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Flood Sensitivity Analysis and Impact Assessment in Parts of Obio/Akpor Local Government Area, Rivers State

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Abstract: This study was conducted on flood sensitive areas in parts of Obio-Akpor Local Government Area, Port Harcourt, Rivers State, Nigeria, in order to determine the impact on the residents of the area. The method of study involved field work, questionnaire administration and laboratory analysis. Field studies involved flood height measurements and soil sampling while laboratory analysis involved particle size distribution analysis, moisture content determination and hydraulic conductivity estimation. Flood heights monitored and measured over a period of one week was used to determine the flood daily encroachment rates and the flood daily receding rates. Flood encroachment rates ranged from 9.47 to 19.67 cm/day in Rumuigbo and 6.47 to 9.00 cm/day in Ozuoba flood sensitive areas. Flood recede rates ranged from 0.87 to 3.93 cm/day and 5.00 to 8.00 cm/day in Rumuigbo and Ozuoba. Geotechnical analysis revealed that the soils of these flood prone areas are 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. These soil properties are not significantly different from those obtained from one of the control sites. Although soil properties at the control site and flood prone areas are 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. Flood incidents experienced in these flood prone areas are often perceived by respondents as moderate to severe. The respondents revealed that flooding occurs in the area only when rainfall is heavy and continuous all through the year. 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 are constructed with concrete and blocks which are susceptible to cracking and failure when constantly immersed in water for prolonged time. Large sloping gutters should be constructed within strategic places in the area in order to properly transport water to the nearby rivers. This will ensure that dumpsites around flood prone areas are evacuated to prevent contaminated water from recharging our aquifer.

Key words: Flood, geotechnical analysis, rainfall, slope, encroachment, topography,impact assessment, Obio/Akpor

INTRODUCTION

Flood disasters are among the most destructive natural disaster in history. Damage caused by flood to agriculture, homes and public facilities around the world runs into several millions of dollars annually. In most cases, flooding occur when rivers overflow their banks as a result of excessive rainfall, dam failure, or obstruction of river channel resulting from encroachment [1-3]. Globally, economic losses from flooding exceeded $19 billion in 2012 [4] and have risen over the past half century [5, 6]. Hence, recent years have seen increased attention for strategic flood risk assessments and their inclusion in global integrated assessments [7].

The occurrence of floods in Nigeria is not a recent phenomenon [8]. There have been several occurrences of flooding in the country such as the Sokoto flood in 2010, Ibadan flood in 2011, Lagos flood in 2011 and the 2012 floods in parts of Lokoja, Makurdi, Rivers, Asaba, Ogbaru and Yenegoa. These flood incidents have shown that flooding is one of the major environmental problems faced in Nigeria. Most research works had examined extensively

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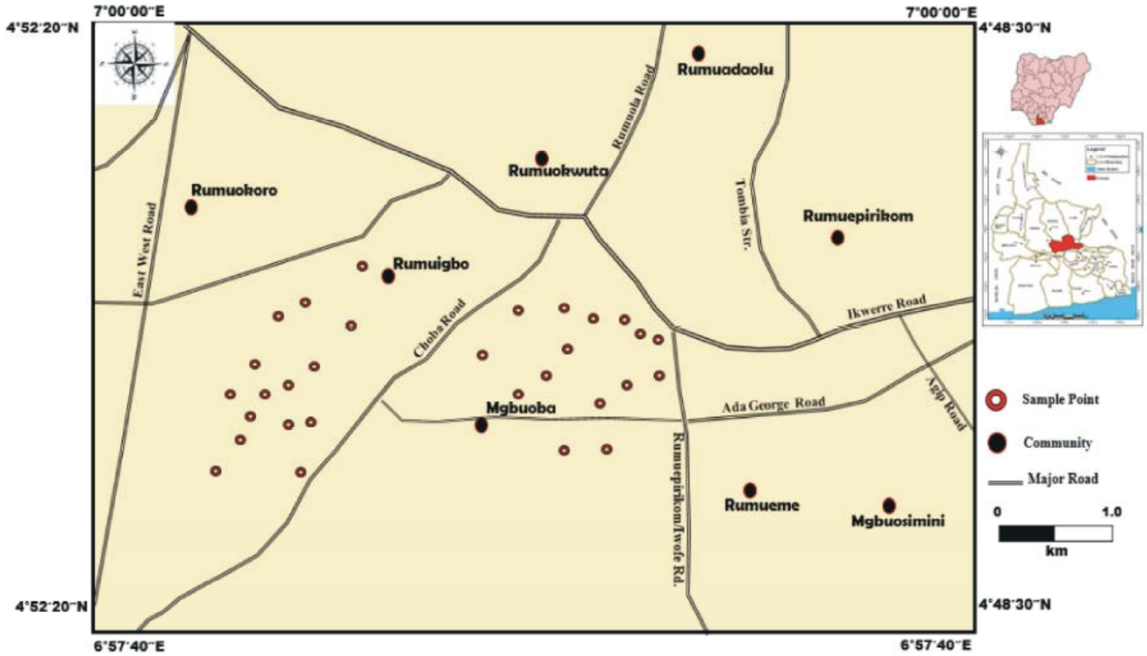

