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Spatial distribution of Soil Permeability across Port Harcourt Area, Southeastern Nigeria

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Abstract Data from 73 soil investigation reports, mainly soil Permeability were used to prepare maps of the variation in the Permeability of the soils in Port Harcourt and its environs on a scale of 1:5000 metres at depths of 3-10m, 11-15m and 16-20m. Data processing and interpretation were made with the help of different professional computer software some of which were; Microsoft office tools for preparation, synthesis and analysis of data, Arc GIS 10.7, Strater 5, Google Earth Pro, surfer 16, for preparation and manipulation of different maps. The aim was to prepare these maps as a quick guide to land use planning, design and construction of civil engineering structures. The permeability of soil samples obtained at depths of 3-10m, 11-15m and 16-20m were 5×10^{-5} to 1.2×10^{-3}, 4×10^{-5} to 2×10^{-4} and 8.0×10^{-3} to 2.0×10^{-3} m/secwith average values of 4×10^{-4}, 3.72×10^{-4} and 9.30×10^{-4}m/sec respectively indicating that the soils in Port Harcourt area mostly have rapid flow rate of water. The soils are also rated as having medium to high permeability. High permeability soils give rise to high seepage flows which lead to leakage, tunnelling or breaking failure in earth dams. The linear regression analysis shows that the relationship between depth and permeability is a significant weak positive relationship indicating that as depth increases, permeability increases. The prevalent engineering problems in the study area will most likely be excessive settlement due to Flow of large volume of water from highly compressible clays. These engineering geological maps were produced to guide decision makers and planners in the land use allocation of the areas for sustainability.

Keywords Permeability, Variation, Spatial Distribution, Land Use, Sustainability

1. Introduction

The rise in foundation failure and building collapse has been a cause for concern in Port Harcourt. These Problems range from collapse of high-rise buildings to differential settlement in foundations carrying various Structures. This issue has caused the Government and regulatory bodies to stand on their toes especially after a case of the recent collapse of a seven-story building in Port Harcourt. The negative impact of foundation failure cannot be over emphasized as several lives and properties have been lost due to these sad occurrences The painful part of this is that these tragic events could have been averted if proper attention had been paid to the geotechnical properties of the soil and the design of the super structure. Civil and geotechnical engineers have a great role to play in the stability of buildings. One of the major challenges is the absence of information concerning the geotechnical properties of soils for land use and planning. This information when displayed on maps and charts gives vital information for land use and planning. Geotechnical maps of Port Harcourt will serve as a tool for curbing the frequent failure of superstructures in Port Harcourt.

The permeability of soils has a decisive effect on the stability of foundations, seepage loss through embankments of reservoirs, drainage of subgrades, excavation of open cuts in water bearing sand, and rate of flow of water into wells [21].

Soil permeability defines the capacity of water (or other liquids) and air to travel through the soil. Water runs extremely quickly through highly permeable soils and very slowly through soils with low permeability when it rains or when it is irrigated. The infiltration rate of a soil may be used to calculate its permeability. Sandy textures feature wide pore openings that allow rainfall to easily drain through the soil. Sandy soils have a high permeability, resulting in high infiltration rates and good drainage. Because clay textured soils have limited pore spaces, water drains slowly through the soil. Clay soils have a limited permeability, resulting in low infiltration rates and poor drainage. The air is pushed out as more water fills the pore space. The soil gets saturated when all pore spaces in the soil are filled with water. Many varieties of plants' roots cannot thrive in saturated soils. Standing water is caused by saturated soil on flat land, which can lead to floods. Saturated soils on sloping land cause runoff, which can increase the volume of water entering a body of water. This situation can cause erosion, floods, and an increase in the amount of contaminants entering the body of water.

Different engineering geological conditions may be depicted on a map. Maps provide the greatest picture of any geological environment, including engineering geological conditions. Geological, hydrogeological, and geomorphological maps should form the foundation for engineering geological maps. While doing so, it must display and assess the fundamental geological engineering facts given by these maps. It's a kind of geological map that provides a comprehensive picture of a geological environment important for civil and mining engineering land use planning and design, building, and maintenance [7].

