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Assessment of Soil Properties for Flood Vulnerability Zones in Parts of Obio/Akpor Local Government Area, Rivers State, Nigeria

Nwankwoala, H.O* and Jibril, T

Department of Geology, University of Port Harcourt, Nigeria

*Corresponding author: Nwankwoala, H.O

Abstract: This study is aimed at assessing soil properties on flood sensitive areas in parts of Obio-Akpor Local Government Area, Port Harcourt Metropolis, Rivers State, Nigeria. Field studies involved soil sampling while laboratory analysis involved particle size distribution, moisture content determination and hydraulic conductivity estimation. Geotechnical analysis revealed that the soils predominantly composed of silty clay, fine sandy silty clay and silty clayey sands. On average, moisture content and permeability are 27% and 2.8x10-6 cm/sec, and 20.41% and 1.3x10-3 cm/sec in Rumuigbo and Ozuoba areas, respectively. The soil properties were not significantly different from those obtained from one of the control sites. Although the soil characteristics at the control site and flood prone areas were similar, flooding does not occur at control sites because they are located at a higher topography compared with the flood prone areas located on a shallow topography. These results are confirmed by the high annual rainfall (2198.73 mm/hr on average) that occurs on average round the year in Rivers State. The buildings in these flood prone areas were constructed with concrete and blocks which are susceptible to cracking and failure when constantly immersed in water for prolonged time. It is therefore recommended that large sloping gutters be constructed within strategic places in the area in order to properly transport water to the nearby rivers and ensure that dumpsites around flood prone areas are evacuated to prevent contaminated water from recharging the aquifer.

Keywords: Flood vulnerability, flood encroachment, geotechnical analysis, soil properties, obio/akpor, port Harcourt metropolis

Introduction

Flood is the accumulation of too much water which rises to overflow land which is not normally submerged (Mukhopadhyay, 2010). Flooding can comprise overflow of a river as a result of prolonged seasonal rainfall, rainstorm, snowmelt, dam-breaks, accumulation of rainwater in low-lying areas with a high-water table, or inadequate storm drainage. Floods could also be caused by intrusion of sea water onto coast lands during cyclonic/tidal surges (Stoltman et al., 2004). According to Zekai (2018), a flood is defined also as any relatively high flow that overtops the natural or artificial banks in any reach of a stream. When banks are overtopped, water spreads over the floodplain and generally comes into conflict with man. Although floods vary from year to year, their measurements should be carried out regularly. Analysis of flood records provides a better understanding of the phenomenon (Linsley et al., 1982).

Low-lying areas suffer the most from the flooding and inundation hazards. Many thousands of populations live in these areas due to the groundwater availability and transportation facilities. In small basins, flash floods occur more frequently, because during an intensive storm rainfall the basin receives more than it could transfer as surface water in a short time of period (Zekai, 2018).

Floods may also result from dam failures, which give destruction and damage to downstream located activity centers such as urban areas, industrial plants, and agricultural lands. Shoreline flooding due to sea level rise is also possible. Alluvium fans are attractive for urban development with their groundwater potentiality, but in the same time especially in arid regions, they create special type of flash flood treats. Alluvial fans are risk-prone environments, because the drainage channels can meander unpredictably across the relatively steep slopes, bringing high velocity flows (5–10 m/s), which are highly loaded with sediment. On the contrary to the natural cases, there are also artificial flood occurrences due to human activities. The closer the urban land use to the main channel stream, the more prone is to inundation, and consequently, drainage cross sections that have not been prone to flood hazard before, may become under the threat of flood danger (Akpokodje, 2007).

Chiadikobi et al., (2011) conducted flood risk assessment in Port Harcourt, Rivers State, Nigeria and examined the flood risk in Port Harcourt using rainfall data, soil texture and other factors. The result of their study showed that the risk of occurrence of potentially damaging floods in Port Harcourt increases with increasing rainfall intensity. Also, the risk of flood is bound to increase in the future with increasing urbanization hence the need to demarcate the flooded areas for effective flood mitigation.

Port Harcourt city experienced an unprecedented flooding which submerged houses, paralyzed economic activities, and rendered some people internally displaced in some zones (Zabbey, 2006). The impact of flooding on any area is usually very significant. Hence, the need to adequately define flood associated impact so as to support management and make informed decisions on how to remedy or curb the menace. It is important that floods should be controlled so that the damage caused by them does not exceed an acceptable amount. Man must acquaint himself/herself with the characteristics of floods if he/she is to control them. Therefore, the assessment of the geotechnical characteristics of soil in parts of Obio/Akpor Local Government Area, Port Harcourt metropolis is crucial for flood management in the area.

Location/Geology of the Study Area

The study areas are located within Obio/Akpor Local Government Area, Port-Harcourt metropolis, Rivers State, Nigeria (Figure 1). The areas are bound geographically by longitudes 6057’40’’E to 7000’00’’E and latitudes 4048’30’’N to 4052’20’’N. The communities within the study areas are Ozuoba and Rumuigbo community. The area falls within the coastal belt dominated by low lying coastal plains which structurally belong to the sedimentary formations of Niger Delta (Chiadikobi et al., 2011). The study area lies within the Tertiary Niger Delta Sedimentary Basin. The sediment infills are composed lithostratigraphically of the Akata Formation (bottom), the Agbada Formation (middle) and the Benin Formation at the base. The Akata Formation is composed predominantly of marine shales and is approximately 3050m in thickness (Adegoke et al., 2017). The Akata Formation is believed by many authors to be the main source of hydrocarbons in the Niger

Delta (Doust and Omatsola, 1990; Ekweozor, 1980). The Agbada Formation is composed predominantly of paralic sediments (sand and shale juxtaposition). The Agbada Formation is mainly shaly at the lower part of the Formation and sandier towards the top. The thickness of the Formation is 1756–2896 m as recognized from the Agbada-2 well (Adegoke et al., 2017).

The Agbada Formation is believed to be the main reservoir rocks in the Niger Delta Petroleum System (Doust and Omatsola, 1990). The older Akata Formation is Paleocene to Holocene in age while the overlying Agbada Formation ranges from Eocene to present day in age. The Benin Formation overlies the Paralic Agbada sequences and is composed predominantly of continental fluvial sands estimated at approximately 3050m thick (Adegoke et al., 2017).

The Benin Formation contains the main aquifers within the Niger Delta which includes the study area. The Benin Formation has been identified as fresh water bearing sand (Amajor and Ofoegbu, 1988) and all aquifers in the deltaic region occurs within this lithostratigraphic unit. Etu-Efeotor and Akpokodje (1990) have been able to identify five aquifer horizons in the Delta as presented in Table 1. The shallow unconfined aquifers are localized while the deeper ones are laterally more extensive. Generally, the depth to the water table in the Delta increases northwards from <1 m at the coast to 16 m at the northeast section (Giadom and Tse, 2014). The regional groundwater flow direction in deep aquifers is generally southwards towards the Atlantic Ocean whilst the local flow direction in shallow aquifers is generally towards the nearest river or stream (Giadom and Tse, 2014).

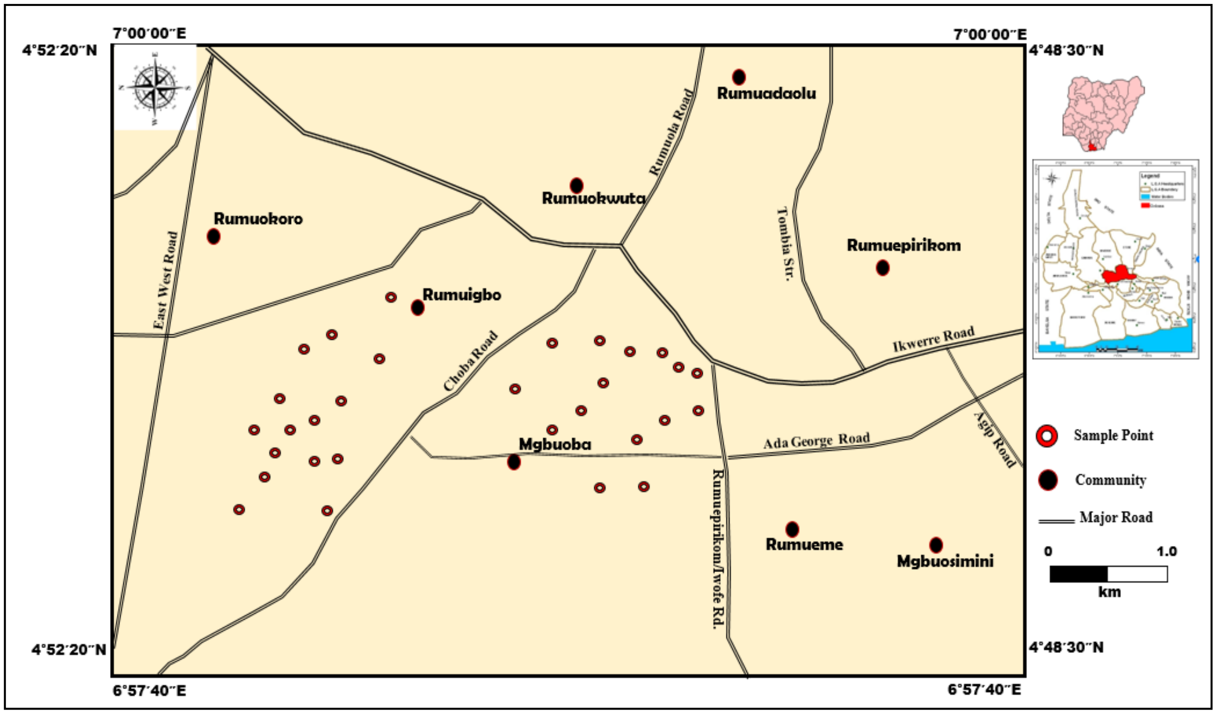

Figure 1 Map of the study area showing the sample location in Rumuigbo and Mgbuoba communities

Methods of Study

Field Techniques: Soil Sampling

Soil sampling was performed in the study areas using a hand auger. A random sampling approach was selected in which case, soil samples were collected from the surrounding residential areas, farmlands and flood plains. The samples were collected from the surface (0.0m) and every 0.50m interval to a depth of 1.50m at each drilled hole. Hence a total of four soil samples were collected at each drilled hole. The reason for sampling soils with depth was to account for the variation of soil properties with depth. In total, thirty locations were sampled from the two communities; 15 sampling locations from Ozuoba community and 15 sampling locations from Rumuigbo community. After sampling each depth, the auger was opened and thoroughly cleaned to remove all remnants from the shallower depth before sampling deeper intervals. Each sample was carefully packed in a polyethene bag and labelled with the correct sampled depth and code number. The geographic reference locations were also recorded for each sampled location.