Fig. 1: Map of the study area showing the sample location in Rumuigbo and Mgbuoba communities

the causal factors and have attributed flooding to topography, soil/vegetation/river alteration, increased heavy rainfall, land use change and unplanned urbanization [6]. The impacts and effects of flooding have also been noted to range from submerging roads, obstruction of traffic, coastal erosion, disruption of economic activities, displacement of people, loss of property, to loss of lives [1].

Port Harcourt is one of such areas considered to be vulnerable to flooding. In 2006, Port Harcourt experienced an unprecedented flooding which submerged houses, paralyzed economic activities and rendered some people internally displaced in some zones [9]. Therefore this study shows the spatial variations to flood vulnerabilities/ flood sensitivity analysis and impact assessment, estimation of flood daily encroachment rates, evaluation of daily flood recede time, as well as examine the socio-economic characteristics and adaptive capacities of the residents in the flood prone areas, within parts of Obio-Akpor, Port Harcourt city, Nigeria.

Location of the Study Area: The study areas are located within Port-Harcourt metropolis, Rivers State, Nigeria (Figure 1). The areas are bounded geographically by longitudes 6°57'40'' E to 7°00'00'' E and latitudes 4°48'30'' N to 4°52'20'' 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 structurallybelong to the sedimentary formations of Niger Delta [10].

Geology and Hydrogeology of the Study Area: 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 [11]. The Akata Formation is believed by many authors to be the main source of hydrocarbons in the Niger Delta [12, 13]. 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 [11].

TheAgbada Formation is believed to be the main reservoir rocks in the Niger Delta Petroleum System [12]. The older Akata Formation is Paleocene to Holocene in age while the overlying Agbada Formation ranges from Eocene to present day in age [11]. The Benin Formation overlies the ParalicAgbada sequences and is composed predominantly of continental fluvial sands estimated at approximately 3050m thick [11].

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 [14] and all aquifers in the deltaic region occurs within this lithostratigraphic unit. Some researchers have been able to identify five aquifer horizons in the Delta [15]. 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 [16, 17]. 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 [16-18].

Methods of Study

Field Techniques - *Soil Sampling*

Soil sampling was performed in the study areas using a hand augering machine. 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.

Flood Height Measurement: The flood heights were measured from marking on the walls of buildings, gates and fences (Figure 3). The current flood levels were measured from the ground surface to the top of the water surface (in cm). The flood marks on structures which were higher than the current flood water level accounted for the highest flood heights in the area. The geographic reference locations were recorded against each measurement station. A total of 15 flood height/flood markings were measured from each of the two communities, making a total of 30 measurements at both locations. The recede flood time was calculated after continuous monitoring of the flood heights at five (5) selected locations for 4 days (96 hour), with measurements taken every 24 hours at each community. During this period when measurements were taken to compute the flood recede time, no additional rainfall occurred and this was a necessary requirement for an accurate calculation to be made. The ground surface elevations above sea level could not be established at most flood height locations where flood water had covered the lands, hence, the elevations above sea level were extracted from google earth satellite imagery through digital elevation modeling.

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, 63µm 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 D_{10}, 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 according to an empirical equation [19]:

$$K = CD_{10}^2 \quad (1)$$

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 115°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 115°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).