It contains remarks on their basic engineering features, as well as a brief outline of the geological materials [5]. A comprehensive engineering geological survey is required to accurately assess the engineering geological conditions of a given region. archival data (boreholes and auger holes) must be collected, analyzed, and works detailing the region of interest are studied thoroughly [19]. The main elements of the engineering geological environment are shown on detailed maps of engineering geological conditions [11]. To collect and display relevant information on the physical characteristics of the environment, engineering geological mapping is very important [12]. All of the symbols and graphical characteristics on the engineering geological maps must be explained with cross-sectional data and occasionally an extra map sheet is required [10]. Regional and local planning uses engineering geological maps, such as determining where to build homes and recreational amenities, or deciding where to dump the trash. By displaying distribution and local ties among these important engineering geological conditions, an engineering geological map may represent not only the past but also the dynamic emergence and development of engineering geological conditions, according to [17]. The geology of the region is also interpreted by an engineering geological evaluation. It provides geotechnical engineers and planners with spatially representable geological data, together with quantitative information on soil and bedrock types [20]. Engineering geological maps are important documents where spatial distribution and mechanical characteristics are shown and are crucial instruments for conserving terrain knowledge [22]. All of these characteristics may be seen on typical engineering geology maps, which were then classified and rated based on several relative weights, such as severity, occurrence frequency, and the complexity of remedying the problem. According to [26], to create an engineering geological map of various sizes that always include information about the engineering geological characteristics of examined regions for the inquiry is the primary objective of engineering geological mapping [15]. Engineering geological maps, as opposed to geological maps specifically produced for engineering activities, were virtually completely unknown until the end of the nineteenth century, despite the obvious significance of geology in building and construction for many civil engineers and geologists [13]. Due to a lack of people and infrastructure in tropical nations, engineering geological mapping, which has shown to be an essential tool in many recent civil engineering and mining projects, has received little attention. There is a lot of evidence to support this theory

Information on soil permeability of an area when displayed on a map will enable the optimal use of earth materials for construction or foundation purposes.

Their major engineering problems include low bearing capacity and differential settlement, Vulnerability to flooding with high groundwater level resulting in water influx problem, poor drainage, high compressibility, among others [1].

1.1 Location and accessibility of Study Area

Port Harcourt Metropolis is located between Latitudes 4°45'N and 4°55'N, and Longitudes 6°55'E and 7°05'E in Rivers State (Figs 1 and 2).

The Study Area is located in the Niger Delta. The Niger Delta is characterized by a network of rivers and creeks which drain the hinterland, transporting both water and sediment to the Atlantic Ocean. This process has created a vast sedimentary region, roughly 3000km^2 in area, and populated by about 35 million inhabitants [1]. The tropical Delta is made up of mainly fine-grained deltaic sediments. It is not tectonically active, and it is also not subject to catastrophic storms, waves or floods. The Niger delta is characterized by widespread and irregular distribution of weak soils whose strength is reduced further by the presence of expansive clays [23]. This gives rise to foundation problems in roads, houses, and embankments. Extensive leaching of salt by rainwater and groundwater results in Niger Delta soil particles losing interparticle attractive forces and results in breaking down of soil structure [24]. Most Niger delta soils do not have gravel fractions. They contain high clay and moisture content leading to large volume changes that result in excessive swelling and shrinkage. The soils are also known to have poor compaction characteristics, with a low bearing capacity, which makes them unsuitable for pavement construction and other foundation purposes [3] and [4],[25], [9].

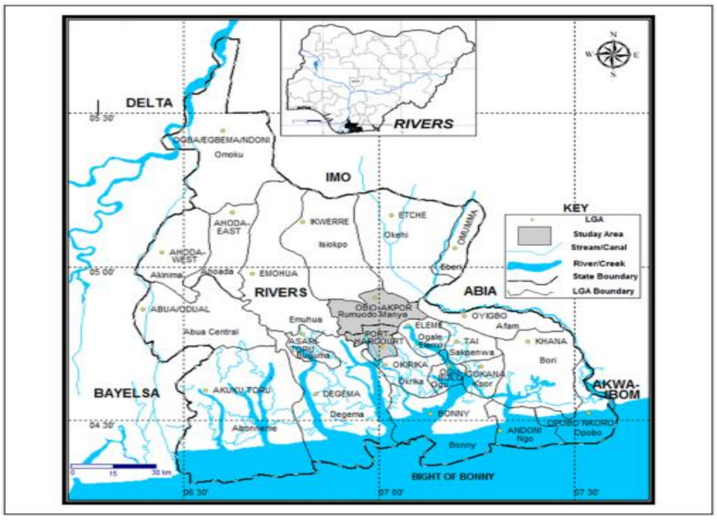

Figure 1: Map of Rivers State Showing study area [6]

