## ARTICLE

# Assessment of Geologic Controls of Flooding in Parts of OBIO/AK-POR L.G.A., Rivers State, Nigeria

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## ARTICLE INFO

## ABSTRACT

Flooding of Municipal areas is a frequent environmental occurrence in Rivers State that occurs when rainfall runoff meets land surfaces with low water absorbing capacity or when it overwhelms drainage channels. In order to assess the flood situation in the study area, an integrated method which involves field-measurement, geographic information system (GIS), laboratory analysis of soil samples and topographic studies were employed. Digital elevation model of the study area reveals that the flooded areas are situated in areas with elevations lower than its surrounding, thereby acting as a natural basin to retain flood waters after rainfall. Four holes were drilled to depth of 3 m to obtain soil samples at 1 m sampling interval, from which laboratory analysis was carried out to determine some geotechnical parameters such as soil's particle size, specific gravity, bulk density, porosity, moisture content, permeability and hydraulic conductivity. Results of the analysis show that permeability, hydraulic conductivity and porosity diminishes with respect to depth. The soil in the flooded areas have high fines content (silt and clay), high bulk density which increase with depth and a specific gravity that is typical of organic rich soils that contain sand mixed with a considerable amount of fines. At Nkpolu, mean permeability rates of 0.003 cm/sec, 0.009 cm/sec and 0.033 cm/sec were obtained at 1, 2 and 3 m respectively. At Eneka, mean permeability rates of 0.011 cm/sec, 0.018 cm/sec and 0.014 cm/sec were obtained at 1, 2 and 3m respectively, while at Rukpokwu, mean Permeability rates of 0.021 cm/sec was obtained at 1 m, while 0.006 cm/sec was obtained at 2 and 3 m respectively. The mean hydraulic conductivity for the locations under study is of the order of 10-4 ft/day. This study has shown that the flooded areas are located in low lying urban areas which act as basins, therefore, the top soil is crusted with highly compacted soil horizons beneath. With high and frequent rainfall in the region which generates a lot of runoff, in addition to poor drainage system, flooding in the study area occurs frequently. Therefore, construction and maintenance of efficient drainage channels for an effective solution to urban pluvial flooding in the study area are thereby recommended.

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## 1. Introduction

Urban flooding in Nigeria is becoming a growing concern and occurs every year, with about 1/5th of the populace faced with at least one form of flooding event [1]. Flood water could have its source from rivers, canals, weighed down sewers and rainfall which temporarily cover land surfaces.

According to Abam *et al.*, [2], Urban Centres in Rivers State experience severe flooding once in two years and pluvial flooding accounts for 41% of flooding nationwide. Frequent and intense rainfall over low lying areas and rapid urbanization which does not take into consideration the natural landscape orientation that allow for drainage, poor refuse management, increase in water resistant surfaces which generates sediments that block drainages, greatly influence flooding in municipal areas [3].

Many factors lead to flooding. Urbanization, human interference, climate change, heavy and frequent rainfall, soil conditions, tidal activity, demographic expansion into flood plains, emission of greenhouse gases (methane and carbon dioxide - according to the IPCC, Methane is 23 times more potent greenhouse gas than $CO_2$) and the obstruction of stream channels by over grown vegetation are some causes of flooding in Nigeria [4-10].

However, the major catalyst for flooding is rainfall coupled with soil conditions and the modification of the earth's natural terrain which block natural drainage pathway resulting to the accretion of storm waters [11]. The flood incidence becomes hazardous with trivial provision for surface drainage which could be blocked by wastes or sediments generated by urbanization [5]. The concept of flooding has been well studied by many scientists and researchers [12-14]

Municipal Flooding is a recurrent problem in parts of Obio Akpor Local Government Area of Rivers State and its effects have become worse overtime. Therefore, the purpose of this study is to scrutinize the interplay and influence of the geomorphology and soil attributes on flooding in some locations within Obio Akpor Local Government, so as to stipulate effective measures to manage or reduce municipal flooding in the area.

An integrated methodology involving GIS, field based measurement, and laboratory method were employed to the appraisal of data in the study area. The study area is located in Obio Akpor Local Government area of Rivers State and three study locations within the area (Eneka, Nkpolu and Rukpokwu), were studied (Figure 1).

Obio Akpor is bordered by four Local Governments which are Ikwere, Port Harcourt, Oyingbo and Emohua Local Government areas to the North, South, East and West respectively. It is situated between latitudes $4^0 45^'$ North and longitude $8^0$ 00' East, with mean elevation of 20 meters above sea level.

The study area is characterized by two seasons - Wet and Dry Seasons with a hot monsoon climate, high temperatures and high humidity of about 60% all year round[15]. The wet season of the year is typically from April to October but rainfall can be experienced all year round, spawning lots of runoffs and accompanied by thunder storms. Rainfall measurements range from 1800 mm to 2800 mm due to proximal distance to the Atlantic Ocean [15]. Rainfall peaks are usually observed in the months of June and July, and a short break follows between the months of July and August. The Dry Season of the year is from January to March, where the weather is dusty, warm and dry. Annual temperatures do not vary much and are constant (between $25^0$c and $28^0$c) [15].

## 2. Geomorphology and Geology

The study area occupies a fraction of the Niger Delta Basin with an altitude of 20-30 meters above sea level, with an undulating topography. The Niger Delta has a sub-aerial extent of about 75,000 km [16], total approximate area of 300,000 $km^2$ [17], a sediment volume of 500,000 $km^3$ [18], and sediment thickness of about 10 km to over 12 km, at the basin depocentre [16]. Extensional forces resulting from a failed tectonic separation of the South American and the African Plates between the Jurassic to Cretaceous periods formed the Niger Delta Basin. Sedimentation is controlled by fluvial processes in the floodplain and the delta top environments. The mangrove-swamp environment is controlled by tidal processes, and wave action dominates the shoreface complexes of the Niger Delta [19]. The Delta sedimentation is wave dominated and longshore drift cells divergent [20]. Short and Stauble [21], recognized three distinct subsurface stratigraphic units in the Niger delta and these are the Benin, Agbada and Akata Formations. The Benin Formation is a deposit which is dated Oligocene to Recent in age with a thickness of about 2000 meters. In the Eocene, the Agbada Formation was deposited and is about 3700 meters thick, laid under a transitional environment. It is a sequence of sandstone and shale, consisting of an upper predominantly sandy unit with minor shale intercalation and a lower shale unit which is thicker than the upper sandy unit. The Akata Formation was deposited first in the Paleocene and is about 7000 meters thick, and composed of thick sequences of over-pressured marine shales, sand, turbidities and channel fills [22]. The Akata Formation was laid under marine environment. The soil in the area is Sandy or sandy loam and is always leached.

## 3. Materials and Method

### 3.1 Materials

Both fields based measurement and laboratory analysis were employed in this study. The field instruments used are Hand Auger and aiding tools. The laboratory equipment used includes a falling head Permeameter, Digital sieve shaker, electrical weighing balance, density bottle, cutter, metre rule, crucibles, drying pans, volumetric cylinder, 1 litre glass cylinder, hydrometer with bouyoucos scale, thermometer, Sodium Hexametaphosphate, multi-mix machines with baffled milkshake cups.

### 3.2 Methods

BS 5930 (British Standard Code for Site Investigation) was employed to obtain soil samples.

A depth of 3 m was drilled for soil sample collection at 1m intervals, labeled and stored in sample bags. In-situ description of soil was conducted in terms of colour, texture, wetness and condition before taken to the laboratory for further analysis.