Results of Flood Height Measurements: The results of flood height markings measured from field studies are presented in Tables 2 and 3 for Rumuigbo and Ozuoba communities respectively. The average flood heights, flood encroachment rate and flood recede time calculated from flood heights measurements are presented in Table 3. Figure 2 is a map showing the surface elevations around the study area.

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

Table 2: Results of flood heights measurement around Rumuigbo area

S/N	Surface Elevation (m)	Highest Flood Marking on wall (cm)	Flood Heights (During Peak Rainfall) in cm Day 1	Day 2	Day 3	Flood Height (After Rainfall Stops) in cm Day 1	Day 2	Day 3
S1	13.00	104.00	33.00	42.00	68.00	60.00	57.00	57.00
S2	14.00	101.00	35.00	46.00	65.00	58.00	54.00	52.00
S3	13.00	102.00	32.00	41.00	62.00	56.00	50.00	50.00
S4	15.00	97.00	31.00	39.00	50.00	45.00	42.00	40.00
S5	14.00	100.00	36.00	48.00	68.00	60.00	57.00	56.00
S6	16.00	89.00	27.00	33.00	52.00	46.00	43.00	43.00
S7	13.00	103.00	30.00	41.00	65.00	60.00	55.00	53.00
S8	18.00	90.00	29.00	38.00	55.00	49.00	45.00	44.00
S9	17.00	92.00	25.00	37.00	58.00	51.00	47.00	47.00
S10	14.00	98.00	25.00	33.00	58.00	50.00	45.00	44.00
S11	19.00	86.00	28.00	39.00	60.00	57.00	52.00	52.00
S12	18.00	88.00	19.00	29.00	41.00	36.00	31.00	30.00
S13	18.00	90.00	28.00	35.00	53.00	47.00	44.00	44.00
S14	15.00	92.00	14.00	24.00	44.00	37.00	34.00	31.00
S15	17.00	88.00	19.00	28.00	49.00	41.00	38.00	38.00

Table 3: Results of flood heights measurement around Ozuoba area

S/N	Surface Elevation (m)	Highest Flood Marking on wall (m)	Flood Heights (During Peak Rainfall) in cm Day 1	Day 2	Day 3	Flood Height (After Rainfall Stops) in cm Day 1	Day 2	Day 3
S16	24.00	92.00	45.00	52.00	58.00	49.00	40.00	35.00
S17	22.00	98.00	77.00	81.00	88.00	80.00	71.00	66.00
S18	26.00	90.00	62.00	70.00	76.00	68.00	60.00	54.00
S19	22.00	98.00	68.00	74.00	81.00	73.00	64.00	60.00
S20	26.00	92.00	58.00	65.00	73.00	64.00	53.00	50.00
S21	25.00	98.00	58.00	64.00	72.00	60.00	52.00	47.00
S22	22.00	95.00	44.00	50.00	68.00	59.00	50.00	44.00
S23	26.00	91.00	56.00	61.00	69.00	59.00	49.00	43.00
S24	25.00	91.00	50.00	58.00	65.00	54.00	44.00	40.00
S25	24.00	98.00	51.00	59.00	66.00	53.00	46.00	40.00
S26	26.00	87.00	49.00	55.00	62.00	54.00	45.00	39.00
S27	24.00	90.00	44.00	50.00	59.00	48.00	40.00	36.00
S28	23.00	95.00	52.00	60.00	72.00	60.00	51.00	46.00
S29	24.00	96.00	56.00	62.00	70.00	59.00	50.00	44.00
S30	26.00	84.00	45.00	51.00	68.00	58.00	48.00	44.00

Table 4: Results of statistical analysis performed on flood height markings

Flood Parameters		Rumuigbo Area Min	Max	Mean	Ozuoba Area Min	Max	Mean
Surface Elevation (m)		13.00	19.00	15.60	22.00	26.00	24.33
Highest Flood Mark (cm)		86.00	104.00	94.67	84.00	98.00	93.00
Flood Heights (During Rainfall) (cm)	Day 1	14.00	36.00	27.40	44.00	77.00	54.33
	Day 2	24.00	48.00	36.87	50.00	81.00	60.80
	Day 3	41.00	68.00	56.53	58.00	88.00	69.80
Flood Height (After Rainfall Stops) (m)	Day 1	36.00	60.00	50.20	48.00	80.00	59.87
	Day 2	31.00	57.00	46.27	40.00	71.00	50.87
	Day 3	30.00	57.00	45.40	35.00	66.00	45.87
Flood Daily Encroachment Rate (m)		9.47	19.67	14.57	6.47	9.00	7.73
Flood Daily Recede Rate (m)		0.87	3.93	2.40	5.00	8.00	6.50
Highest Flood Marking on wall - Highest current flood height (m)		36.00	45.00	38.13	10.00	26.00	23.20