Laboratory Analysis

Sieve Analysis

The grain size analysis was aimed at determining grain size distribution of the sediments. All the samples were first air-dried. Mechanical sieving method using sieve shaker was used for separating the grains to their individual sizes. 100g of each sample were disaggregated using a mortar and pestle. The disaggregated samples were thoroughly mixed and a representative fraction of the sample was obtained by quartering. This was weighed in a dial spring balance and 50g of each sample were poured into a set of US mesh sieves comprising 2mm, 1mm, 425μm, 250 μm, 150 μm, 63 μm and a receiving pan were weighed in the dial spring balance, and their weights were recorded. The percentages of these weights, as well as the cumulative weights and percentage passing were determined, and tabulated. The percent passing was plotted on a graph against grain size on the x-axis. These graphs were used to determine the dominant grain sizes in the soil which will be used to classify the soils. Also, another important parameter measured was the D10, which will later be used to calculate the hydraulic conductivity of the soils in the area.

The equation used to estimate the hydraulic conductivity is the Hazen (1911) empirical equation which is presented below;

$$K = CD_{10}^2$$

(1)

Where K = Permeability

D10 = Diameter which 10% of the sample's mass contains particles less than D10

C = Hazen's constant usually varying between (1 and 1.5)

Moisture Content Determination

This method, in accordance with the BS 1377: 1990 Part 2 Section 3.2, was used to determine the percentage of water in a sample by drying the sample to a constant weight. The water content is expressed as the percentage, by weight, of the dry sample. An oven suitable for drying samples at a uniform temperature not exceeding 115º C was used at the engineering geology laboratory, university of Port-Harcourt. A balance was used to weigh the representative sample before and after drying. The moisture sample was weighed and measured immediately and recorded as "wet weight of sample". The sample was dried to a constant weight; at a temperature not exceeding 115º C using the suitable drying equipment and sample was allowed to cool. The cooled sample was weighed again, and recorded as the "dry weight of sample". The moisture content of the sample is calculated using the following equation:

$$\%W = \frac{A-B}{B} \times 100 \quad (2)$$

Where:

%W = Percentage of moisture in the sample,

A = Weight of wet sample (grams), and

B = Weight of dry sample (grams).

Table 1 Field sampling locations and geographic references within the study area

Community	Sample Code	Easting (m)	Northing (m)	Surface Elevation (m)
RUMUIGBO	S1	274994	537171	13.00
	S2	275390	537142	14.00
	S3	275331	537361	13.00
	S4	275003	537899	15.00
	S5	275188	537728	14.00
	S6	275321	537648	16.00
	S7	275543	537803	13.00
	S8	275502	537548	18.00
	S9	275702	537650	17.00
	S10	275603	537386	14.00
	S11	275748	537180	19.00
	S12	276074	537453	18.00
	S13	276161	537241	18.00
	S14	276018	536868	15.00
	S15	276411	536816	17.00
OZUOBA	S16	276190	535564	24.00

	S17	275637	535471	22.00
	S18	275991	535123	26.00
	S19	275639	534832	22.00
	S20	276223	534652	26.00
	S21	275790	534602	25.00
	S22	276262	535159	22.00
	S23	275301	535095	26.00
	S24	275832	534364	25.00
	S25	276208	534916	24.00
	S26	275329	534751	26.00
	S27	275771	535277	24.00
	S28	275854	535794	23.00
	S29	276132	534517	24.00
	S30	276119	534380	26.00
Rumu-Oparali Control site	S31	277973	534065	53.00
Rumuadaolu Control site	S32	272630	536022	45.00

Results and Discussion

Soil Geotechnical Analysis

Results of grain size analysis revealed that Rumuigbo soils around the flood prone areas were predominantly silty clay, underlain by fine sandy silty clay. In Ozuoba, the soils were predominantly silty clayey sands and fine sandy silty clay. The soil types in both flood prone areas were similar, although more sandy sands were recorded from soils around Ozuoba area. The presence of silts and clays in the soil fabric were responsible for the slow percolation of water into the subsurface realms. At Rumuadaolu control site (C1), the soils fine silty clay capped by silty clay, while at Rumu-Oparali control site, the soils were composed of fine sands at the base 2.0 – 3.0 m, and capped by medium to fine sands at the top.

Moisture content ranges from 21.45 to 32.22% and from 17.80 to 24.56% in Rumuigbo and Ozuoba areas. On average, moisture content is 27% and 20.41% in Rumuigbo and Ozuoba areas, compared with the control sites, having moisture content values of 14.30% and 18.48% respectively. The high moisture content recorded by the flood prone soils suggests a high retention time for water in these soils compared with low retention time interpreted from the low moisture content soils of the control site.

Hydraulic conductivity ranges from 2.25x10-12 to 3.6x10-5 cm/sec in soils from Rumuigbo area, and from 1.0x10-14 to 6.7x10-2 cm/sec in Ozuoba area. On average, hydraulic conductivity is 2.8x10-6 cm/sec and 1.3x10-3 cm/sec in Rumuigbo and Ozuoba areas respectively. Based on the classification scheme adopted from Chiadikobi et al., (2011), the average hydraulic conductivities recorded in Rumuigbo is classed as very low, while Ozouba soil hydraulic conductivity is classed as low to medium. The permeability recorded at the control sites are 3.5x10-3 cm/sec (Rumu-Oparali) and 8.2x10-5 cm/sec (Rumuadaolu) indicating the soils were having low to medium hydraulic conductivities.

Average flood receding rates recorded are 2.4 cm/day and 6.5 cm/day for Rumuigbo and Ozuoba communities. The slow receding daily rate recorded by Rumuigbo area is related to the lithology, moisture content and hydraulic conductivity. The soils were predominantly silty clay and fine sandy silty clay which tends to prevent surface water from easily percolating through the soils in Rumuigbo area. The average moisture content (27%) revealed that the soils in Rumuigbo had fairly high moisture content. The higher the soil moisture content, the more difficult it becomes for proper drainage to occur through such soils. Similarly, average permeability revealed that the soils had very low permeability (2.8x10-6 cm/sec) in Rumuigbo area, thus, confirming the reason for the difficulty in water to flow through the soils. The high recede daily rates recorded by Ozuoba area is also related to the nature and characteristics of the soils in the area. The soils were predominantly composed of silty clayey sands and fine sandy silty clay. The presence of sands in the soil fabric tends to lower the moisture content and also increase the ease for fluids percolation. Soil moisture content is 20.41% on average. This is lower than the recorded moisture content in Rumuigbo area. Also, the permeability recorded in Ozuoba

(1.3x10-3 cm/sec) is much higher than those recorded in Rumuigbo area. These characteristics of Ozuoba soils were responsible for the higher daily flood recede rates. The soils at Rumuadaolu control site have similar characteristics as soils within the flood risk zones but Rumuadaolu was never flooded. This is attributed to the high lying topography of the area when compared with the surrounding areas. Meanwhile, soils around Rumu-Oparali control site never flooded because of the sandy soil type, low moisture content and high topography of the area. The map of flood vulnerability of the study area revealed that Rumuigbo area is very highly vulnerable to flooding while Ozuoba area is moderately to highly vulnerable to flooding. Meanwhile, the control sites were not vulnerable to flooding. Figures 2 to 10 shows the grain size analysis of the soils in the area while figures 11, 12 and 13 showed the soil profile. Also, figure 14 shows the moisture content while figure 15 depicts hydraulic conductivity compared with control sites. More so, figure 16 shows the flood vulnerability index map of the area.

Table 2 Soil particles percentages, descriptions and hydraulic conductivity for Rumuigbo area

Sample Code	Sample Depth (m)	% Silty clay	% Medium Sand	% Fine Sand	Soil description	Moisture Content (%)	D10	D60	Hydraulic conductivity
S1	0.00	79.4	8.5	12.1	Silty clay	29.41	0.00002	0.009	4E-10
	1.00	75.8	10.8	13.4	Silty clay	27.22	0.0007	0.05	0.00000049
	2.00	73.4	14.1	12.5	Silty clay	28.93	0.00006	0.02	3.6E-09
	3.00	56.32	18.8	24.88	fine Silty Clay	22.45	0.0017	0.1	0.00000289
S2	0.00	78.6	9.3	12.1	Silty clay	30.22	0.00003	0.015	9E-10
	1.00	75.9	9.8	14.3	Silty clay	28.17	0.00009	0.02	8.1E-09
	2.00	70.8	9.2	20	fine Silty Clay	24.56	0.00006	0.02	3.6E-09
	3.00	54.1	17.77	28.13	fine Silty Clay	23.44	0.0017	0.15	0.00000289
S3	0.00	78.6	9.3	12.1	Silty clay	22.89	0.000025	0.01	6.25E-10
	1.00	75.9	9.8	14.3	Silty clay	24.66	0.00009	0.02	8.1E-09
	2.00	70.8	9.2	20	fine Silty Clay	23.18	0.00015	0.025	2.25E-08
	3.00	54.1	17.77	28.13	fine Silty Clay	22.15	0.002	0.15	0.000004
S4	0.00	77.8	10.5	11.7	Silty clay	29.67	0.00004	0.017	1.6E-09
	1.00	74.1	10.6	15.3	Silty clay	28.38	0.00009	0.02	8.1E-09