A preliminary risk assessment was adopted using the European Water Management and Implementation of floods directive [23], whose focus is Pluvial Flooding and Surface Water.

Sample locations, depths, GPS coordinates and elevations are shown in Table 1.

### 3.2.1 Rate of Infiltration (Drain Test)

Six holes were drilled to 15 cm and in-situ drain test were carried out using Rubber Infiltrometer with Diameter of 30 cm and Height of 25 cm. A height of constant water head was maintained at 10 cm till a stable rate of intake was established. The rate of water drop in unit time was measured till it drained completely. The rate of infiltration was inferred using the relation:

Rate of infiltration = distance drop per unit time          (1)
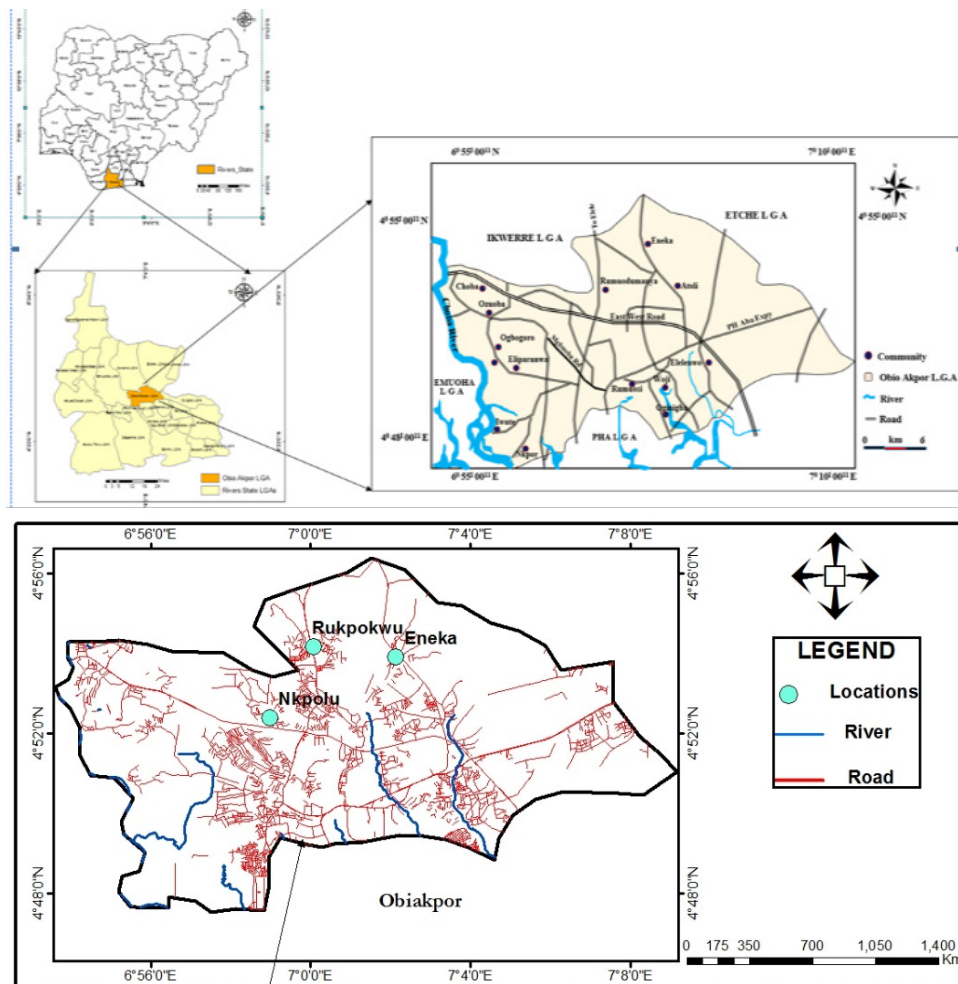


**Figure 1 (a, b):** Map of Study area showing sampling locations in Obio Akpor Local Government Area of Rivers State, Nigeria.

**Table 1.** Sample Locations, geographic coordinates and elevation.

| LOCATION | SAMPLE ID | DEPTH(m) | GPS COORDINATES | | ELEVATION(m) |
| | | | NORTHINGS | EASTINGS | |
|---|---|---|---|---|---|
| *NKPOLU* | *NKPOLU  1 | 1 | N4°52'18.114" | E6°57'57.342" | 16 |
| | | 2 | | | |
| | | 3 | | | |
| | *NKPOLU  2 | 1 | N4°52'22.6" | E6°58'224" | 10 |
| | | 2 | | | |
| | | 3 | | | |
| | *NKPOLU  3 | 1 | N4°52'204" | E6°58'622" | 13 |
| | | 2 | | | |
| | | 3 | | | |
| | *NKPOLU  4 | 1 | N4°52'443" | E6°58'520" | 7.1 |
| | | 2 | | | |
| | | 3 | | | |
| *RUKPOKWU* | *RUKPOKWU 1 | 1 | N4°55'37.518" | E6°59'57.738" | 21 |
| | | 2 | | | |
| | | 3 | | | |
| | *RUKPOKWU 2 | 1 | N4°55'34.638" | E6°55'59.316" | 20 |
| | | 2 | | | |
| | | 3 | | | |
| | *RUKPOKWU 3 | 1 | N4°55'37.458" | E6°59'55.392" | 24 |
| | | 2 | | | |
| | | 3 | | | |
| | *RUKPOKWU  4 | 1 | N4°5524.8" | E6°59'49.9" | 16.3 |
| | | 2 | | | |
| | | 3 | | | |
| *ENEKA* | *ENEKA 1 | 1 | N4°53'16.188" | E7°2'32.634" | 20 |
| | | 2 | | | |
| | | 3 | | | |
| | *ENEKA 2 | 1 | N4°53'25.716" | E7°2'47.838" | 20 |
| | | 2 | | | |
| | | 3 | | | |
| | *ENEKA 3 | 1 | N4°53'28.962" | E7°2'43.260" | 18 |
| | | 2 | | | |
| | | 3 | | | |
| | *ENEKA 4 | 1 | N4°53'17.1" | E7°2'51.3" | 10.3 |
| | | 2 | | | |
| | | 3 | | | |

* *Drilled holes.*

### 3.2.2 Digital Elevation Modelling

A Digital Elevation Model was generated using Google Earth Pro and ArcGIS software program. The data points utilized for generating the DEM were digitized from Google Earth Pro. Over 10,000 elevation points were generated from Google earth pro and converted to elevations using the TCX online converter which converts latitudes, longitudes and distances into actual elevations. The coordinates and elevations were entered into ArcGIS software program and the elevations were contoured and coloured using the Kriging Interpolation Method.

### 3.2.3 Pluvial Flood Risk Assessment

The risk assessment of the study area was evaluated using the scoring matrix for preliminary risk assessment as proposed by Ronnie [23] (Table 2). The attributes adopted in the assessment includes: depth of flooding, properties at risk and extent of flooding, flow path and topographic depression, velocity of flow, sensitivity of land use and doorway threshold levels. The scores allocated range from 0–5. A score between 0-2 is reported as not significant, between 3-5 is reported as low, between 6-8 is reported as moderate, between 9-10 it is reported high, and greater than 10 is reported as severe.