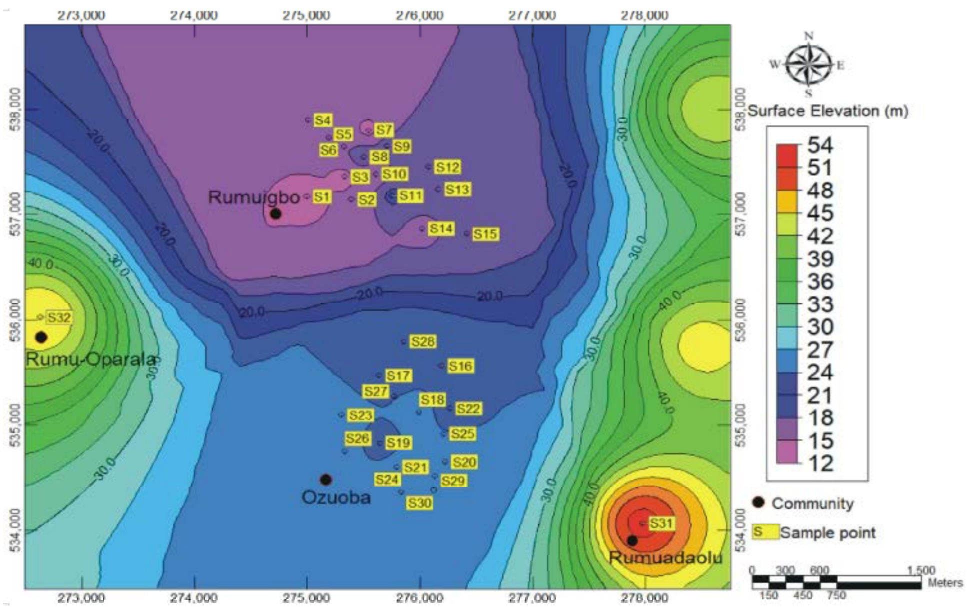

Fig. 2: Surface Elevation acquired from field studies within the study area

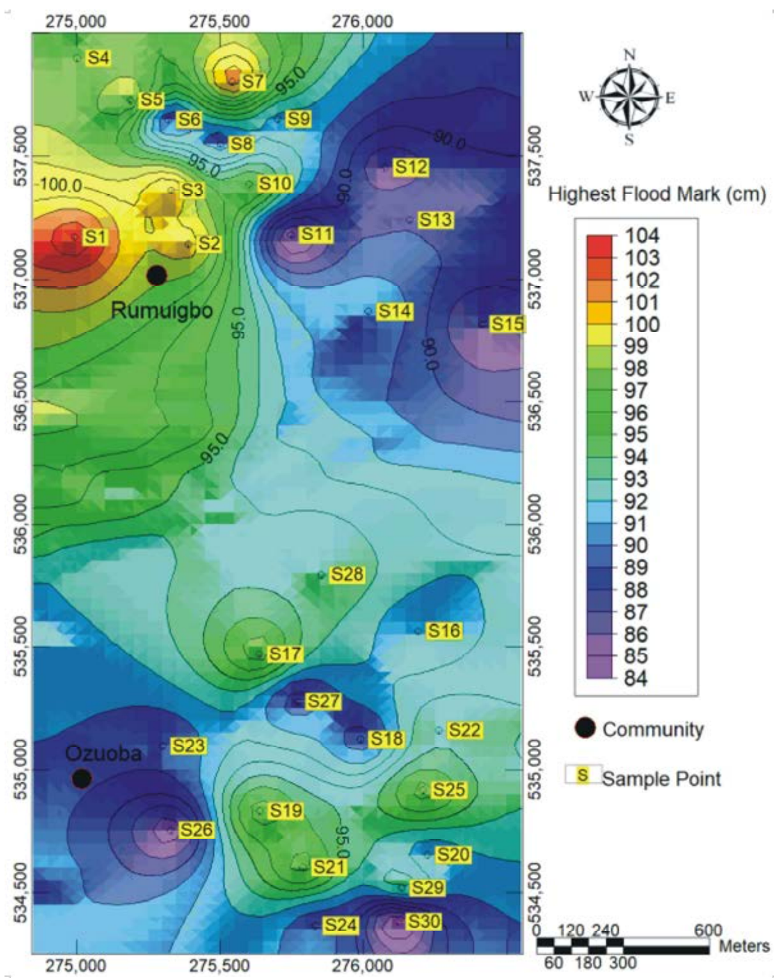