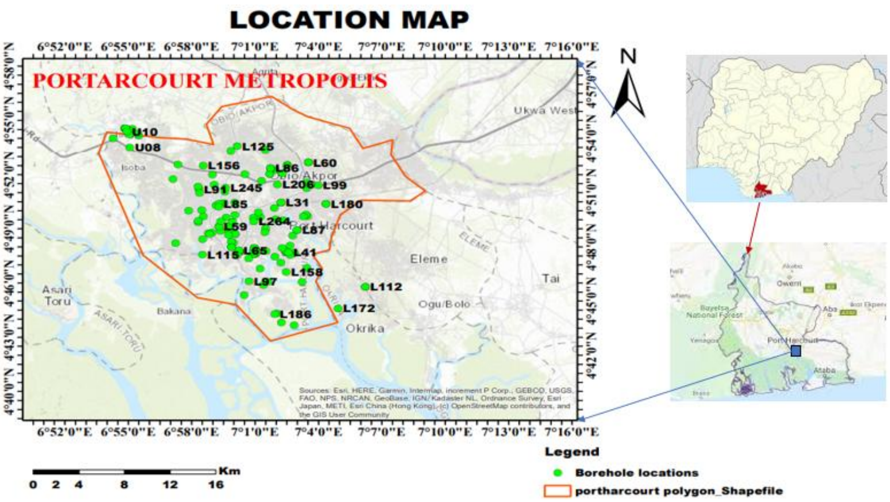

Figure 2: Location Map of study area

2. Literature Review

Several works have been done on Engineering Geological Mapping. Research on The Importance of Engineering Geological Mapping in the Development of the Niger Delta Basin was embarked on by [2]. He carried out a detailed analysis of the various constraints to the overall development of the basin by an integrated study of all kinds of maps, physical properties of the soils, and field observations of both completed and on-going engineering projects in the area. From the study, an engineering geological map (derived from information present on soil, geological, geomorphological, hydrogeological, hydrological maps, and geodynamic processes) of a part of the basin was presented to illustrate its usefulness in the environmental development and management planning of the area.

Some authors carried out Engineering Geological Mapping in the Urban and Suburban Region of Nafplion City (Argolis, Greece) [8]. In the region of interest, four (4) sampling boreholes were drilled, up to the depth of 40m. During the boring procedure in situ SPT and permeability tests were carried out, also the lithology from obtained material has been described. Samples, undisturbed and disturbed, have also collected for further laboratory tests. After the completion of each borehole, piezometric tubes were installed, for the monitoring of the underground water table. Laboratory tests for the determination of physical and mechanical characteristics of all drilled formations were carried out.The combination of the results of the drilling programme as well as the engineering geological approach and the geological structure of the studied area resulted in the compilation of the engineering geological map (scale 1:5,000) of Nafplion city-wide area, where 18 engineering geological types are distinguished. As the task of this project was the contribution to the urban development of Nafplion city, this engineering geological map was a useful tool for engineers, planners, and civil authorities.

Methodology for Creating National Engineering Geological Maps of the UK was carried out by [16]. Prior to their research, there had been no comprehensive, readily available engineering geological map of the UK to provide a broad context for ground investigation. They were able to prepare a 1:1 000 000 scale engineering geology superficial and bedrock maps of the UK.

Similarly, Engineering Geology Mapping in the Southern Part of the Metropolitan Area of San Salvador was carried out by [12]. The use of classic geologic maps, where geological layers are grouped according to their age or origin, made it difficult for the interpretation and use of civil engineering design or urban planning to people without in-depth knowledge in geology. Due to this reason, the researchers carried out engineering geological mapping of the study area. The objective of the methodology was that geological information, geological hazards and geotechnical recommendations as well, could be represented and grouped depending on the intrinsic characteristics of each zone. This way information can be easily interpreted for urban planners, private builders and government agencies.

3. Materials and Methods

This study relied on soil investigation reports from secondary sources and additional data from field studies by the author during subsoil investigations were used to calibrate the reliance of data from the secondary sources. Soil investigation reports for one hundred and forty-seven locations were collated (from Groundscan Services Nigeria Limited and physical and Urban planning department, University of Port Harcourt) and examined for the accuracy of data. Following this, some were chosen on account of the reliability of the sources. For use in this work data on moisture content, consistency limits, particle size distribution and strength tests were used. Data were obtained from boreholes drilled to depths of 20m.

3.1 Data Processing

The following approaches were used:

Data processing and interpretation were made with the help of different professional computer software. Some of the softwares were; Microsoft office tools for preparation, synthesis and analysis of data, Arc GIS 10.7, Strater 5, Google Earth Pro, surfer 16, for preparation and manipulation of different maps.