	2.00	68.7	10.9	20.4	fine Silty Clay	21.65	0.00035	0.037	1.225E-07
	3.00	55.6	16.5	27.9	fine Silty Clay	23.55	0.0017	0.1	0.00000289
S5	0.00	79.6	8.3	12.1	Silty clay	29.80	0.00002	0.01	4E-10
	1.00	76.8	8.3	14.9	Silty clay	29.81	0.00003	0.013	9E-10
	2.00	69.4	10.5	20.1	fine Silty Clay	27.20	0.00035	0.035	1.225E-07
	3.00	56	17	27	fine Silty Clay	25.16	0.0015	0.14	0.00000225
S6	0.00	79.4	8.5	12.1	Silty clay	31.33	0.000002	0.005	4E-12
	1.00	75.8	10.8	13.4	Silty clay	30.19	0.00002	0.01	4E-10
	2.00	73.4	14.1	12.5	Silty clay	32.22	0.00006	0.02	3.6E-09
	3.00	56.32	18.8	24.88	fine Silty Clay	27.17	0.006	0.15	0.000036
S7	0.00	76.5	10.5	13	Silty clay	26.82	0.0000025	0.005	6.25E-12
	1.00	73.8	8.9	17.3	Silty clay	29.48	0.0001	0.024	0.00000001
	2.00	69	11	20	fine Silty Clay	22.16	0.000065	0.024	4.225E-09
	3.00	57.6	16	26.4	fine Silty Clay	24.18	0.0025	0.1	0.00000625
S8	0.00	75.6	12.6	11.8	Silty clay	29.98	0.000015	0.008	2.25E-10
	1.00	73.4	9.8	16.8	Silty clay	31.16	0.00007	0.016	4.9E-09
	2.00	70.6	17.7	11.7	Silty clay	30.33	0.00008	0.023	6.4E-09
	3.00	54	21	25	fine Silty Clay	29.87	0.004	0.15	0.000016
S9	0.00	77.8	10.5	11.7	Silty clay	22.32	0.000035	0.006	1.225E-09
	1.00	74.1	10.6	15.3	Silty clay	30.91	0.00007	0.016	4.9E-09
	2.00	68.7	10.9	20.4	fine Silty Clay	26.43	0.0013	0.12	0.00000169
	3.00	55.6	16.5	27.9	fine Silty Clay	21.81	0.0027	0.12	0.00000729
S10	0.00	74.5	11.8	13.7	Silty clay	27.44	0.000018	0.011	3.24E-10
	1.00	72.1	8.6	19.3	Silty clay	26.54	0.00007	0.016	4.9E-09
	2.00	71.5	15.4	13.1	Silty clay	27.81	0.00007	0.02	4.9E-09
	3.00	54.6	11.7	33.7	fine Silty Clay	30.97	0.006	0.14	0.000036
S11	0.00	75.4	8.3	16.3	Silty clay	31.32	0.000015	0.01	2.25E-10
	1.00	70.6	11.8	17.6	Silty clay	30.72	0.0001	0.025	0.00000001
	2.00	68.5	14.3	17.2	Silty clay	31.91	0.00015	0.028	2.25E-08
	3.00	54.3	17.4	28.3	fine Silty Clay	30.77	0.003	0.1	0.000009

S12	0.00	73.3	11.8	14.9	Silty clay	28.60	0.0000015	0.04	2.25E-12
	1.00	73	10.8	16.2	Silty clay	28.34	0.00007	0.018	4.9E-09
	2.00	68.8	12.2	19	Silty clay	27.30	0.00025	0.035	6.25E-08
	3.00	53.8	18.3	27.9	fine Silty Clay	24.55	0.0035	0.14	0.00001225
S13	0.00	70.2	13.8	16	Silty clay	21.45	0.00015	0.03	2.25E-08
	1.00	64.1	13.9	22	fine Silty Clay	22.67	0.0007	0.05	0.00000049
	2.00	66.6	13.3	20.1	fine Silty Clay	24.11	0.00065	0.05	4.225E-07
	3.00	55.3	11.6	33.1	fine Silty Clay	22.38	0.001	0.012	0.000001
S14	0.00	70.3	9.7	20	fine Silty Clay	25.71	0.00015	0.025	2.25E-08
	1.00	69.5	12.9	17.6	Silty clay	28.90	0.0002	0.03	0.00000004
	2.00	69	12	19	Silty clay	29.40	0.00015	0.03	2.25E-08
	3.00	60.1	14.5	25.4	fine Silty Clay	24.10	0.001	0.07	0.000001
S15	0.00	71.3	14	14.7	Silty clay	30.88	0.00008	0.02	6.4E-09
	1.00	69.4	12	18.6	Silty clay	29.18	0.00015	0.015	2.25E-08
	2.00	64	13.5	22.5	fine Silty Clay	22.14	0.00011	0.05	1.21E-08
	3.00	54.6	19.6	25.8	fine Silty Clay	25.65	0.005	0.16	0.000025

Table 3 Soil particles percentages, descriptions and hydraulic conductivity for Ozuoba area

Sample Code	Sample Depth (m)	% Silty clay	% Medium Sand	% Fine Sand	Soil description	Moisture Content (%)	D10	D60	Hydraulic conductivity (cm/sec)
S16	0.00	23.5	13	63.5	Silty-Clayey Sand	19.45	0.018	3.5	0.000324
	1.00	25.2	13.8	61	Silty-Clayey Sand	22.22	0.032	0.5	0.001024
	2.00	71.5	4.6	23.9	Fine Silty Clay	23.45	0.00036	0.028	1.296E-07
	3.00	34.2	11.8	54	Silty-Clayey Sand	18.75	0.009	0.7	0.000081
S17	0.00	30	15	55	Silty-Clayey Sand	21.44	0.018	3.3	0.000324
	1.00	33.4	11.9	54.7	Silty-Clayey Sand	24.56	0.006	1.5	0.000036
	2.00	72.3	2.8	24.9	Fine Silty Clay	20.9	0.00023	0.024	5.29E-08
	3.00	35.4	12.7	51.9	Silty-Clayey Sand	20	0.009	0.7	0.000081
S18	0.00	29	15.5	55.5	Silty-Clayey Sand	18.67	0.02	0.7	0.0004
	1.00	36.8	14.5	48.7	Silty-Clayey Sand	17.9	0.014	0.4	0.000196

	2.00	77.5	1.3	21.2	Fine Silty Clay	18.22	0.000001	0.005	1E-12
	3.00	33.6	13.4	53	Silty-Clayey Sand	20.54	0.009	0.8	0.000081
S19	0.00	22.8	18	59.2	Silty-Clayey Sand	21.44	0.013	2.4	0.000169
	1.00	28.5	16.8	54.7	Silty-Clayey Sand	17.8	0.001	2	0.000001
	2.00	75.5	1.9	22.6	Fine Silty Clay	24.32	0.000001	0.004	1E-12
	3.00	32.7	15.5	51.8	Silty-Clayey Sand	22.1	0.005	0.7	0.000025
S20	0.00	29.5	15.6	54.9	Silty-Clayey Sand	20.88	0.012	1.3	0.000144
	1.00	31	13.8	55.2	Silty-Clayey Sand	19.8	0.018	0.4	0.000324
	2.00	63.6	1.7	34.7	Fine Silty Clay	20.3	0.002	0.006	0.000004
	3.00	33.55	14.3	52.2	Silty-Clayey Sand	18.98	0.0085	0.7	0.00007225
S21	0.00	30	16.3	53.7	Silty-Clayey Sand	22.1	0.018	0.7	0.000324
	1.00	32.4	17.5	50.1	Silty-Clayey Sand	19.7	0.018	0.4	0.000324
	2.00	78.23	0.5	21.3	Fine Silty Clay	21.56	0.0000001	0.0018	1E-14
	3.00	37.1	14.5	48.4	Silty-Clayey Sand	19.43	0.015	0.3	0.000225
S22	0.00	25.6	16.4	58	Silty-Clayey Sand	20.23	0.26	0.75	0.0676
	1.00	29.4	14.6	56	Silty-Clayey Sand	17.86	0.03	0.55	0.0009
	2.00	76	2	22	Fine Silty Clay	23.1	0.0000007	0.0045	4.9E-13
	3.00	33.8	16.4	49.8	Silty-Clayey Sand	19.75	0.018	0.4	0.000324
S23	0.00	33.6	15.4	51	Silty-Clayey Sand	19.45	0.009	0.8	0.000081
	1.00	35.5	16.3	48.2	Silty-Clayey Sand	18.9	0.011	0.4	0.000121
	2.00	77	1.7	21.3	Fine Silty Clay	20.3	0.0000005	0.0035	2.5E-13
	3.00	37.8	15.9	46.3	Silty-Clayey Sand	19.44	0.013	0.35	0.000169
S24	0.00	76.4	1.9	21.7	Fine Silty Clay	23.54	0.00008	0.015	6.4E-09
	1.00	35.5	15.1	49.4	Silty-Clayey Sand	18.76	0.011	0.4	0.000121
	2.00	37.5	14.4	48.1	Silty-Clayey Sand	18.4	0.00055	3.5	3.025E-07
	3.00	33.7	16.1	50.2	Silty-Clayey Sand	19.66	0.013	0.3	0.000169
S25	0.00	72.3	1.7	26	Fine Silty Clay	20.22	0.00013	0.02	1.69E-08
	1.00	31.9	17.6	50.5	Silty-Clayey Sand	18.54	0.015	0.5	0.000225
	2.00	32.7	15	52.3	Silty-Clayey Sand	20.1	0.005	1.5	0.000025
	3.00	32.4	13.6	54	Silty-Clayey Sand	19.4	0.014	0.17	0.000196

S26	0.00	74.2	1.6	24.2	Fine Silty Clay	22.2	0.00013	0.02	1.69E-08
	1.00	38.3	16.6	45.1	Silty-Clayey Sand	21.3	0.015	0.3	0.000225
	2.00	31.6	14.3	54.1	Silty-Clayey Sand	20.5	0.03	0.25	0.0009
	3.00	32.3	17.1	50.6	Fine Silty Clay	21.24	0.013	0.16	0.000169
S27	0.00	74.3	0.4	25.3	Fine Silty Clay	20.41	0.0001	0.08	0.00000001
	1.00	32.4	17.1	50.5	Silty-Clayey Sand	21.67	0.02	0.38	0.0004
	2.00	33.3	15.6	51.1	Silty-Clayey Sand	20.68	0.02	0.45	0.0004
	3.00	34.5	15.7	49.8	Silty-Clayey Sand	18.65	0.011	0.6	0.000121
S28	0.00	71.32	11.6	17.1	Silty Clay	23.65	0.00013	0.02	1.69E-08
	1.00	38.9	12.6	48.5	Silty-Clayey Sand	20	0.001	1.8	0.000001
	2.00	35.4	14.7	49.9	Silty-Clayey Sand	19.43	0.015	0.4	0.000225
	3.00	32.6	17.1	50.3	Silty-Clayey Sand	20.1	0.015	0.55	0.000225
S29	0.00	32.4	14.4	53.2	Silty-Clayey Sand	18.77	0.029	0.3	0.000841
	1.00	73.1	0.4	26.5	Fine Silty Clay	23	0.00003	0.015	9E-10
	2.00	33.5	15.4	51.1	Silty-Clayey Sand	19.84	0.008	1	0.000064
	3.00	36.1	16	47.9	Silty-Clayey Sand	19.32	0.014	0.4	0.000196
S30	0.00	34.2	13.5	52.3	Silty-Clayey Sand	20	0.02	0.3	0.0004
	1.00	74.2	1.7	24.1	Fine Silty Clay	23.46	0.00004	0.015	1.6E-09
	2.00	34.1	11.6	54.3	Silty-Clayey Sand	19/41	0.007	0.9	0.000049
	3.00	33.2	16.4	50.4	Silty-Clayey Sand	18	0.011	0.7	0.000121