Fig. 3: Flood Markings acquired from fences and building walls in the study area

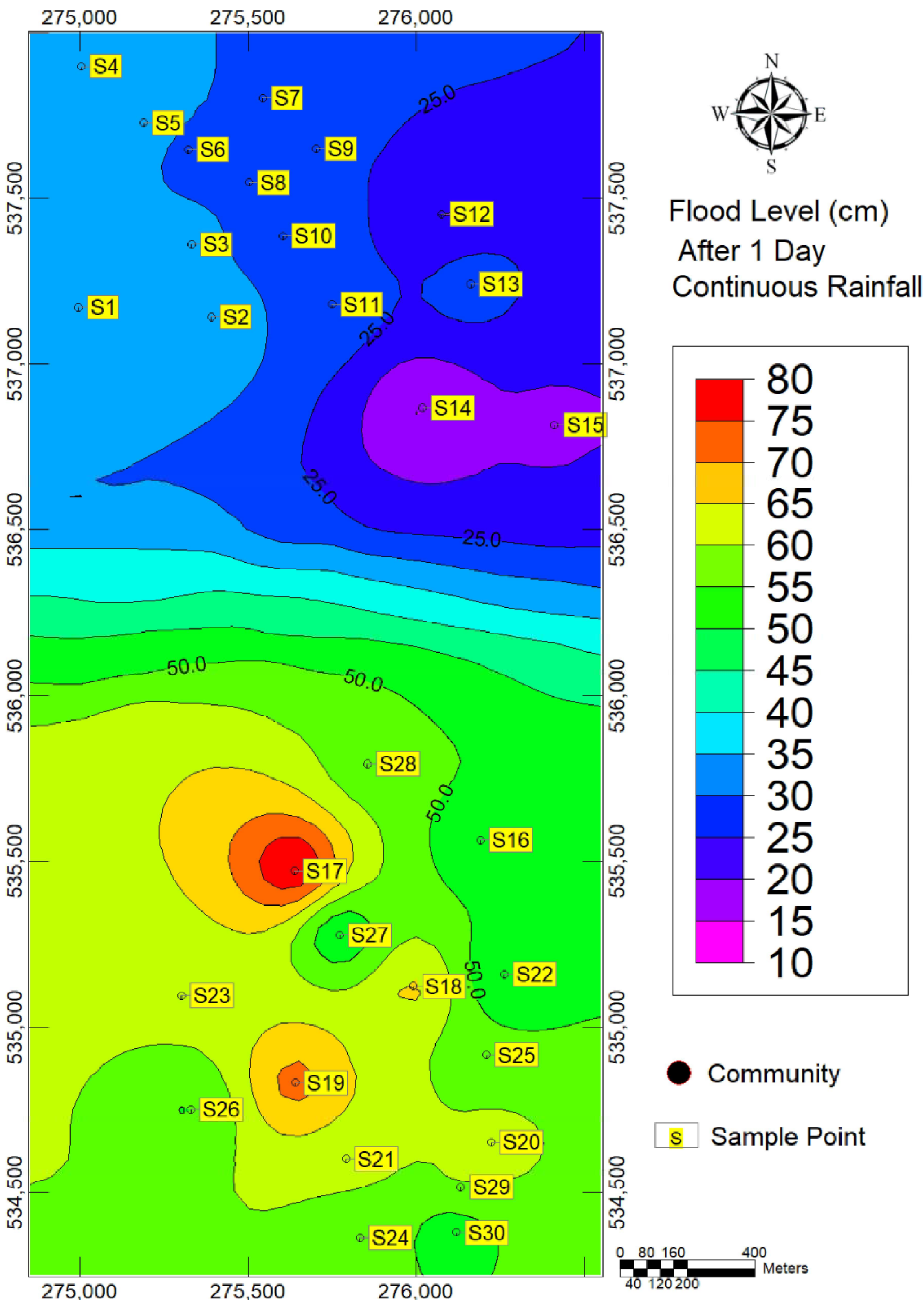