3.2 Computation of Soil Properties

3.2.1 Permeability

Hazen's formula, [18] given below, was used to determine permeability:

$$k = C(D_{10})^2 \quad (1)$$

Where: k = coefficient of permeability (m/sec)

C = constant ranging from 0.4 to 1.2, typically assumed to be 1.0.

D_{10} = grain size corresponding to 10% by weight passing.

4. Results and Discussion

The surface deposits in this area consists of silty and sandy clays with a few clays layer and peaty clay layers. The sandy layers underlying the silty sandy clay are predominantly medium to coarse in grain sizes and are found to exist in various stages of compaction. Permeability values for different depths and location coordinates are presented in table 1 below

Table 1: Location coordinates and permeability (k) results

Latitude (˚)	Longitude (˚)	Elevation (m)	Borehole	Depth (m)	d10 (mm)	K(m/sec) * 10^{-4}
4.811706	7.000869	9	1	5.0	0.20	6.000
4.780778	7.05756	2	1	12.0	0.20	6.000
4.790992	7.032322	13	1	15.0	0.12	2.160
4.738569	7.033714	14	1	3.0	0.24	8.640
4.727692	7.047508	9	1	10.0	0.09	1.084
4.876212	6.955643	13	1	15.5	0.20	6.000
4.862631	6.951889	14	1	12.5	0.10	1.500
4.840851	7.000584	13	1	8.5	0.25	9.375
4.86675	6.983081	12	1	9.8	0.23	7.935
4.878117	7.058672	15	1	14.5	0.13	2.535
4.840783	7.037075	14	1	10.5	0.19	5.415
4.8724	7.028964	16	1	4.5	0.05	0.375
4.797069	7.003881	3	1	10.0	0.10	1.500
4.84003	6.989568	18	1	10.5	0.08	0.960
4.819997	6.996989	8	1	10.0	0.16	3.840
4.794778	7.041194	9	1	4.5	0.45	30.375
4.822789	6.971744	14	1	9.5	0.10	1.500
4.828339	7.057991	15	1	8.8	0.22	7.260
4.794358	7.047508	9	1	12.5	0.11	1.815
4.812692	6.979983	15	1	12.0	0.20	6.000
4.817023	7.025028	14	1	0.3	0.15	3.375
4.857594	7.034286	14	1	11.5	0.12	2.160
4.763244	7.103739	14	1	12.0	0.10	1.500
4.795528	7.00425	9		3.0		0.000
4.878117	7.058672	15	1	10.0	0.11	1.815
4.815553	7.049844	1	1	15.5	0.15	3.375
4.84985	6.972928	16	1	9.8	0.10	1.500
4.893055	7.002551	19	1	9.5	0.18	4.860
4.794972	7.041125	7	1	4.5	0.05	0.304
4.792517	7.044475	5	1	10.5	0.20	6.000
4.793253	7.01493	5	1	6.0	0.24	8.640
4.834058	6.974481	16	1	12.0	0.12	2.160
4.763244	7.103739	14	1	12.0	0.05	0.375
4.832008	7.019158	0	1.00	9.0	0.18	4.860

4.803953	6.999603	9	1	6.5	0.14	2.940
4.792989	6.975181	6	1	9.0	0.12	2.160
4.853403	6.972306	16	1	10.5	0.20	6.000
4.803544	6.953997	10	1	12.0	0.09	1.215
4.785508	7.037106	8	1	10.5	0.23	7.935
4.835981	7.031864	16	1	13.5	0.12	2.160
4.810408	7.046317	6	1	12.5	0.11	1.815
4.850902	6.992883	9	1	10.0	0.22	7.260
4.780036	7.020692	0	1	1.5	0.19	5.415
4.792517	7.044475	5	1	10.5	0.20	6.000
4.811706	7.000869	9	1	10.5	0.10	1.500
4.840605	6.992063	13	1	10.0	0.10	1.500
4.85416	7.057255	20	1	9.5	0.07	0.694
4.909	6.914083	9	1	15.0	0.20	6.000
4.827127	6.99377	14	1	10.5	0.10	1.500
4.829493	7.000644	15	1	10.0	0.10	1.500
4.859503	7.057393	19	1	9.0	0.12	2.160
4.867335	7.028321	18	1	0.5	0.20	6.000
4.867105	7.008676	17	1	9.8	0.23	7.935
4.799955	6.997851	11	1	10.0	0.12	2.160
4.818764	6.988033	10	1	7.5		0.000
4.824806	7.038727	11	1	6.0	0.26	10.140
4.825645	7.032897	13	1	12.5	0.20	6.000
4.823554	6.989642	8	1	5.0		0.000
4.810978	6.995733	10	1	9.0	0.07	0.634
4.828096	6.975925	12	1	12.0	0.09	1.215
4.798924	7.037945	15	1	12.5	0.10	1.354
4.874859	7.041779	23	1	10.0	0.12	2.160
4.815554	7.049844	8	1	9.0	0.07	0.735
4.738028	7.032285	8	1	9.5	0.07	0.735
4.872765	7.028778	17	1	9.5	0.12	2.160
4.743216	7.082116	8	1	10.8	0.20	6.000
4.839769	7.072702	16	1	3.0		0.000
4.828096	6.975925	12	1	10.5	0.22	7.260
4.867335	7.028321	18	1	9.8	0.24	8.640
4.872765	7.028778	17	1	12.5	0.13	2.535
4.823543	7.015768	8	1	5.0		0.000
4.789275	7.01169	12	1	23.5		0.000
4.81475	6.989389	5	1	6.0	0.20	6.000