Table 4 Soil particles percentages, descriptions and hydraulic conductivity for control area

Sample Code	Sample Depth (m)	% Silty clay	% Medium Sand	% Fine Sand	Soil description	Moisture Content (%)	D10	D60	Hydraulic conductivity (cm/sec)
C1 (Rumu-Oparali)	C1-0m	12.7	22.6	64.7	Medium-Fine Sand	14.34	0.06	3.5	0.0036
	C1-1m	20.6	25.8	53.6	Medium-Fine Sand	12.55	0.058	0.2	0.003364
	C1-2m	23.2	27.8	49	Medium-Fine Sand	15	0.052	0.22	0.002704
	C1-3m	14.65	12.9	72.45	Fine Sand	15.32	0.065	0.3	0.004225
C2 (Rumuadaolu)	C2-0m	75	10.4	14.6	Silty Clay	18.6	6E-06	0.009	3.6E-11
	C2-1m	68.2	12.4	19.4	Silty Clay	19.41	9E-08	0.008	7.23E-15

	C2-2m	52.3	17.1	30.6	Fine Silty Clay	18.9	0.009	0.11	7.23E-05
	C2-3m	41.3	21.7	37	Fine Silty Clay	17	0.016	0.2	0.000256

Table 5 Statistical parameters determined from soil properties

Community	Statistical Parameters	Moisture Content (%)	Hydraulic conductivity (cm/sec)
Rumuigbo	Min	21.45	2.25E-12
	Max	32.22	0.000036
	Mean	27.03	2.80668E-06
Ozuoba	Min	17.80	1E-14
	Max	24.56	0.0676
	Mean	20.41	0.00130713
Rumu-Oparali		14.30	0.00347325
Rumuadaolu		18.48	8.20625E-05

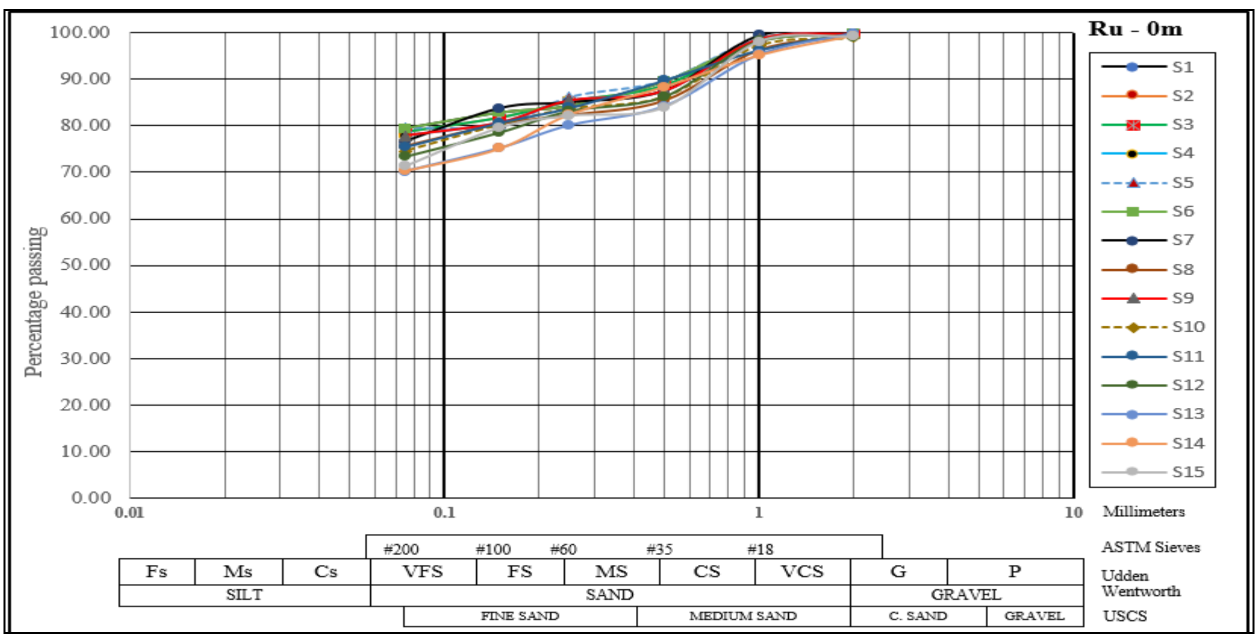

Figure 2 Grain size analysis for top-soils (0 m) obtained from Rumuigbo flooded area

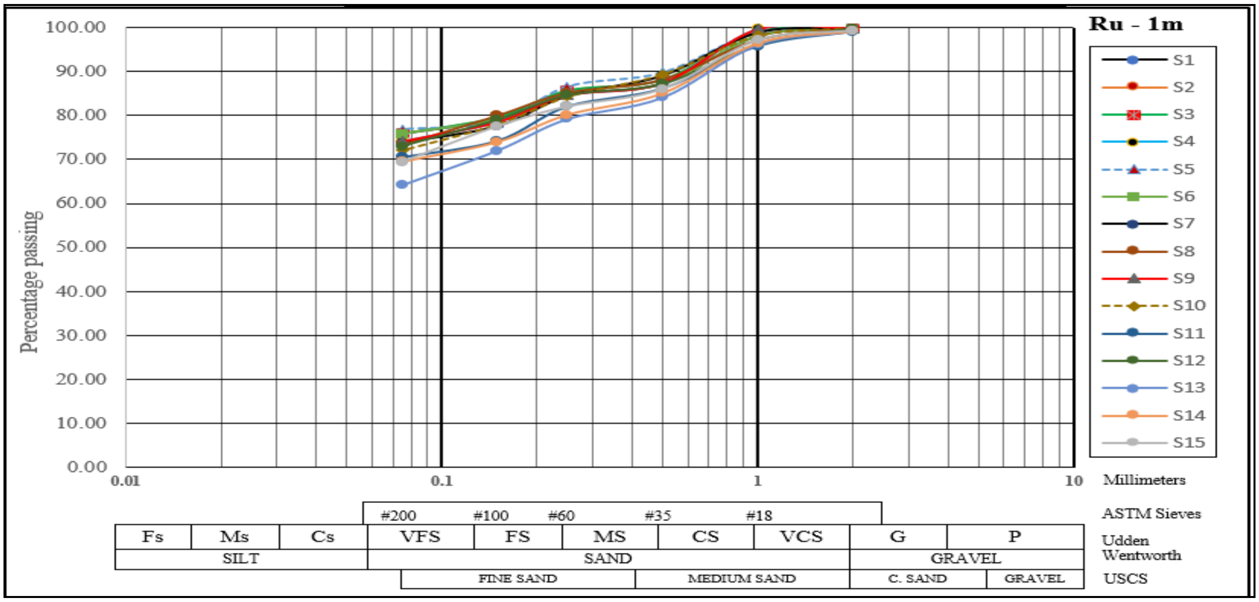

Figure 3 Grain size analysis for top-soils (1.0 m) obtained from Rumuigbo flooded area

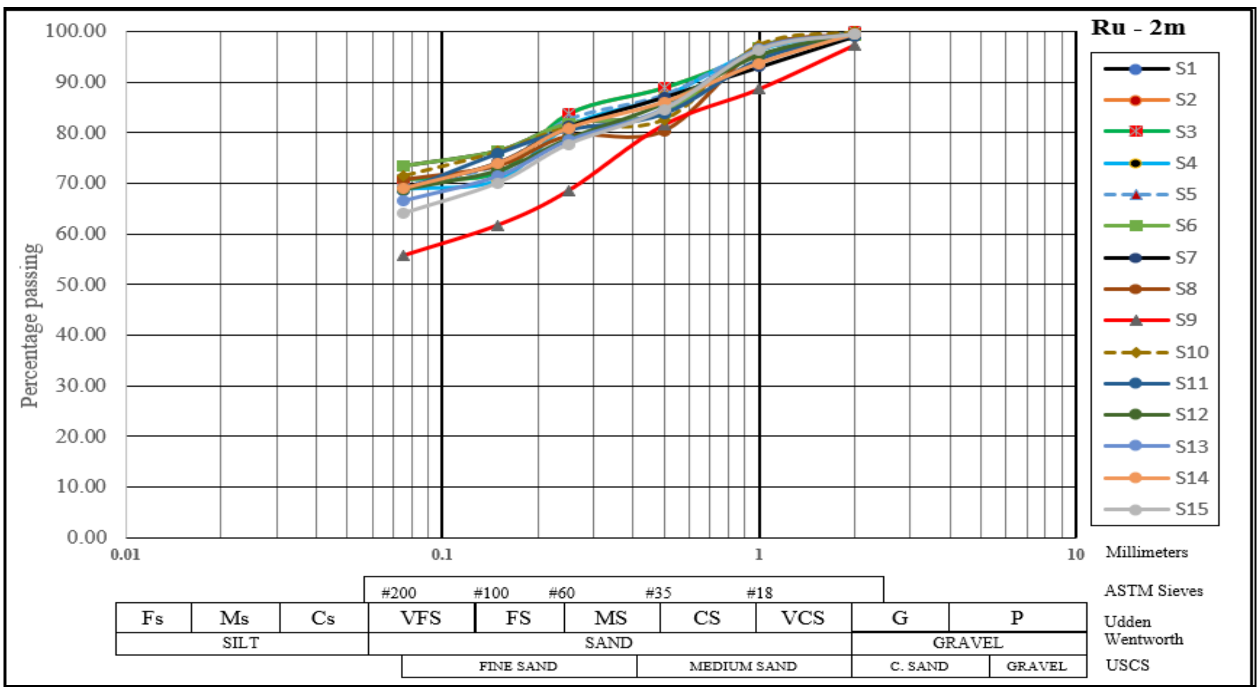

Figure 4 Grain size analysis for top-soils (2.0 m) obtained from Rumuigbo flooded area