### 3.2.4 Grain Size Analysis

36 soil samples were collected from three locations each in the study area at depth of 1m interval. 52 grams of soil was used for the hydrometer test and 200 grams of soil was used for wet sieve analysis to account for the coarse and fine fractions of the soil. Sieving was done through mesh with sizes of 2.00 mm, 0.500 mm, 0.250 mm, 0.150 mm, 0.063 mm and the weight retained. The absolute mass of soil passing through each sieve was noted. The wet sieving method was employed (BS 1377) where soil samples are weighed, oven dried and then washed through sieve number 200. The samples were sieved for 10 minutes in an electric sieve shaker using (US Mesh size). The percentage of sand, silt and clay was plotted on a semi log graph.
Therefore,

$$\%sand + \%silt + \%clay = 100\% \tag{2}$$

### 3.2.5 Determination of Soil Properties

The following soil properties were determined within each case study using established empirical relations: Permeability, hydraulic conductivity, moisture content, specific gravity/ bulk density and porosity.

Permeability test was carried out using the china designed ZEALCHON, ISO certified C032 Permeameter, and the permeability co-efficient was obtained using the expression:

$$k = \frac{2.3 * a * L * \log_{10} {}^{h_0}/_{h_1}}{A * t} \tag{3}$$

where:
k = Permeability
a = cross sectional area (soil)
A = area of stand pipe
L = length (soil)
h0= total head before test
h1= total head after test
$\Delta t$ = time interval for head to drop.

By interpretation, when k is over $10^{-1}$ cm/sec, the permeability is high, when k is equivalent to $10^{-1}$ cm/sec, the permeability is medium, and when k is below $10^{-1}$ cm/sec, it is interpreted as low.

Hydraulic conductivity (K), is a soil attribute used to elucidate the ease of flow of a fluid through pores or fractures in soil. For hydraulic conductivity, we adopted an empirical formula to establish the ease of fluid flow in the soils researched for soils with clay content < 35%, Delgado et al., [24].

$$K = 0.101176 * FINES^{-1.62} \tag{4}$$

Fines = percentage of sand and silt (determined by texture by Bouyoucos hydrometer test).

Moisture content (M) was calculated as the result of the ratio between the weights of water to that of dry soil. It was evaluated by oven drying for about 18 hours at $105^0$c (BS 1377, 1990).

$$M = \frac{mass\ of\ water}{mass\ of\ solid\ soil} \times 100\% \tag{5}$$

Specific gravity ($G_s$), an important property of soils that is employed to classify soils was estimated as the mass of a given volume of soil divided by the mass of an equal volume of water. In this study, a standard density bottle was used to measure specific gravity. Heterogeneous soils can have $G_s$ ranging from 2.70-2.80. High organic clay in the Niger Delta can have values ranging from 2.2-2.5. Porous diatomaceous earth with measurable organic content can have values below 2.00 and higher values of specific gravity can be observed and it indicates the presence of heavy minerals in soil (iron) (University of Port Harcourt Engineering Geology Manual).

$$Gs = \frac{Mass\ of\ given\ volume\ of\ soil}{Mass\ of\ an\ equal\ volume\ of\ water} \tag{6}$$

Bulk density, the ratio of the dry solid mass to the soil bulk volume was measured by means of a cylindrical mould. The cylindrical mould employed in this study had

**Table 2.** Preliminary risk assessment values (after Ronnie [23]), showing the scoring Matrix used for Preliminary Risk Assessment.

| Attribute | Hazard Level | Very Low | Low | Moderate | High | Very High |
|---|---|---|---|---|---|---|
| **Depth of Flooding** | Description | <0.2m | 0.2m to 0.50m | 0.5m to 1m | 1m to 2m | >2m |
| | Score | 0 | 1 | 2 | 3 | 4 |
| **Properties at Risk and Extent of Flooded Area** | Description | No properties potentially at risk Localized <0.1ha | 1 property potentially at risk Localized <0.1ha | Up to 10 properties potentially at risk. Moderate (up to 1ha) | Up to 100 properties potentially at risk. Extensive (up to 10ha) | More than 100 properties potentially at risk. Widespread (>10ha) |
| | Score | 0 | 1 | 2 | 3 | 4 |
| **Flowpath feeds topographic depression** | Description | No or Flowpath only | Yes. Depth <0.5m | Yes. Depth <0.5-1m | Yes. Depth 1-2m | Yes. Depth >2m |
| | Score | 0 | 0 | 1 | 2 | 3 |
| **Velocity of Flow** | Description | Still Water or velocity <0.1m/s (generally flat terrain) | Velocity 0.1 to 0.5m/s (generally moderatel sloping terrain) | Velocity 0.5-1m/s (generally moderately sloping terrain) | Velocity more than 1m/s (generally sleeply sloping terrain) | Velocity more than 1m/s (generally sleeply sloping terrain) and depth of flow more than 0.5m |
| | Score | 0 | 1 | 2 | 3 | 4 |
| **Sensitivity of Land Use** | Description | Open areas that can be flooded without significant consequence. | Parkland, open ground or farmland where flooding would have some consequence. | Suburban residential/commercial/retail/industrial areas where flooding would have moderate consequence. | Central urban or town centre residential/commercial/retail/industrial areas where flooding would have high consequence. | Critical infrastructure present. Critical transportation links present. Basement flats present. |
| | Score | 0 | 1 | 2 | 3 | 4 |
| **Doorway Threshold Levels** | Description | Most above 0.2m above ground level | Most above 0.2m but some 0m to 0.2m above ground level | Most 0m to 0.2m above ground level | Most at ground level. Some below ground level | Most below ground level |
| | Score | 0 | 1 | 2 | 3 | 4 |
| **Total Score** | | 0 to 2 | 3 to 5 | 6 to 8 | 9 to 10 | >10 |
| **Overall Preliminary Risk Rating** | | Not Significant | Low | Moderate | High | Severe |

a 4.5 cm diameter, a 7.6 cm length, weighed 197.1g and a volume of 120.8 cm$^3$.

The bulk density was obtained from dry density (ρdry) and moisture content. Dry density was calculated using:

$$\rho_{dry} = \frac{\text{mass of dry soil}}{\text{internal vol of cylinder}} \qquad (7)$$

From the dry density values obtained, bulk density was estimated from the relation:

$$\rho_{dry} = \frac{\text{bulk density}}{1+m} \quad (m = \text{moisture content in percentage})$$
$$(8)$$

where:

$\rho_{dry}$ = dry density computed from equation (7)

m = moisture content in percentage computed from equation (5)

Porosity which is a natural property of rocks that describes the degree of voids that are present within a given rock material and exists between the grains of minerals, was determined from bulk density and dry density of the rock material. Dry density of a rock in (g/cm$^3$) is equal to its specific gravity (Gs) as density of water is (1 g/cm$^3$). Therefore, porosity (n) was computed using

$$n = \left(1 - \frac{\rho b}{Gs}\right) \times 100 \qquad (9)$$

where:

$\rho^b$ = bulk density

$G_s$ = specific gravity

## 4. Presentation of Results and Discussion

Results of average values of drain test is summarized in Table 3. The result reveal that water drains at an average rate of 6.4x10$^{-5}$ cm/sec at Nkpolu, 2.5x10$^{-4}$ cm/sec at Eneka and 5.3 x 10$^{-5}$ cm/sec at Rukpokwu (Table 3). However, it was observed that the areas are bare and crusted, and thus water drain very slowly which results to flooding.