Permeability maps were obtained for 3-10m, 11-15m and 16-20m.

At depths of 3 to 10m (Fig. 3), Abuloma, Apaihe, GRA, GRA phase I, Emerelu, Rumuokwuroshi, Elimgbu, Oroigwe, Eneka, Rumueme areas have permeability values ranging between 5×10^{-5} to 3.5×10^{-4} m/sec. From the map it can be seen that Borokiri, Abuloma, Rumueprikom and Oroigwe areas have permeability values ranging between 3.5×10^{-4} and 6.5×10^{-4} m/sec at 3 to 10m depth indicating rapid flow rate of water through the soil,while Rumuokoro, Trans-Amadi, Woji, Nkpogu-Ogbunabali have permeability values of 6.5×10^{-4} to 1.2×10^{-3} m/sec. at the same depth. This distribution also indicates rapid flow rate of water. Rapid flow rates are mostly consistent in soils with large pore spaces (Poorly Graded Soils).

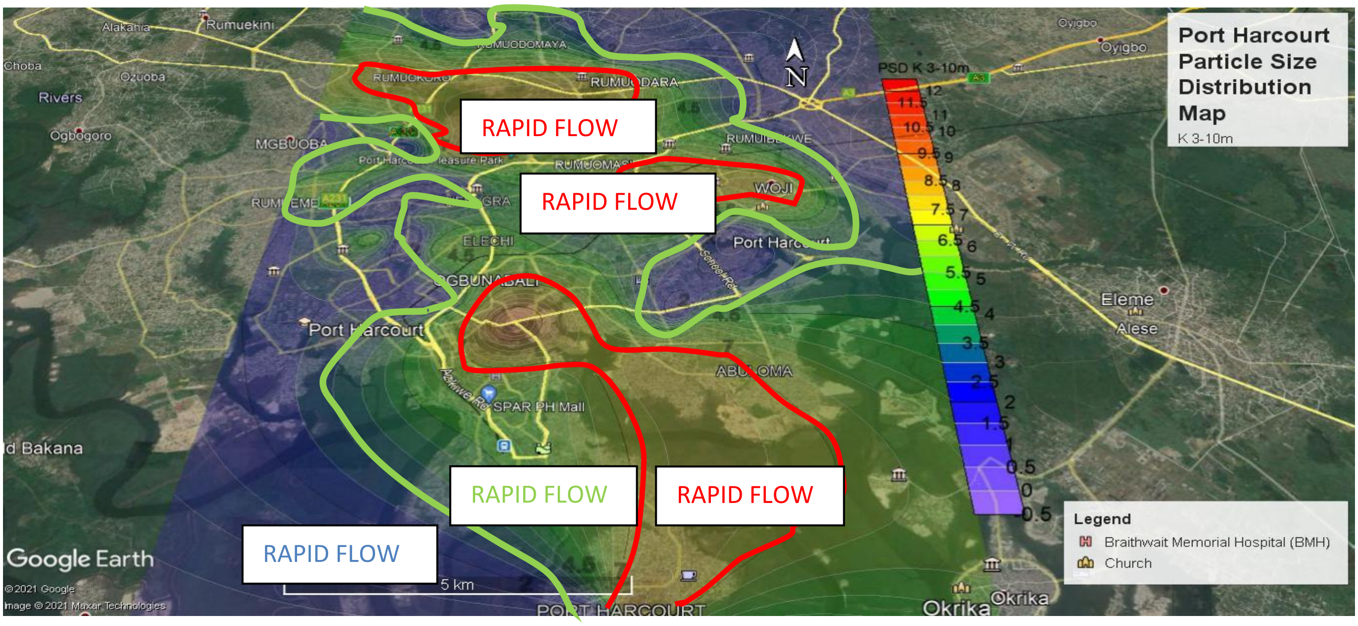

Figure 3: Permeability Map of Port Harcourt at 3m-10m

The contours on the map for 11-15m (Fig. 4) show variation of permeability values from 4×10^{-5} to 2×10^{-4}m/sec at Nkpogu-Ogbunabali, Rumuorosi, Old GRA, Obirikwere, and Oroigwe. An increase in permeability shows in areas like Borokiri, Abuloma, Trans- Amadi, Amadi Ama, Emerule, Elim-Oroigwe, Rumuokorosi, Eliozu, Eneka, Rumuodumaya, Ada George, Rumueme, Rumuelumeni, Ogbogoro, Rumuekini, with values of 4×10^{-4} to 2×10^{-4} m/sec while GRA, GRA phase II, Rumuomasi and Woji areas have values that falls between 4×10^{-4} to 6×10^{-4} m/sec. The values of 10^{-4} m/sec indicates rapid flow rate of water at this depth.

