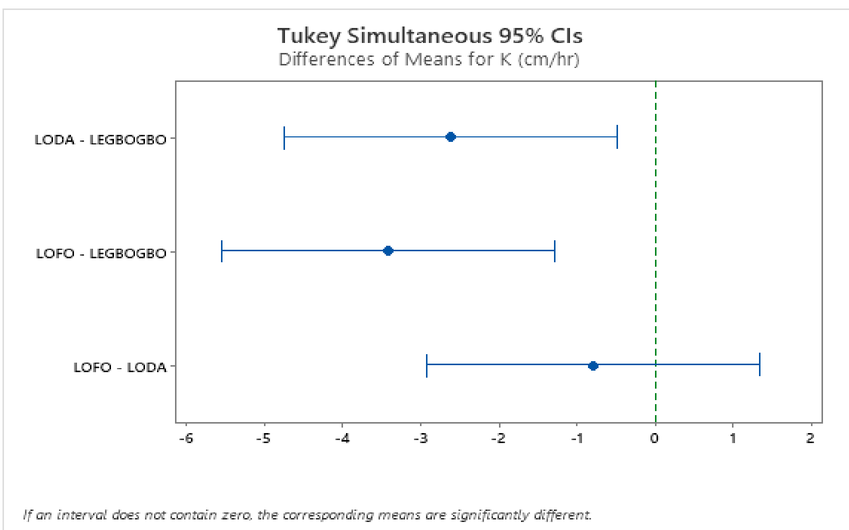


Fig.2. (a) Box plots (b) Differences of means for Hydraulic conductivity (k) of soils in different locations or experimental sites.

Box plots showed the rectangular boxes representing the middle 50 % (interquartile range) of the data, the median value indicated by the horizontal line inside the box. Lines (called ''whiskers'') extending from the box representing the upper and lower 25 % of the distribution (excluding outliers), and outliers indicated by asterisks beyond the whiskers.

4.0 Conclusion

This research shows that the soils in the experimental sites are the same (sandy loam soils) despite the fact that Loda and Lofo are bituminous soils and Legbogbo is bitumen free. It was also observed that the particle size distribution of the soil at Loda site is slightly different from the other two sites and this shows that the texture of soil can determine the rate of infiltration, bulk density and the hydraulic conductivity of the soil. There was increase in the moisture content at Legbogbo down the depth while there was a fluctuation in Loda and Lofo sites as a result of the bitumen deposits which definitely affects infiltration of water in the soil. Soil bulk density was significantly affected by soil depth and the interaction of bitumen concentration in the soil at different sites. At Legbogbo (control site), soil bulk density increased with increase in depth while Loda and Lofo exhibited decrease in bulk density at increasing depth in some region which may be due to soil aggregation and organic matter content present in the soil. The hydraulic conductivity of the soil at various locations was compared together and it was observed that Loda and Legbogbo are statistically and significantly different, also with Lofo and Legbogbo while comparism of the hydraulic conductivity of the bituminous soils (Loda and Lofo) are not significantly different because of the bitumen deposit which make infiltration and permeability to be reduced since soil hydraulic conductivity properties can be influenced significantly by compaction.

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