The Digital Elevation Model of the study locations within the study area is shown in Figure 2. The elevation model reveals the current topography of the area under study which is lower than adjoining areas, thus acting as a basin receptacle that retain flood water and water draining from surrounding uplands, as water naturally flows from higher elevations to lower elevations. At Eneka, elevation variation is from 18.56 m to 21.50 m, at Rukpokwu, elevation variation is from 18.56 m to 24.54 m, and at Nkpolu, elevation variation is from 12.56 m to 18.55 m

**Table 3.** Summary of Rate of Infiltration (Drain test) result obtained within the study locations.

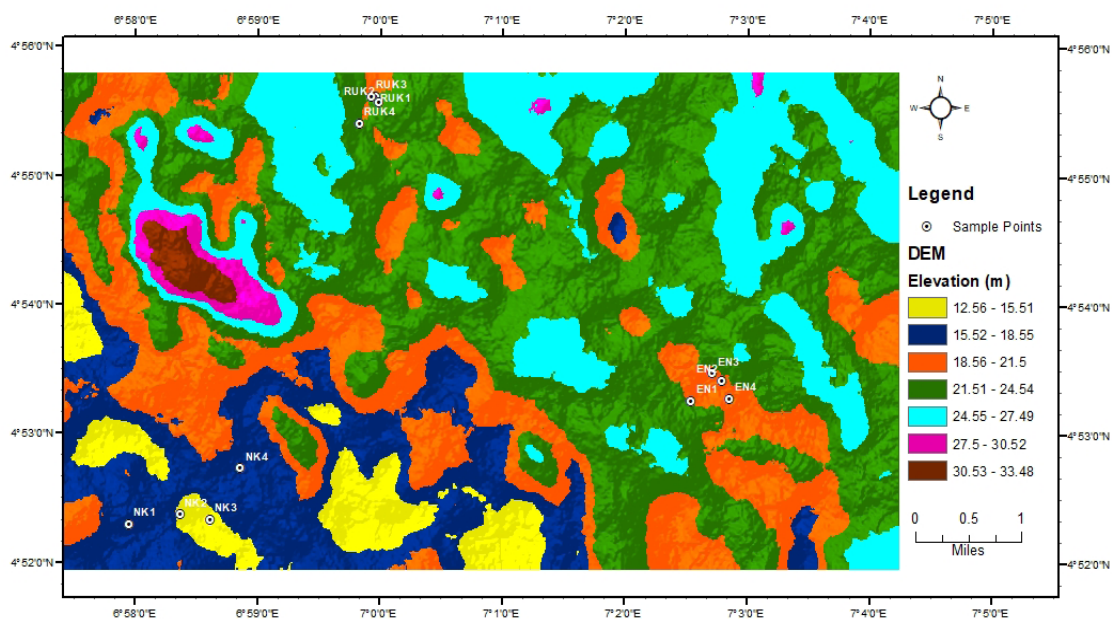| Location | | | | | | |
|---|---|---|---|---|---|---|
| **NKPOLU** | | | | | | |
| H1 (cm) | 10 | 10 | 10 | 10 | 10 | 10 |
| H2 (cm) | 0.5 | 6.7 | 0.9 | 4.1 | 0.4 | 6.1 |
| Time (sec) | 86,400 | 79,200 | 48,900 | 27,300 | 50,400 | 48,840 |
| Drain Rate (cm/s) | 5.7x10-6 | 8.4x10-5 | 1.8 x10-5 | 1.5 x10-4 | 7.9 x10-6 | 1.2x10-4 |
| Average | 6.4x10-5 | | | | | |
| **ENEKA** | | | | | | |
| H1 (cm) | 10 | 10 | 10 | 10 | 10 | 10 |
| H2 (cm) | 8.3 | 7.4 | 3.3 | 6.6 | 5.5 | 0.4 |
| Time (sec) | 13,500 | 24,660 | 12,700 | 34,620 | 35,220 | 34860 |
| Drain Rate (cm/s) | 6.1 x10-4 | 3.0x10-4 | 2.58x10-4 | 1.9x10-4 | 1.56x10-4 | 1.1x10-5 |
| Average | 2.5x10-4 | | | | | |
| **RUKPOKWU** | | | | | | |
| H1 (cm) | 10 | 10 | 10 | 10 | 10 | 10 |
| H2 (cm) | 0.69 | 2.1 | 1.6 | 2.2 | 0.09 | 6.1 |
| Time (sec) | 40,620 | 40,080 | 41,460 | 38,640 | 41,040 | 40,320 |
| Drain Rate (cm/s) | 1.69x10-5 | 5.2x10-5 | 3.8 x10-5 | 5.7x10-5 | 2.19x10-6 | 1.5x10-4 |
| Average | 5.3x10-5 | | | | | |

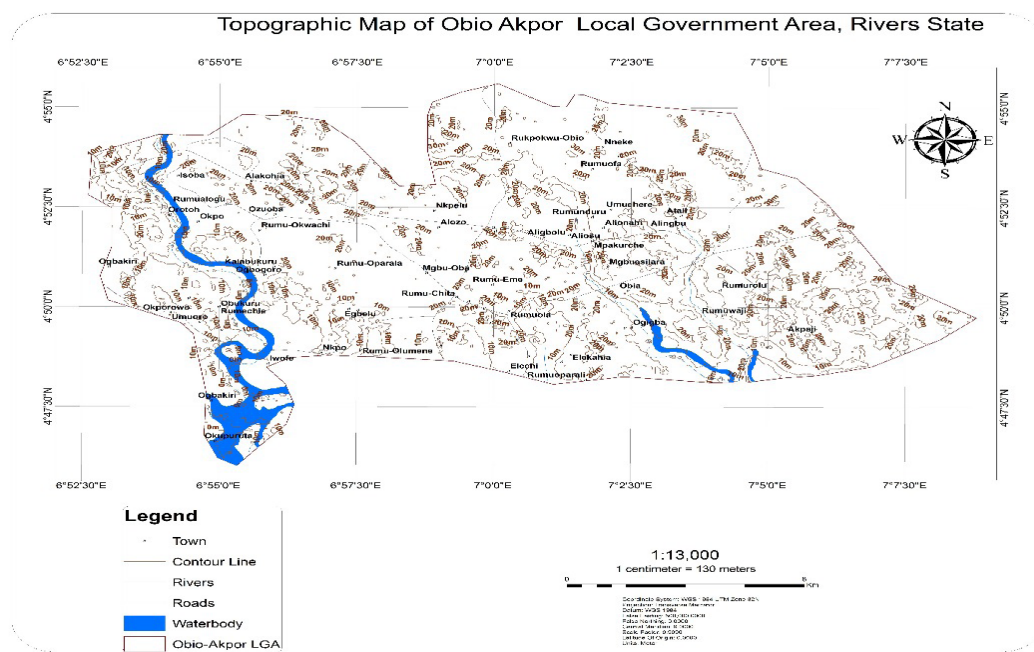**Figure 2.** Digital Elevation Model of the Study area. (EN - Eneka; Ruk - Rukpokwu; NK – Nkpolu).



**Figure 3.** Topographic Map of Study area, Obio Akpor Local Government Area, Rivers State Nigeria.

(Figure 2). Flooded areas of Nkpolu are its lowest areas of about 11–14 m above sea level. It was also observed that the major roads that run through the study area have distorted the landscape of the area by either blocking natural drainage paths or act as impervious surfaces constructed on low lying areas thus creating a dip on both sides of the road or have higher elevations than the flooded areas (21-24 m above sea level).

3D topographic map of the study locations (Figure 4

a,b) show that the study locations are located in basins which act as gathering points for flood water and waters draining from surrounding upland areas.

At Nkpolu, elevation ranged from 8 m to 11 m above sea level (Figure 4a), thus Nkpolu having the lowest elevation among the study locations has its low lying areas receive flood waters after rainfall thereby making it more prone to flood risk.