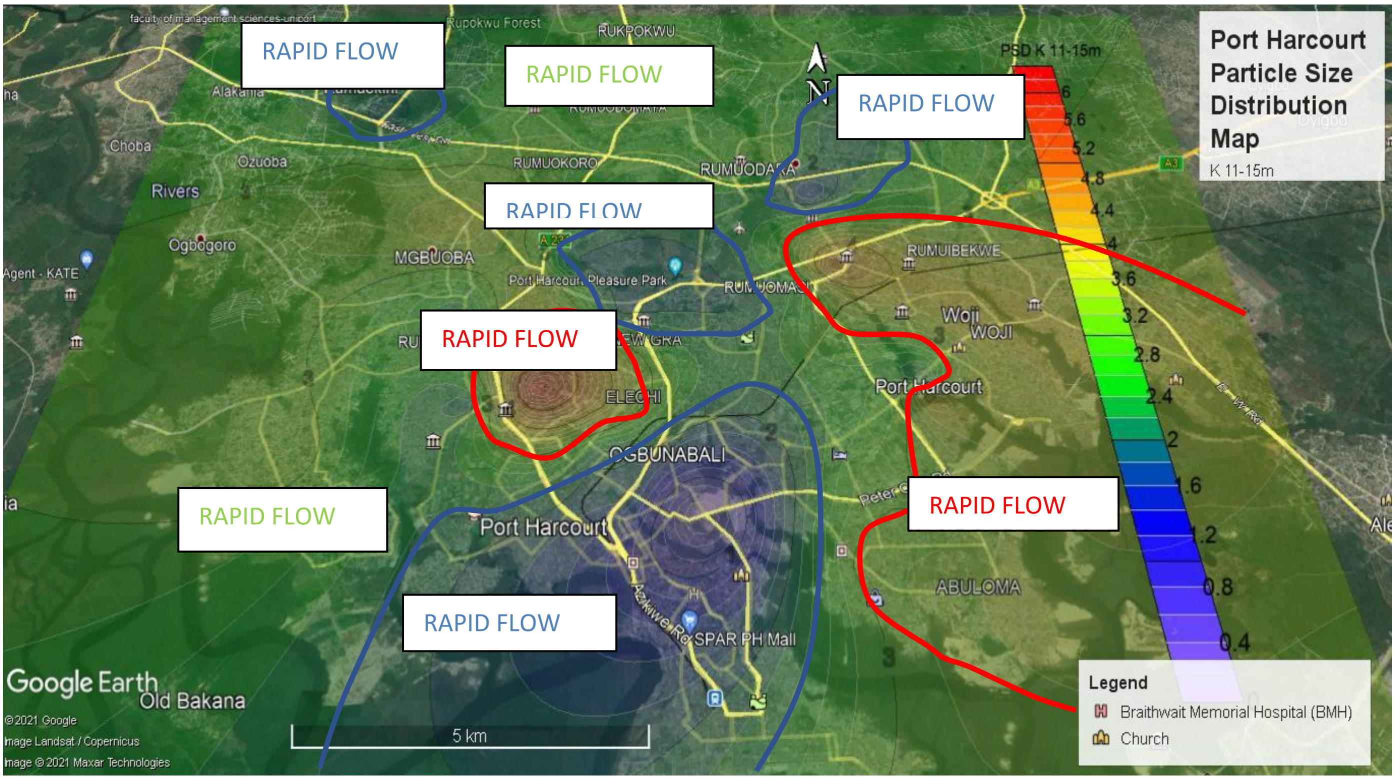

Figure 4: Permeability Map of Port Harcourt at 11-15m

As seen on the map of permeability at 16 to 20m (Fig. 4), NTA Road, Ada George, Amadi Ama, Abuloma, Woji, Monorail, Okrika water front, Rumuelumeni and Eneka have permeability value of about 2.0×10^{-3} m/sec. Variation between 2.0×10^{-3} and 4.5×10^{-3} m/sec can be noticed at areas like Elelenwo, Trans-Amadi, rumuigbo while Rumueme area has permeability values of about 5×10^{-3} to 8×10^{-3} m/sec. This indicates rapid flow and presence of clean sands or clean sands with gravel mixtures.