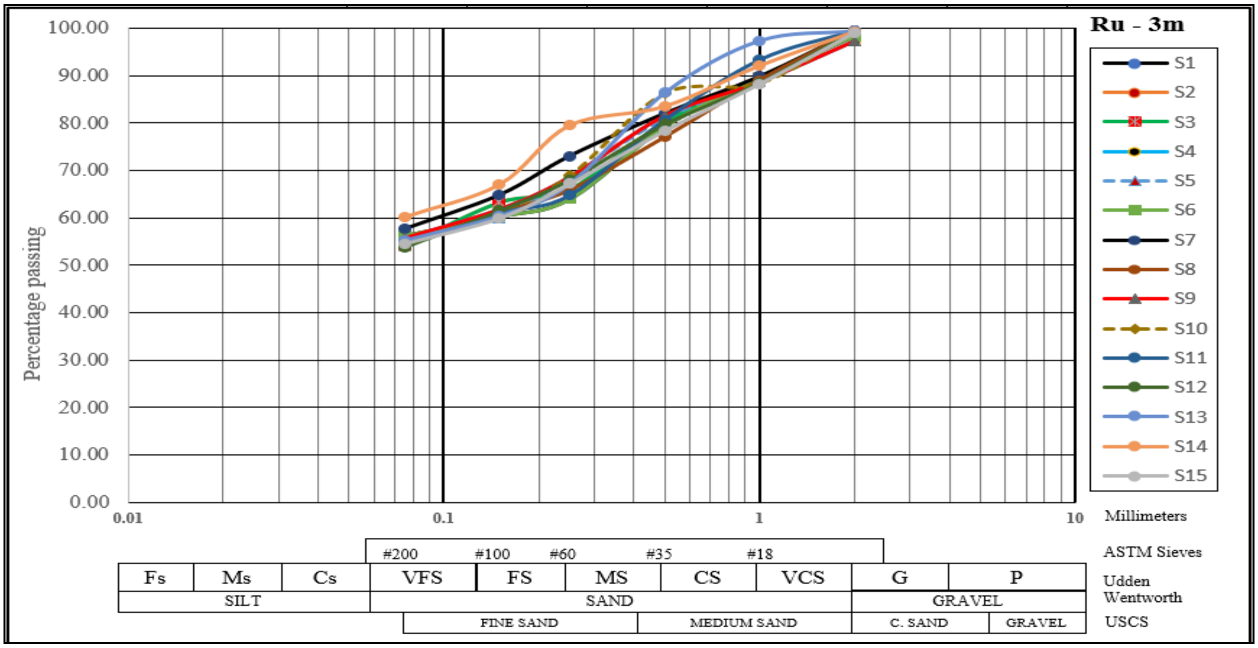

Figure 5 Grain size analysis for top-soils (3.0 m) obtained from Rumuigbo flooded area

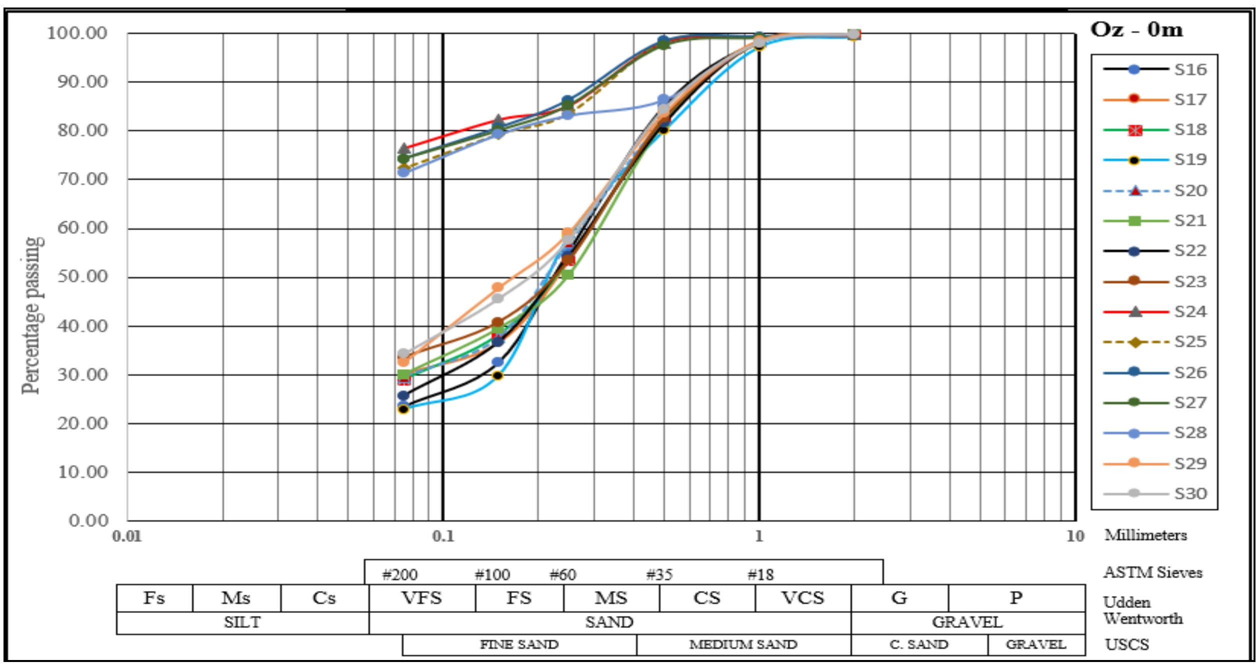

Figure 6 Grain size analysis for top-soils (0 m) obtained from Ozuoba flooded area

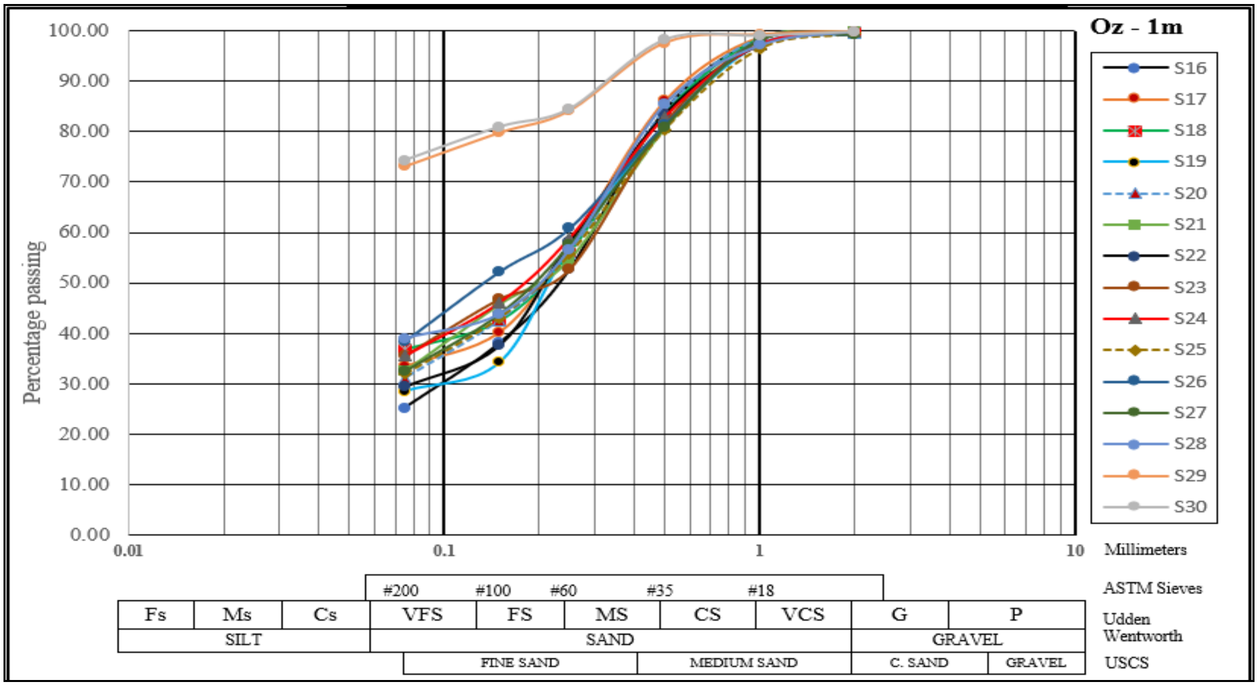

Figure 7 Grain size analysis for top-soils (1.0 m) obtained from Ozuoba flooded area

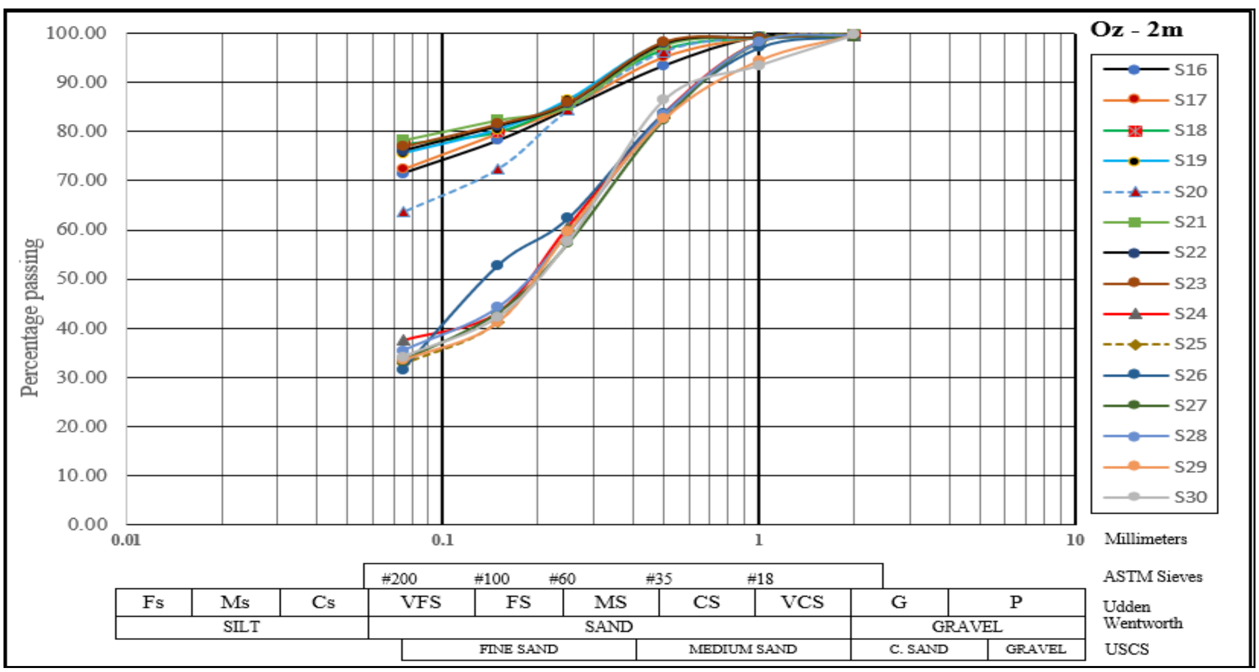

Figure 8 Grain size analysis for top-soils (2.0 m) obtained from Ozuoba flooded area