From Table 4, the risk assessment of the study locations
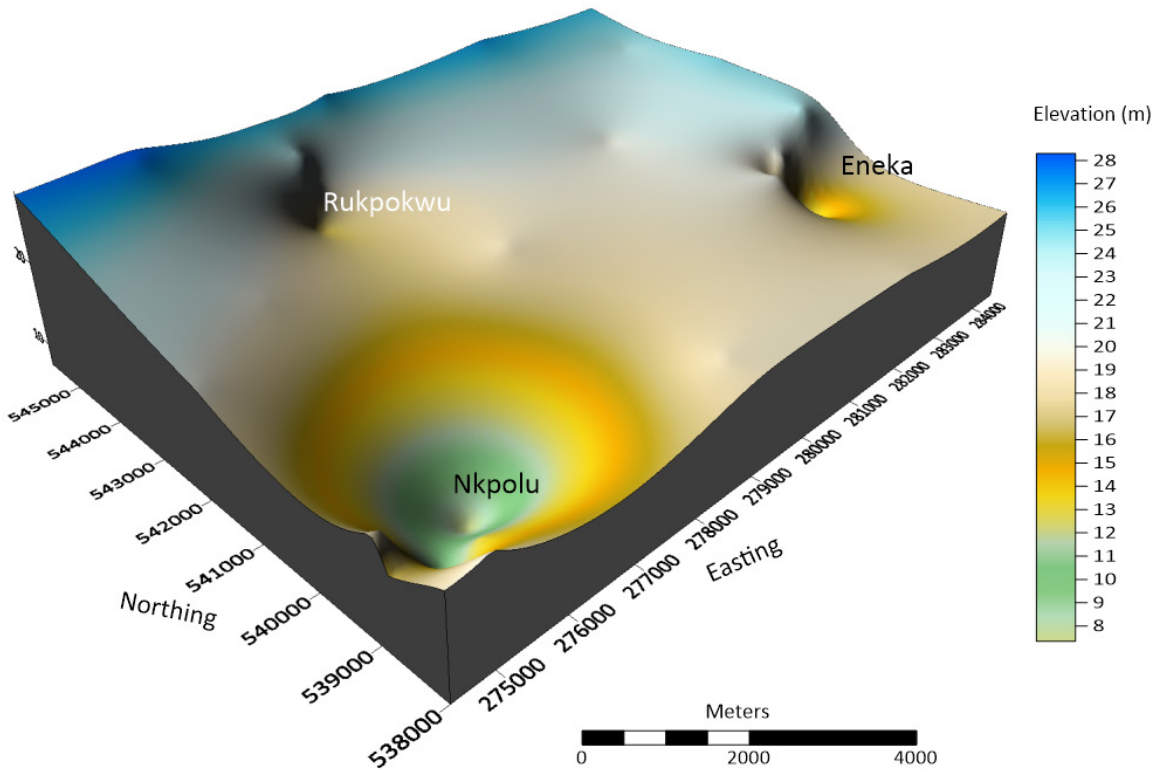
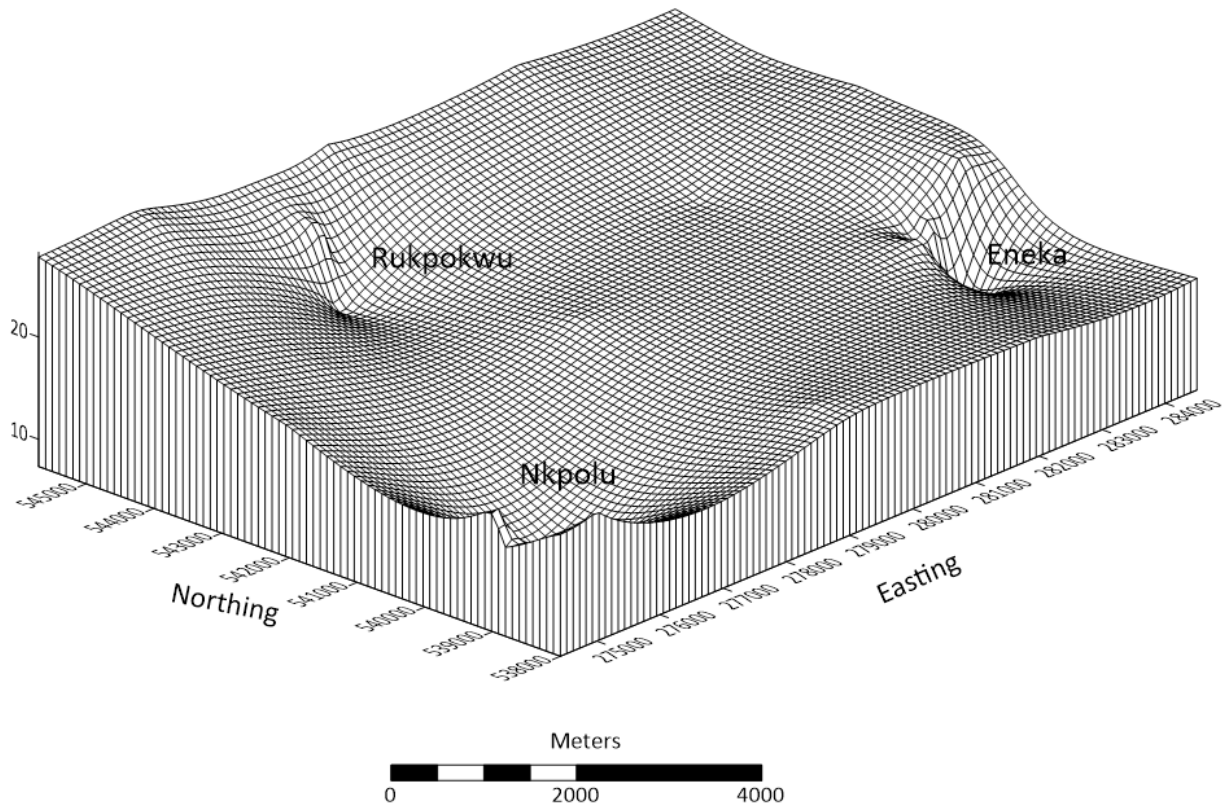**Figure 4(a).** 3D Topographic map of study locations, showing the topography of the area



**Figure 4(b).** Wireframe of topographic map in 4(a).

**Table 4.** Result of Preliminary Flood Risk Assessment (Pluvial flooding).

| ATTRIBUTES | NKPOLU SCORE | ENEKA SCORE | RUKPOKWU SCORE |
|---|---|---|---|
| Depth of flooding | 4 | 3 | 4 |
| Properties at risk | 3 | 2 | 2 |
| Flow path (topographic depression) | 1 | 1 | 2 |
| Velocity of flow (m/sec) | 2 | 2 | 1 |
| Sensitivity of land use | 4 | 2 | 2 |
| Doorway threshold levels | 0 | 0 | 0 |
| Total Score: | 14 | 10 | 11 |
| Overall risk rating | ◉ Severe | ◉ High | ◉ Severe |

show that Nkpolu and Rukpokwu are severely affected by pluvial flooding, while Eneka is highly affected.