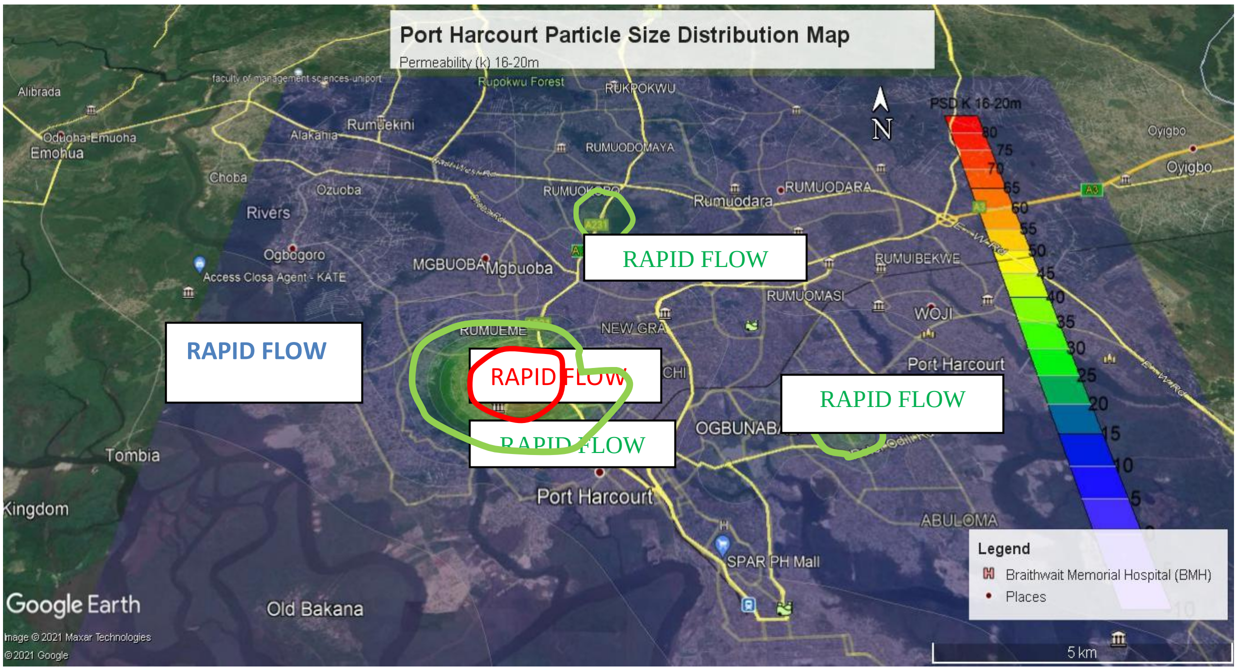

Figure 5: Permeability Map of Port Harcourt at 16-20m

The maps are stacked with increasing depth (Fig. 6) and it can be noticed that permeability values increase with depth with the highest values of 10^{-3} m/sec at 16 to 20m depth which indicates rapid flow rate of water. This can be attributed to the soil type as this value shows that the soils are either clean sands or clean sand with gravel mixtures.