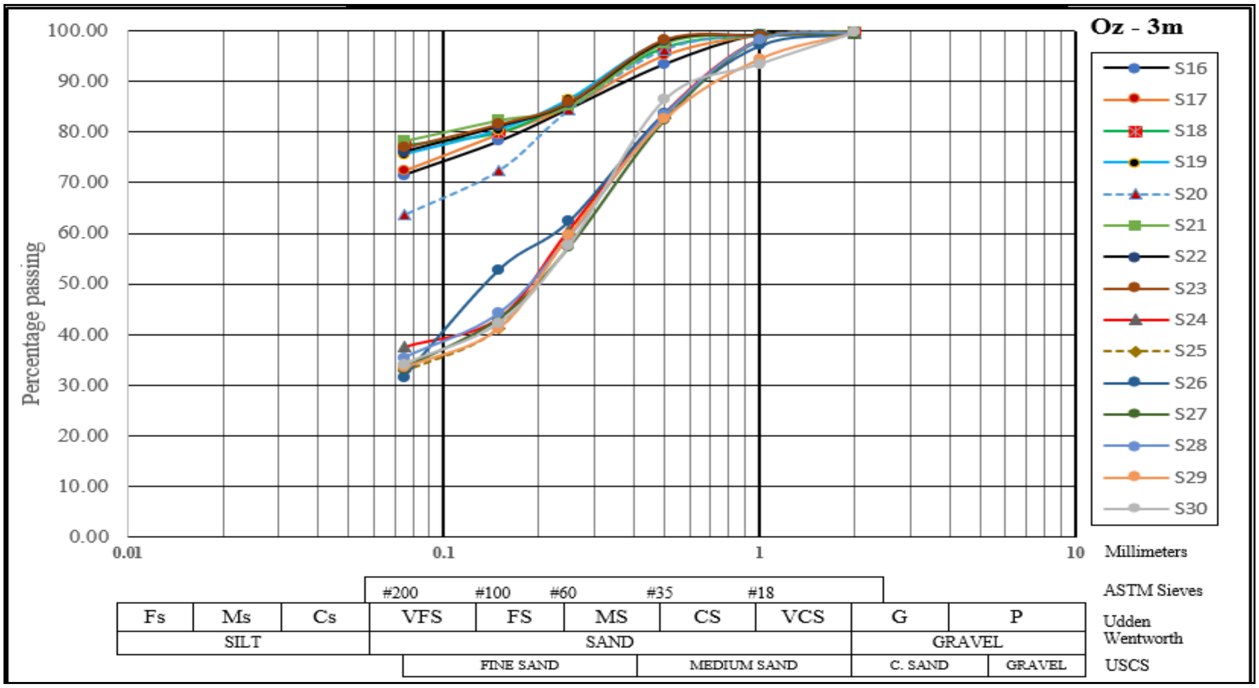

Figure 9 Grain size analysis for top-soils (3.0 m) obtained from Ozuoba flooded area