Fig. 4: Flood height after 1 day of continuous rainfall in the study area

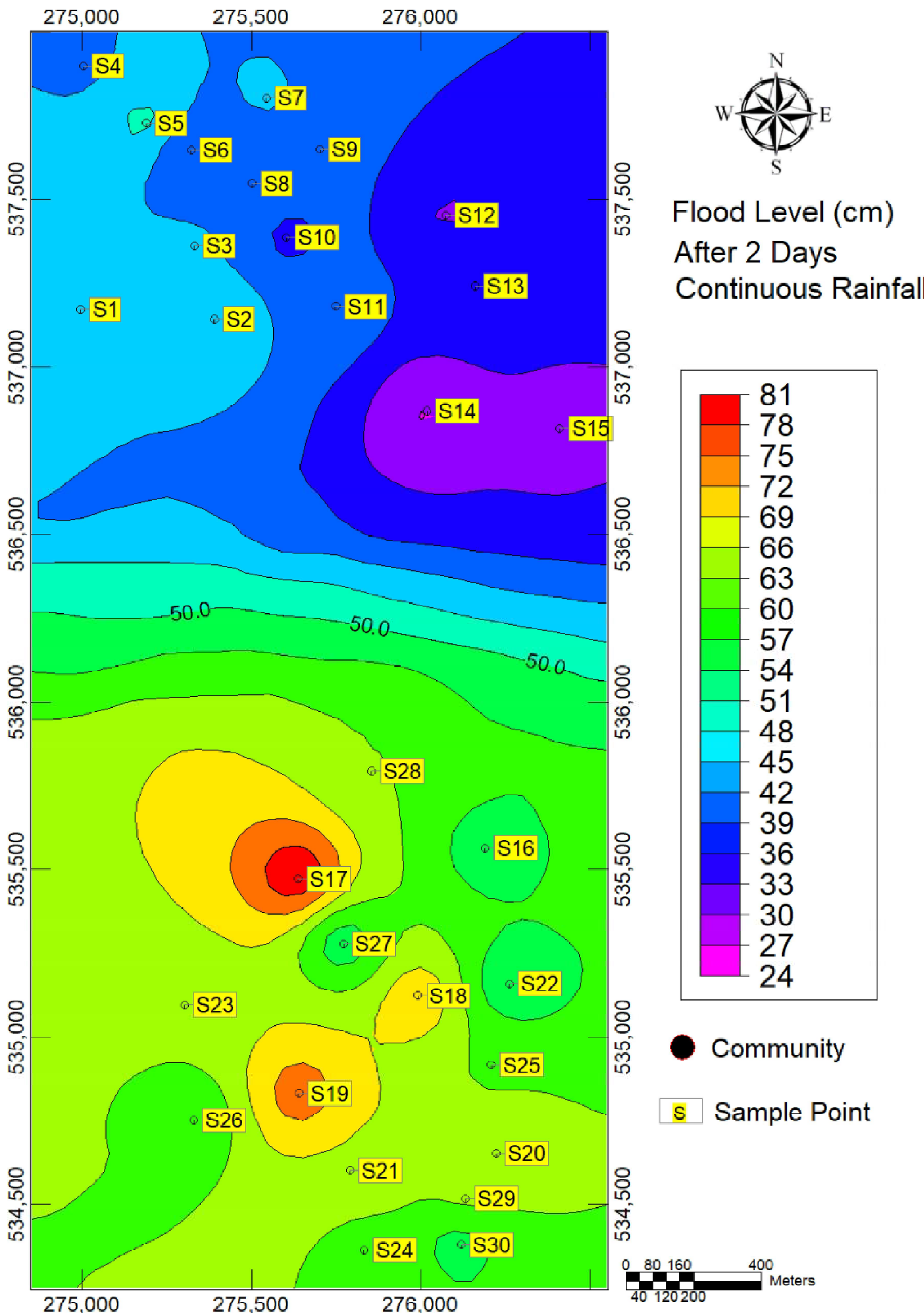

Fig. 5: Flood height after 2 days of continuous