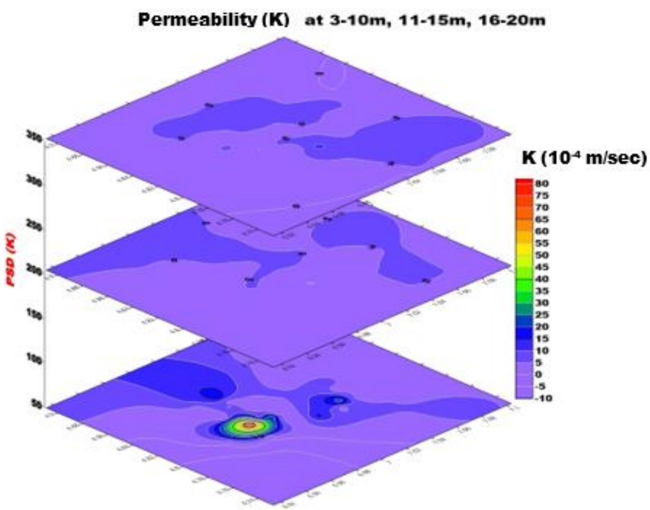

Figure 6: Stack maps of Permeability

Linear Regression Analysis of depth and permeability in Study Area

The linear regression analysis (Fig. 7) shows that the relationship between depth and permeability is a significant weak positive relationship indicating that as depth increases, permeability increases. As depth increases the lithology of the area mostly changes from silty clay and clayey sands to sands.

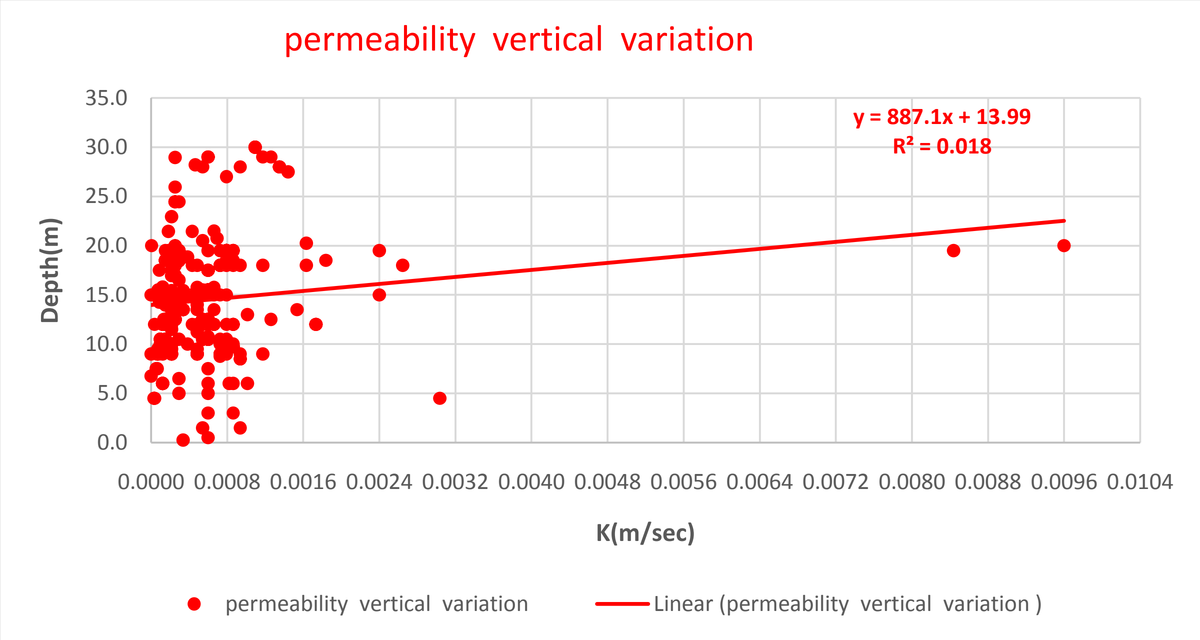

Figure 7: Linear regression Plot of Depth against Permeability

5. Conclusion

- At depth of 3 to10 m, 11 to 15 m, and 16 to 20 m permeability values ranges were 5×10^{-5} to 1.2×10^{-3}, 4×10^{-5} to 2×10^{-4} and 8.0×10^{-3} to 2.0×10^{-3} m/sec with average values of 4×10^{-4}, 3.72×10^{-4} and 9.30×10^{-4} m/sec respectively indicating that the soils in Port Harcourt area mostly have rapid flow rate of water.
- The soils are also rated as having medium to high permeability. High permeability soils give rise to high seepage flows which lead to leakage, tunneling or breaking failure in earth dams.
- The prevalent engineering problems in the study area will be excessive settlement due to Flow of large volume of water from highly compressible clays.

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