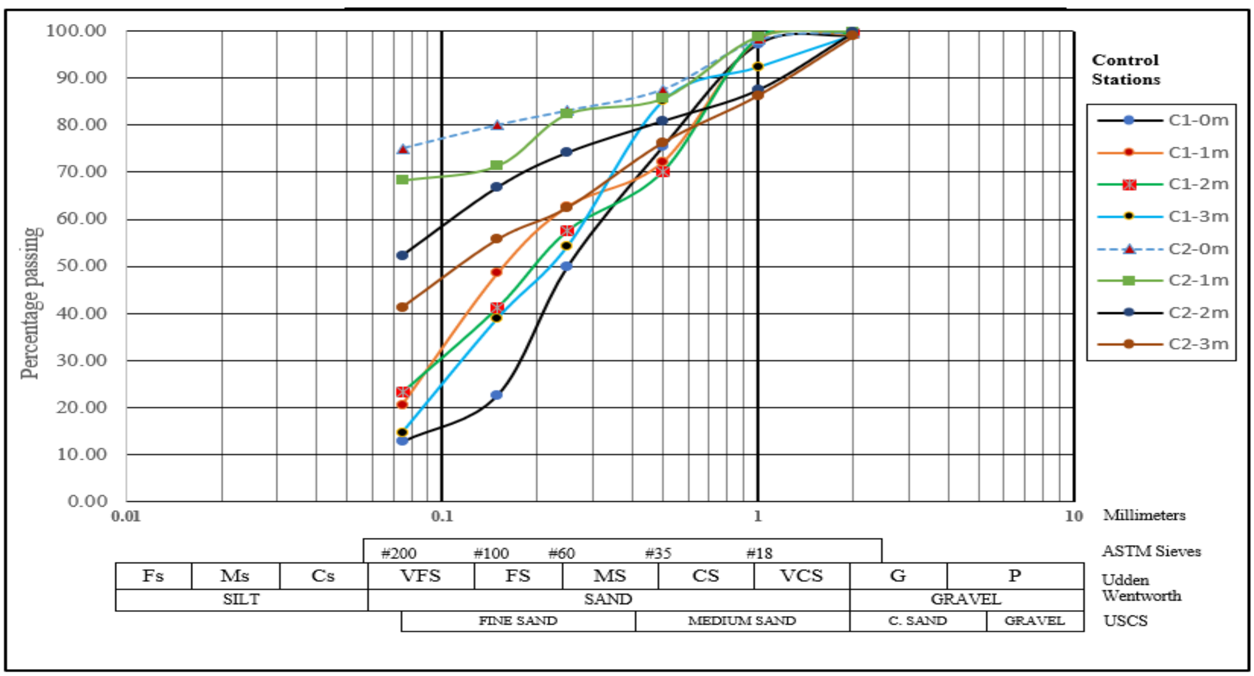

Figure 10 Grain size analysis for soils obtained from control site

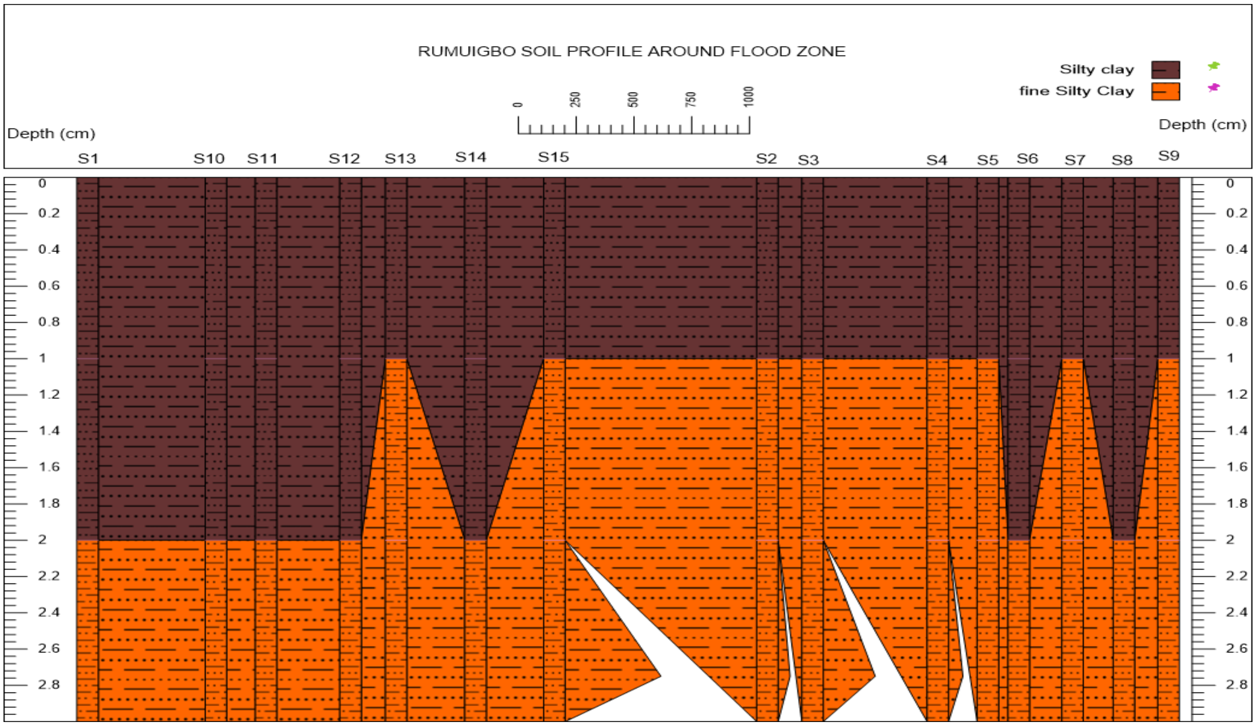

Figure 11 Soil profile around Rumuigbo flood risk area

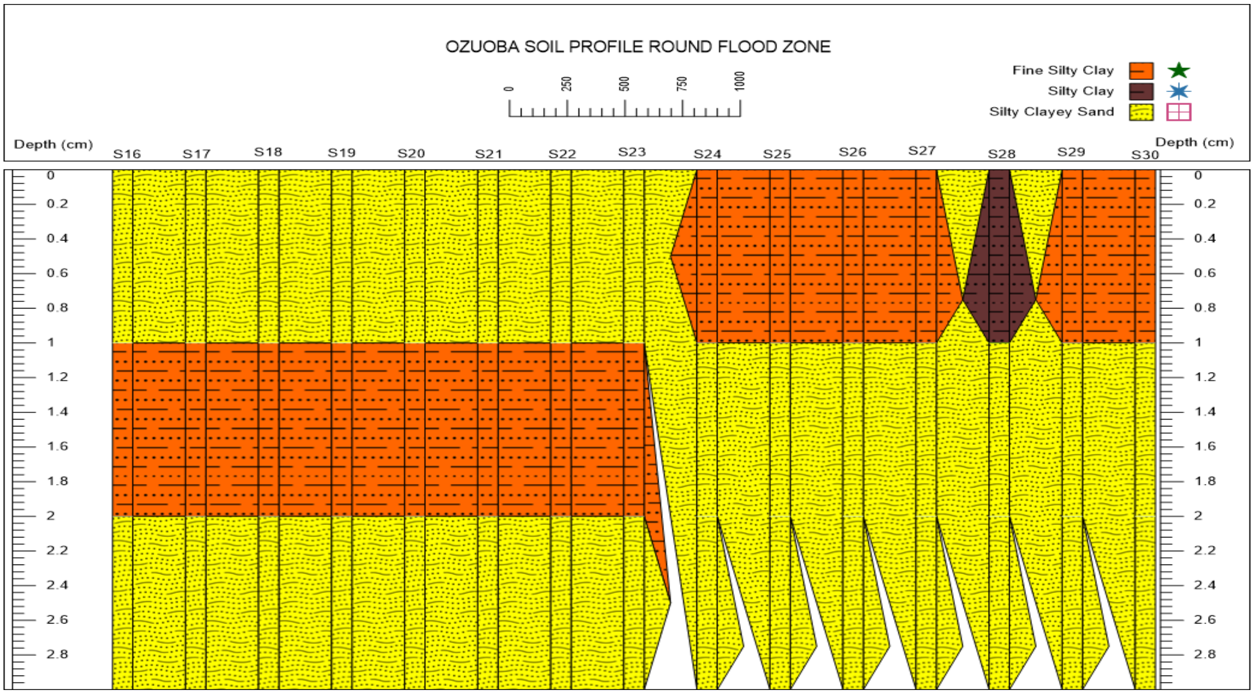

Figure 12 Soil profile around Ozuoba flood risk area

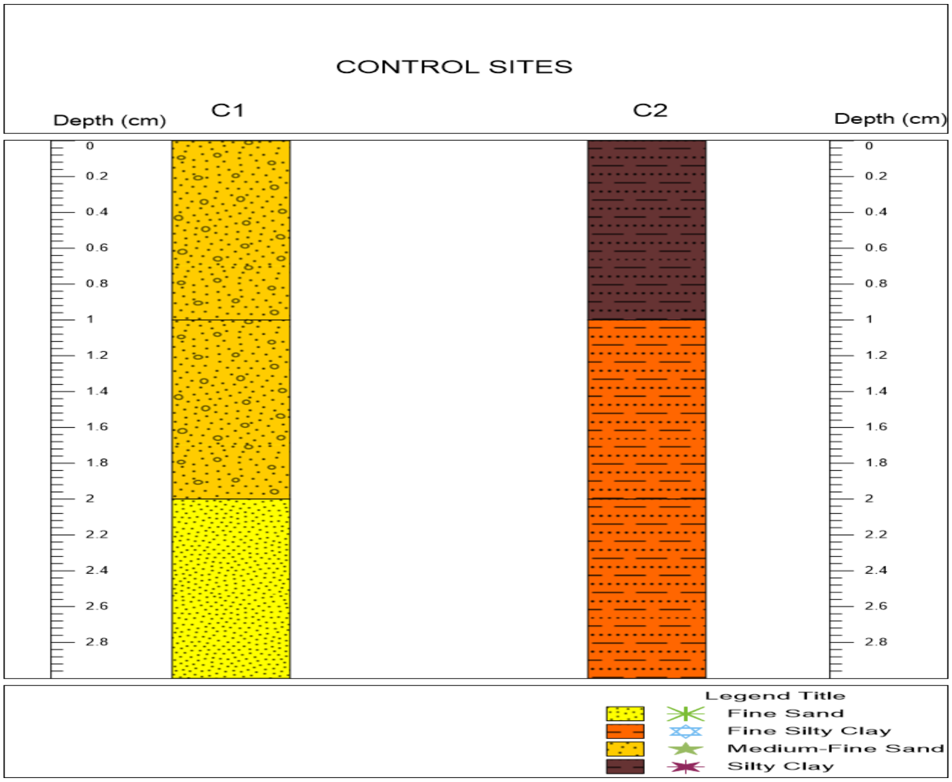

Figure 13 Soil profile around control sites. C1-Rumuadaolu; C2-Rumu-Oparali

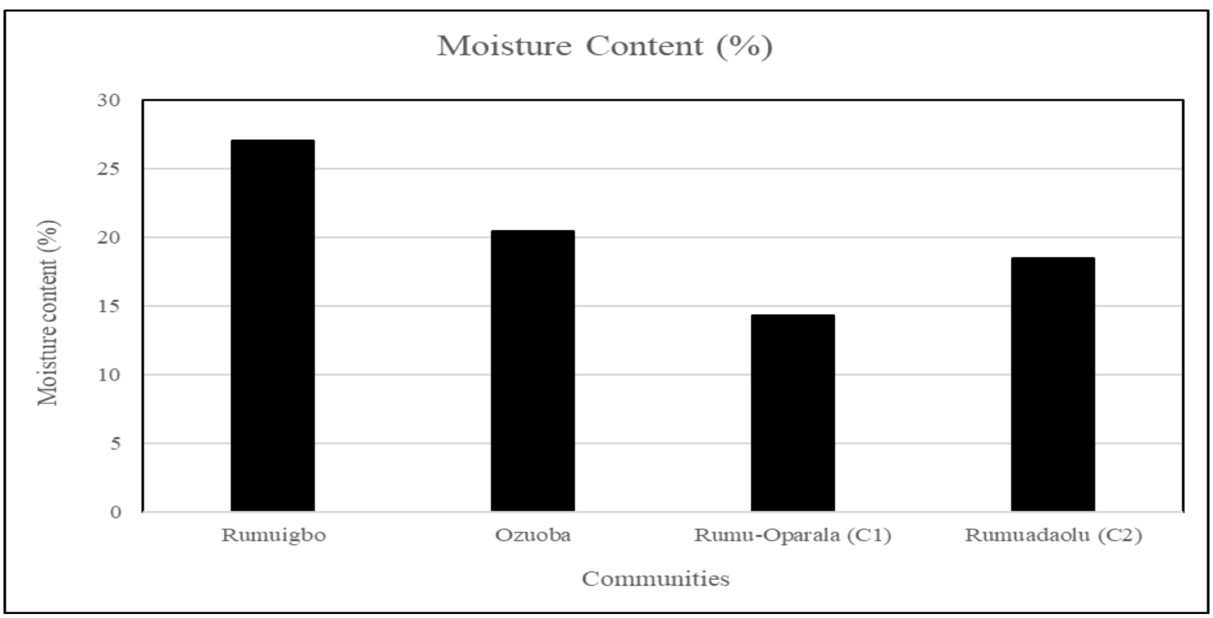

Figure 14 Average moisture content compared with control sites

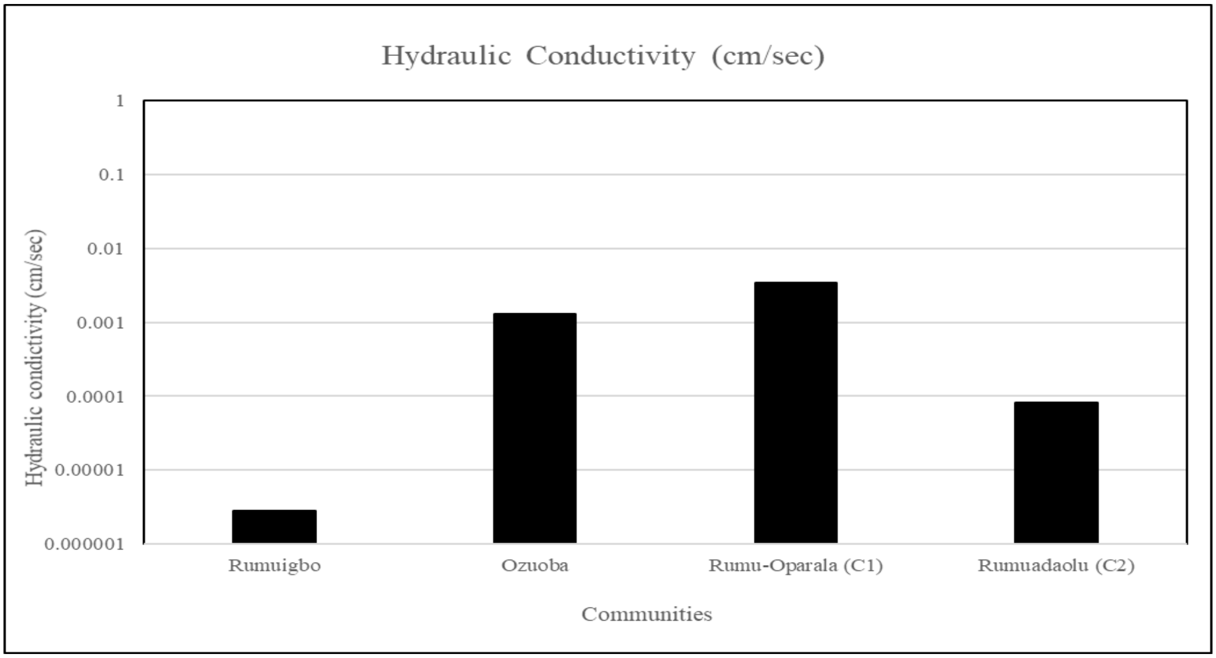

Figure 15 Average hydraulic conductivity compared with control sites

Table 6 Results of vulnerability rating for soils obtained from flood prone areas