## 4.1 Result of Wet Sieve Analysis

Result of wet sieve analysis reveal that the soils are medium to fine grain sand, with fines content of 42%, 45% and 40% at 1 m, 2 m and 3 m respectively at Nkpolu (Table 5), 50%, 48%, and 49% at 1 m, 2 m and 3 m respectively at Eneka (Table 6), and 48%, 54% and 56% at Rukpokwu at 1 m, 2 m, and 3 m respectively (Table 7). The soil in the study locations show a high proportion of fines (silt and clay dominant). The soils are Sand loamy, well graded silt clayey sand (1 meter), well graded clay silty sand (2 meters) at Nkpolu, and well graded silt clayey sand (3 meters). Soils at Eneka and Rukpokwu are well graded clay silty sand from 1 m to 3 m. The results show that the soils in the study locations are well graded, medium to fine grained, with high bulk density and high fines content. Well graded soils experience good compaction than poorly graded soils [25]. Kenneth et al., [26], opined that soils with fines greater than 30%, exceeding the transitional fines content of 15-30%, are susceptible to increase in compaction by successive increase in load thus the topsoil in the study locations are hard and crusted due to frequent rainfall, increase in load, repeated wetting and drying and lack of surface cover. The applied load could be by rainfall intensity, urbanisation, gravity and flooding. Tables 5 to 7, show the results of wet sieve analysis for the study locations.

**Table 5.** Wet Sieve analysis result of Nkpolu

| Nkpolu (Loc1) | 1meter | 2meters | 3meters |
|---|---|---|---|
| %Sand | 48.5 | 50.8 | 51.2 |
| % Passing sieve no 200 (Fine | 51.4 | 49.2 | 48.8 |
| %Gravel | 0.1 | - | - |

| Nkpolu (Loc2) | 1meter | 2meters | 3meters |
|---|---|---|---|
| %Sand | 56.1 | 59.1 | 55.1 |
| % Passing sieve no 200 (Fines) | 43.9 | 40.8 | 44.9 |
| %Gravel | - | 0.1 | - |

| Nkpolu (Loc3) | 1meter | 2meters | 3meters |
|---|---|---|---|
| %Sand | 58.9 | 55.5 | 68.6 |
| % Passing sieve no 200 (Fines) | 41.1 | 44.4 | 31.0 |
| %Gravel | - | 0.1 | 0.4 |

| Nkpolu (Loc4) | 1meter | 2meters | 3meters |
|---|---|---|---|
| %Sand | 66.6 | 54.8 | 63.1 |
| % Passing sieve no 200 (Fines) | 33.1 | 45.0 | 36.9 |
| %Gravel | 0.3 | 0.2 | - |

**Table 6.** Wet Sieve analysis result of Rukpokwu

| Rukpokwu (Loc1) | 1meter | 2meters | 3meters |
|---|---|---|---|
| %Sand | 46.8 | 48.7 | 51.6 |
| % Passing sieve no 200 (Fines) | 53.2 | 51.3 | 48.2 |
| %Gravel | - | - | 0.2 |

| Rukpokwu (Loc2) | 1meter | 2meters | 3meters |
|---|---|---|---|
| %Sand | 50.8 | 39.6 | 32.2 |
| % Passing sieve no 200 (Fines) | 49.2 | 60.2 | 67.7 |
| %Gravel | - | 0.2 | 0.1 |

| Rukpokwu (Loc3) | 1meter | 2meters | 3meters |
|---|---|---|---|
| %Sand | 47.7 | 45.5 | 44.2 |
| % Passing sieve no 200 (Fines) | 52.3 | 54.4 | 55.7 |
| %Gravel | - | 0.1 | 0.1 |

| Rukpokwu (Loc4) | 1meter | 2meters | 3meters |
|---|---|---|---|
| %Sand | 63.0 | 47.1 | 47.8 |
| % Passing sieve no 200 (Fines) | 36.8 | 52.4 | 52.0 |
| %Gravel | 0.2 | 0.5 | 0.2 |

**Table 7.** Wet Sieve analysis result of Eneka

| Eneka (Loc1) | 1meter | 2meters | 3meters |
|---|---|---|---|
| %Sand | 51.6 | 57.6 | 49.0 |
| % Passing sieve no 200 (Fines) | 48.4 | 42.4 | 51.0 |
| %Gravel | - | - | 0.2 |

| Eneka (Loc2) | 1meter | 2meters | 3meters |
|---|---|---|---|
| %Sand | 50.3 | 48.9 | 52.4 |
| % Passing sieve no 200 (Fines) | 49.7 | 49.7 | 47.60 |
| %Gravel | - | 0.1 | - |

| Eneka (Loc3) | 1meter | 2meters | 3meters |
|---|---|---|---|
| %Sand | 42.6 | 49.2 | 46.0 |
| % Passing sieve no 200 (Fines) | 53.5 | 50.8 | 54.0 |
| %Gravel | - | 0.2 | 0.5 |

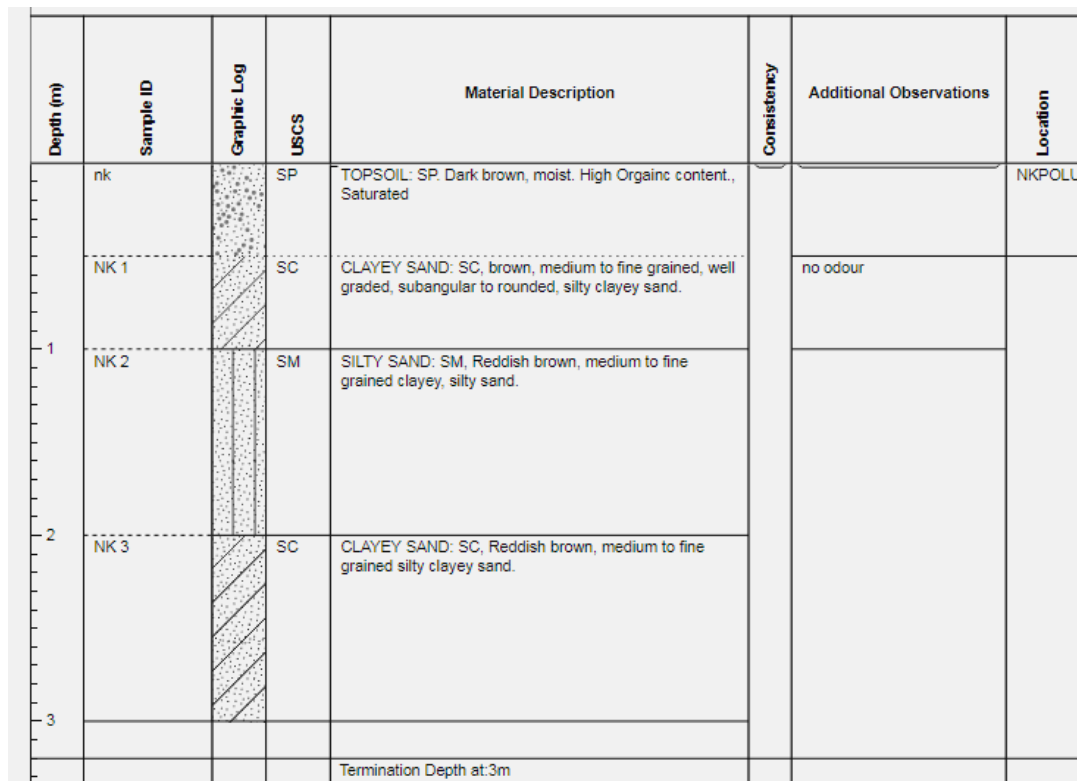| Eneka (Loc4) | 1meter | 2meters | 3meters |
|---|---|---|---|
| %Sand | 61.9 | 46.6 | 51 |
| % Passing sieve no 200 (Fines) | 38.1 | 53.4 | 53.4 |
| %Gravel | - | - | 0.1 |



**Figure 5(a).** Lithological Profile of Nkpolu showing lithological description of subsurface materials at 1m, 2m and 3m respectively

| Depth (m) | Sample ID | Graphic Log | USCS | Material Description | Consistency | Additional Observations | Location |
|---|---|---|---|---|---|---|---|
| | ENEKA | | SP | TOPSOIL: SP. brown, moist. High Orgainc content., Saturated | | | ENEKA |
| | EN 1 | | SM | SILTY SAND: SC, brown, medium to fine grained, well graded, subangular to rounded, saturated clayey silty sand. | | no odour | |
| 1 | EN 2 | | SM | SILTY SAND: SM, Reddish brown, medium to fine grained, saturated clayey silty sand. | | | |
| 2 | EN 3 | | SM | SILTY SAND: SC, Reddish brown, medium to fine grained, clayey silty sand. | hard | | |
| 3 | | | | | | | |
| | | | | Termination Depth at:3m | | | |

**Figure 5(b).** Lithological Profile of Eneka showing lithological description of subsurface materials at 1m, 2m and 3m respectively

| Depth (m) | Sample ID | Graphic Log | USCS | Material Description | Consistency | Additional Observations | Location |
|---|---|---|---|---|---|---|---|
| | RUKPOKWU | | SP | TOPSOIL: SP. brown, moist. High Orgainc content., Saturated | | | RUKPOKWU |
| | RK 1 | | SM | SILTY SAND: SC, brown, medium to fine grained, well graded, subangular to rounded, saturated clayey silty sand. | | no odour | |
| 1 | RK 2 | | SM | SILTY SAND: SM, Reddish brown, medium to fine grained, saturated clayey silty sand. | | | |
| 2 | RK 3 | | SM | SILTY SAND: SC, Reddish brown, medium to fine grained, clayey silty sand. | hard | iron staining, no odour | |
| 3 | | | | | | | |
| | | | | Termination Depth at:3m | | | |

**Figure 5(c).** Lithological Profile of Rukpokwu showing lithological description of subsurface materials at 1m, 2m and 3m respectively

## 4.2 Result of Soil Properties

Moisture content values at Nkpolu have an average of 23.4% at 1 m, 28.9% at 2 m and 28.9% at 3 m. At Eneka, the moisture content values have an average of 23.8%, 25.5% and 25% at 1 m, 2 m and 3 m respectively, while at Rukpokwu, moisture content values have an average of 27.2%, 27.3%, and 29% at 1 m, 2 m and 3 m respectively. These findings, show that the water content of soils in the area is high, which validates the level of soil retention capacity. The moisture content increases with respect to depth due to the underline lithology. The moisture content models of the area within the sampled locations is shown in Figure 6(a), (b), and (c).

Result of porosity computed within the study area show that at Nkpolu, the mean porosity values are 27.4% at 1 m, 21.8% at 2 m and 20.8% at 3 m. At Eneka, the mean Porosity values are 25.3% at 1 m, 26% at 2m, and 24.7% at 3 m, while at Rukpokwu, the mean porosity values are 25.5% at 1 m, 18.7% at 2 m and 37.3% at 3 m. The porosity models of the study locations are shown in Figure 7 a, b, c. The models reveal that porosity reduces with depth at Nkpolu and at Eneka porosity increased from 1 m to 2 m and decreased at 3 m, while in Rukpokwu, porosity increased with depth at 3 m. This shows the wide range and variation of pore sizes inherent in the soil horizon which influences the porosity of soils and reflects in the range and arrangement of the particle sizes. The measured bulk density of soils in the study areas increases downwards to the depth of probe. It ranges from 1.8 $g/cm^3$ at 1 and 2 m to 1.9 $g/cm^3$ at 3 m for each of the sampled locations.

The hydraulic conductivity model, which describes the ease at which water passes through a soil under gravity is shown in Figure 8. Hydraulic conductivity, has more sturdy impact on the rate at which water moves progressively into the soil than most other soil properties. Hydraulic Conductivity fluctuates with increasing depth with an average of 4.94 $x10^{-4}$ ft/day, 6.31 $x10^{-4}$ ft/day and 7.01$x10^{-4}$ ft/day at 1 m, 2 m, and 3 m in Eneka respectively, 7.11 $x10^{-4}$ ft/day, 6.39 $x10^{-4}$ ft/day and 4.79 $x10^{-4}$ ft/day at 1 m, 2 m, and 3 m in Rukpokwu respectively and 6.58 $x10^{-4}$ ft/day, 7.37 $x10^{-4}$ ft/day, 6.35 $x10^{-4}$ ft/day at 1 m, 2 m, and 3 m in Nkpolu respectively. From the model (Figure 8), it was observed that hydraulic conductivity decreases with respect to depth.

Permeability describes the measure at which a soil will permit the flow of water through it. Measured permeability values were observed to be less than $10^{-1}$ cm/sec, and was rated low and typical of soils with high fine content (silt and clay). At Nkpolu, mean permeability rates of 0.003 cm/sec, 0.009 cm/sec and 0.033 cm/sec were ob-

tained at 1, 2 and 3 m respectively. At Eneka, mean permeability rates of 0.011 cm/sec, 0.018 cm/sec and 0.014 cm/sec were obtained at 1, 2 and 3 m respectively while at Rukpokwu, mean Permeabiliy rates of 0.021 cm/sec was obtained at 1 m and 0.006 cm/sec was obtained at 2 and 3 m respectively. The permeability model (Figure 9) shows that at Eneka, the surface soils have a low permeability rate and a more permeable layer was observed to be sandwiched between a low permeable top and bottom layer. At Rukpokwu, permeability decreases downward.
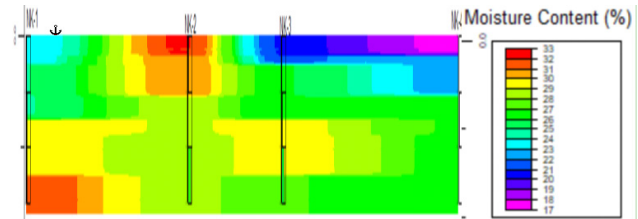


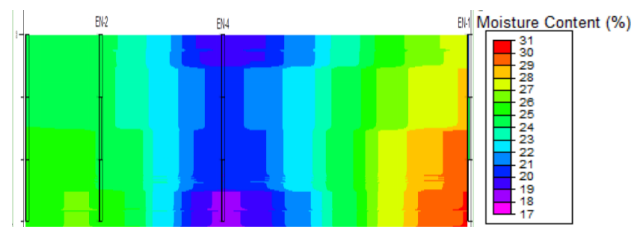**Figure 6(a).** Moisture content model of Nkpolu showing variations in moisture content



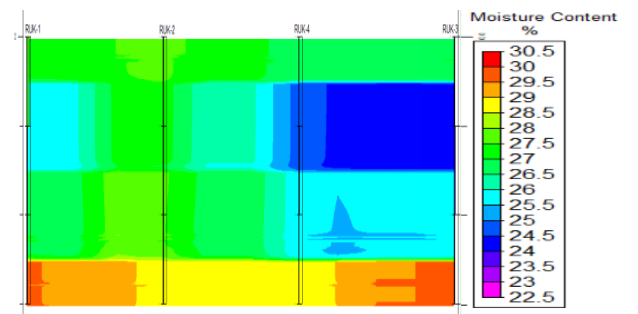**Figure 6(b).** Moisture content model of Eneka showing variations in moisture content



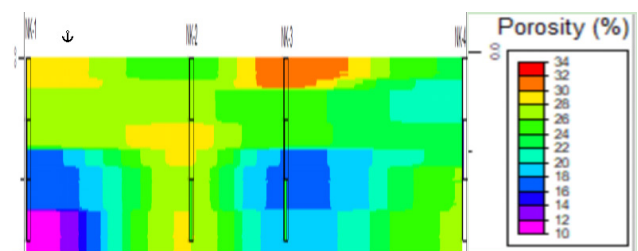**Figure 6(c).** Moisture content model of Rukpokwu showing variations in moisture content