S/No	Surface Elevation	Lithology	Moisture Content	Hydraulic Conductivity	Highest flood marking on wall	Flood Encroachment rate	Flood Recede Rate	Vulnerability index	Vulnerability Rating
S1	3.00	3.00	2.00	3.00	3.00	3.00	3.00	20.00	Very High
S2	3.00	3.00	2.00	3.00	3.00	3.00	3.00	20.00	Very High
S3	3.00	3.00	2.00	3.00	3.00	3.00	3.00	20.00	Very High
S4	3.00	3.00	2.00	3.00	3.00	2.00	3.00	19.00	High
S5	3.00	3.00	2.00	3.00	3.00	3.00	3.00	20.00	Very High
S6	3.00	3.00	3.00	3.00	3.00	3.00	3.00	21.00	Very High
S7	3.00	3.00	2.00	3.00	3.00	3.00	2.00	19.00	High
S8	3.00	3.00	3.00	3.00	3.00	3.00	3.00	21.00	Very High
S9	3.00	3.00	2.00	3.00	3.00	3.00	3.00	20.00	Very High
S10	3.00	3.00	3.00	3.00	3.00	3.00	3.00	21.00	Very High
S11	3.00	3.00	2.00	3.00	3.00	3.00	3.00	20.00	Very High
S12	3.00	3.00	2.00	3.00	3.00	3.00	3.00	20.00	Very High

S13	3.00	3.00	2.00	3.00	3.00	3.00	3.00	20.00	Very High
S14	3.00	3.00	2.00	3.00	3.00	3.00	2.00	19.00	High
S15	3.00	3.00	2.00	3.00	3.00	3.00	3.00	20.00	Very High
S16	2.00	3.00	2.00	2.00	3.00	2.00	1.00	15.00	High
S17	2.00	3.00	2.00	2.00	3.00	2.00	1.00	15.00	High
S18	2.00	3.00	1.00	2.00	3.00	3.00	1.00	15.00	High
S19	2.00	3.00	2.00	3.00	3.00	2.00	1.00	16.00	High
S20	2.00	3.00	1.00	2.00	3.00	2.00	1.00	14.00	Moderate
S21	2.00	3.00	2.00	2.00	3.00	2.00	1.00	15.00	High
S22	2.00	3.00	2.00	2.00	3.00	3.00	1.00	16.00	High
S23	2.00	3.00	1.00	3.00	3.00	2.00	1.00	15.00	High
S24	2.00	3.00	2.00	3.00	3.00	2.00	1.00	16.00	High
S25	2.00	3.00	1.00	2.00	3.00	2.00	1.00	14.00	Moderate
S26	2.00	3.00	2.00	2.00	3.00	2.00	1.00	15.00	High
S27	2.00	3.00	2.00	2.00	3.00	2.00	1.00	15.00	High
S28	2.00	3.00	2.00	2.00	3.00	3.00	1.00	16.00	High
S29	2.00	3.00	2.00	2.00	3.00	2.00	1.00	15.00	High
S30	2.00	3.00	2.00	2.00	3.00	3.00	1.00	16.00	High
C1	1.00	2.00	1.00	2.00				6.00	Low
C2	1.00	3.00	1.00	2.00				7.00	Low

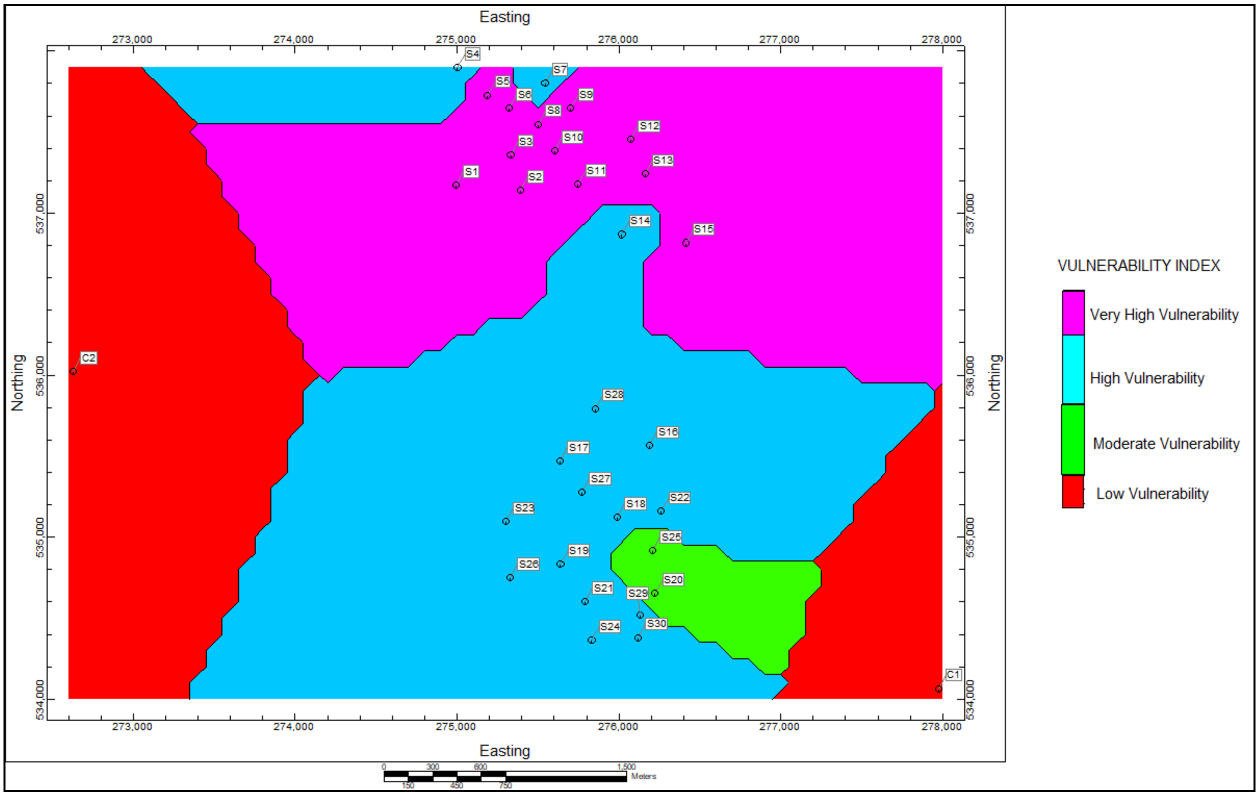

Figure 16 Flood vulnerability index map for the study area showing areas prone to flooding

Conclusion

The results of this study revealed that Rumuigbo area suffers high flood rise compared to Ozuoba area because of the type of soils, moisture content and permeability of the soils. Ozuoba soils had more sand, with lower moisture content and higher permeability values compared with Rumuigbo soils. Similarly, the daily recede rate revealed that Ozuoba soils takes a shorter time to get completely dry compared to Rumuigbo area. Flood encroachment and recede rates recorded were 14.57 cm/day and 2.4 cm/day in Rumuigbo and 7.73 cm/day and 6.5 cm/day in Ozuoba area respectively. The control sites have better soil quality and are situated at a higher topography than Rumuigbo and Ozuoba communities. Rumuigbo area is highly vulnerable to flooding when compared with Ozuoba area where the soils are moderately to highly vulnerable to flooding.

The study has also shown that there is significant impact of flooding on residents of the area. Although Rumuigbo and Ozuoba are flood prone areas, yet, Ozuoba area is significantly less vulnerable compared with Rumuigbo. The areas suffer several flood incidents every year because of their soil type, moisture content, hydraulic conductivity and shallow topography compared with the surrounding communities.

Reference

Adegoke, O.O; Oladotun, A.O; Ehinola, O.A & Okeugo, C.G (2017). Modeling Hydrocarbon Generation Potentials of Eocene Source Rocks in the Agbada Formation, Norther Delta Depobelt, Niger Delta Basin, Nigeria. *Journal of Petroleum Exploration and Production Technology*, 7(2): 379 – 388.

Akpokodje, E. (2007). A Colloquium Paper Presented on Flood Risk Assessment at the Nigerian Association of Hydrogeologists (NAH) Conference held at Hotel Presidential, Port Harcourt, Nigeria.

Amajor, L.C and Ofoegbu, C.O (1988). Determination of polluted aquifers by stratigraphically controlled biochemical mapping, example from the Eastern Niger Delta, Nigeria. Groundwater and Mineral Resources of Nigeria, pp 62 – 73.

Chiadikobi, K. C., Omoboriowo, A. O., Chiaghanam, O. I., Opatola, A.O. and Oyebanji, O. (2011). Flood Risk Assessment of Port Harcourt, Rivers State, Nigeria. *Advances in Applied Science Research*, 2(6): 287-298.

Doust H, Omatsola E (1990) Niger Delta in Edwards JD and Santogrossi, P.A., eds. Divergent/passive margin Basins, AAPG Memoir 48; Tulso, *America Association of Petroleum Geologists*, 14: 239-248.

Ekweozor, C.M (1980). Petroleum source-bed evaluation of Tertiary Niger Delta. *American Association of Petroleum Geologists Bulletin*, 64:1251-1259

Etu-Efeotor, J.O and Akpokodje, E.G (1990). Aquifer systems of the Niger Delta. 10. *Journal of Mining Geology*, 26 (2): 279-284.

Giadom, F.D and Tse, A.C., (2014). Groundwater Contamination and Environmental Risk Assessment of a Hydrocarbon Contaminated Site in Eastern Niger Delta, Nigeria. *Journal of Environment and Earth Sciences*.5 (14): 123-133.

Hazen, A. (1911). Discussion of "Dams on Sand Foundations" by A.C. Koenig, Transactions of the American Society of Civil Engineers, 73.

Linsley, R. K., Kohler, M. A., and Paulhus, J. L. H. (1982). Hydrology for engineers. Third edn. (p. 508). New York: McGraw-Hill.

Mukhopadhyay, S. (2010). A geo-environmental assessment of flood dynamics in lower Ajoy River inducing sand splay problem in Eastern India. *Ethiopian Journal of Environmental Studies and Management*, 3(2), 1-15.

Stoltman, J.P., Lidstone, J., and Dechano, L.M. (2004). International perspectives on natural disasters: Occurrence, mitigation, and consequences. New York, NY: Springer.

Zabbey, N. (2006). Flood hazard vulnerabilities and coping strategies of residents of urban settlements in Metro Manila, the Philippines. In D. J. Parker (Ed.), Floods, London, England: Routledge,pp69-88.

Zekai, S. (2018). Flood Modeling, Prediction, and Mitigation. Springer International Publishing, Switzerland. ISBN 978-3-319-52355-2.

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