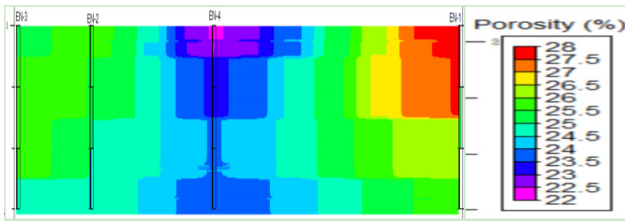**Figure 7(a).** Porosity model of Nkpolu showing variations in Porosity

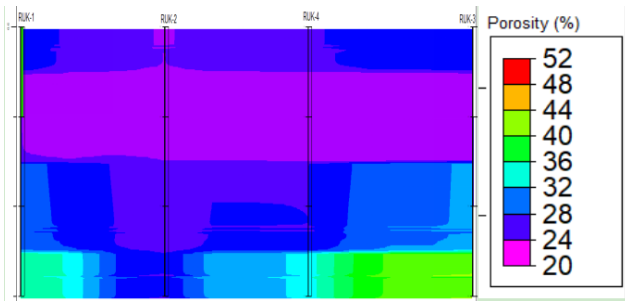**Figure 7(b).** Porosity model of Eneka showing variations in Porosity



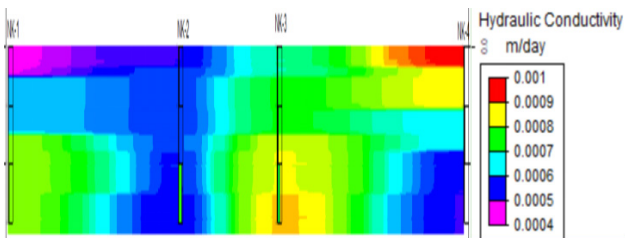**Figure 7(c).** Porosity model of Rukpokwu showing variations in Porosity



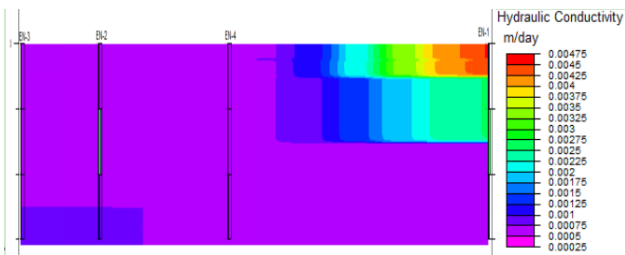**Figure 8(a).** Hydraulic conductivity model of Nkpolu



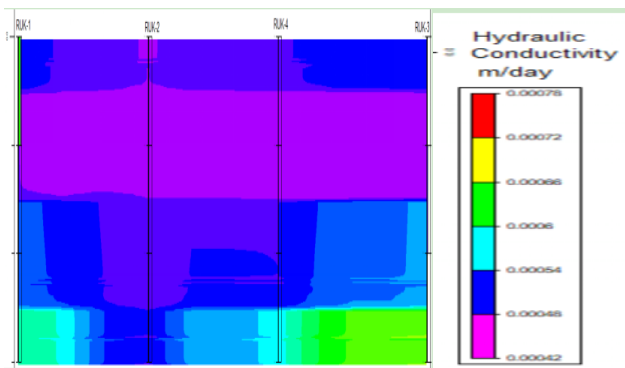**Figure 8(b).** Hydraulic conductivity model of Eneka



**Figure 8(c).** Hydraulic conductivity model of Rukpokwu

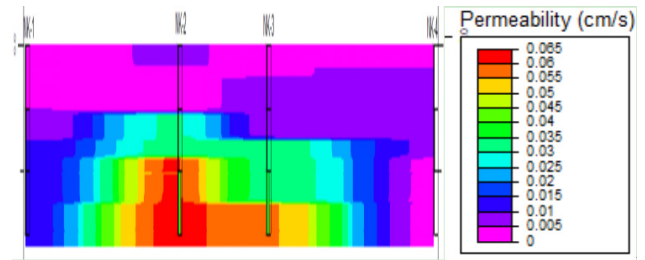The model shows that hydraulic conductivity decreases with respect to depth.



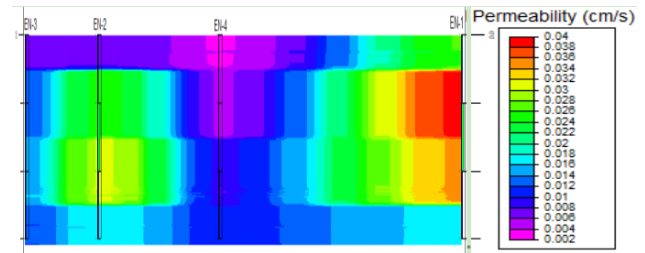**Figure 9(a).** Permeability model of Nkpolu.



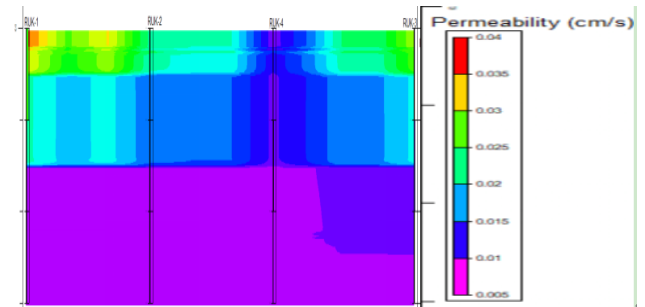**Figure 9(b).** Permeability model of Eneka.



**Figure 9(c).** Permeability model of Rukpokwu.

The model shows that at 1m depth soils have low permeability, while at 2 m and 3 m depth, permeability increases in the study area.

## 5. Conclusions

This study has examined several factors which includes geomorphology, grain size analysis, and soil properties which contributes to flooding of urban areas within Port Harcourt metropolis. Urbanization trend has led to expansion of non-pervious surfaces and bare land with considerable crusted depths, alteration of natural landscapes, blocking of drainage paths by debris and waste and the construction of roads at higher elevations than surrounding areas. Results of wet sieve analysis and hydrometer test of grain size, show that the study area contains dominant fines with respect to depth of probing. The soil textural classification is silty, clayey sand and clayey silt sand (sandy loam) with high concentration of fines. Soils with high concentration of fines are most susceptible to com-

pression and crusting. The study area experiences intense and frequent rainfall over extended periods of time, which generates a lot of runoff and has led to crusting of the soil which is evident in the high bulk density values of the soil and compaction of lower soil horizons. The development of crusted soils, highly compacted soil horizons, increase in impervious surfaces and poor drainage system network in the study area reduces the flow and seepage of floodwaters under gravity, thereby making the area more prone to flooding.

In view of these findings, the following recommendations are made for consideration:

● Good flood control policies be made; standard and efficient engineering designed drainage channels should be constructed and maintained.

● Infrastructures in municipal areas should be designed adequately to create alternative drainage routes for floodwaters to discharge points i:e nearby water body.

● Illegal structures on rivers or waterways should be discouraged and excavated to pave way for good drainage systems

## Funding

## Conflicts of Interest/Competing Interests

We declare that this research work has never been submitted previously by anyone to any journal for peer review and publication, hence it is an original work. All the ethical principles of research in the data collection, preparation, analysis and interpretation were implemented.

## Availability of Data and Material

Not applicable.

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