rainfall in the study area

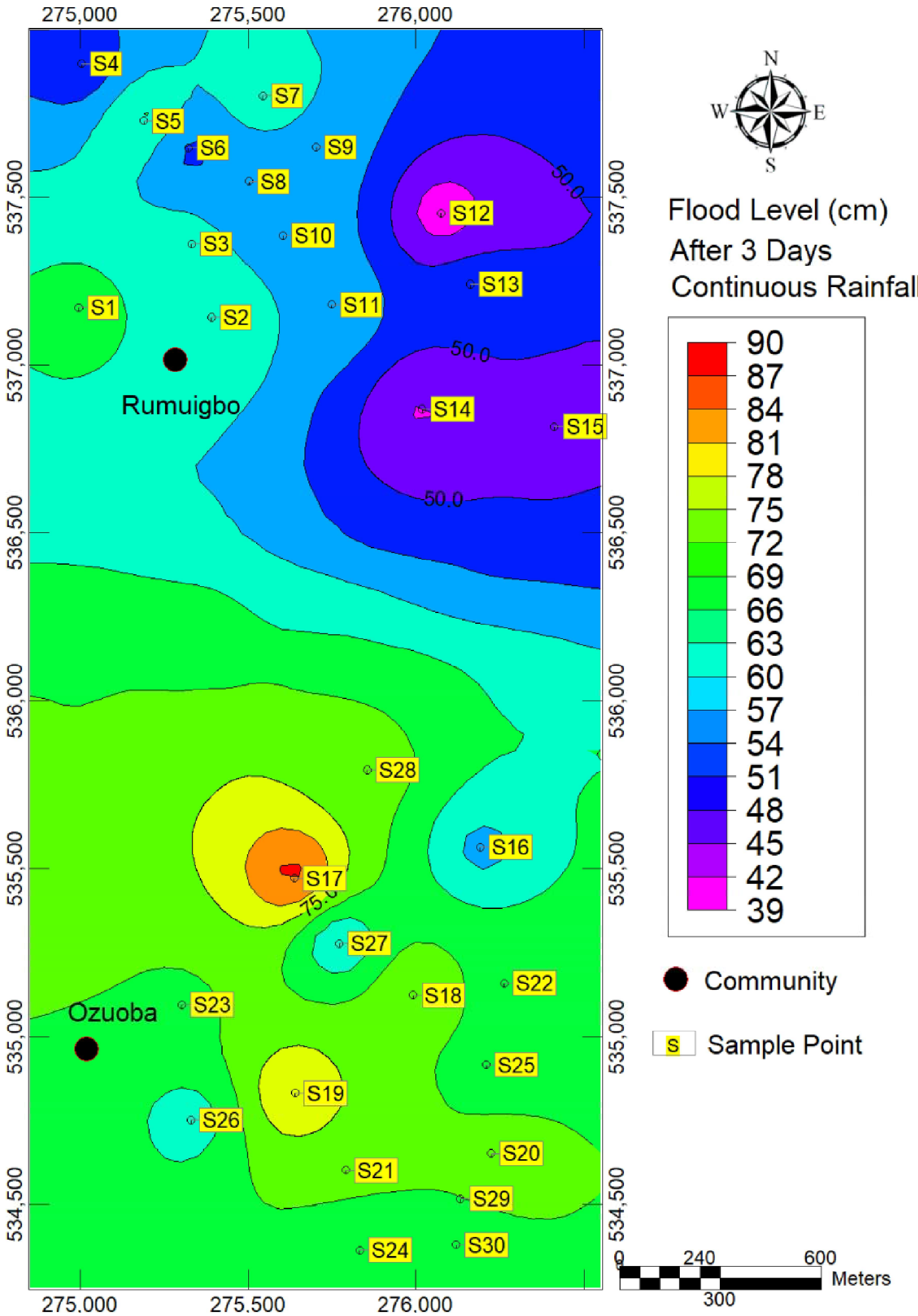

Fig. 6: Flood height after 3 days of continuous rainfall in the study area

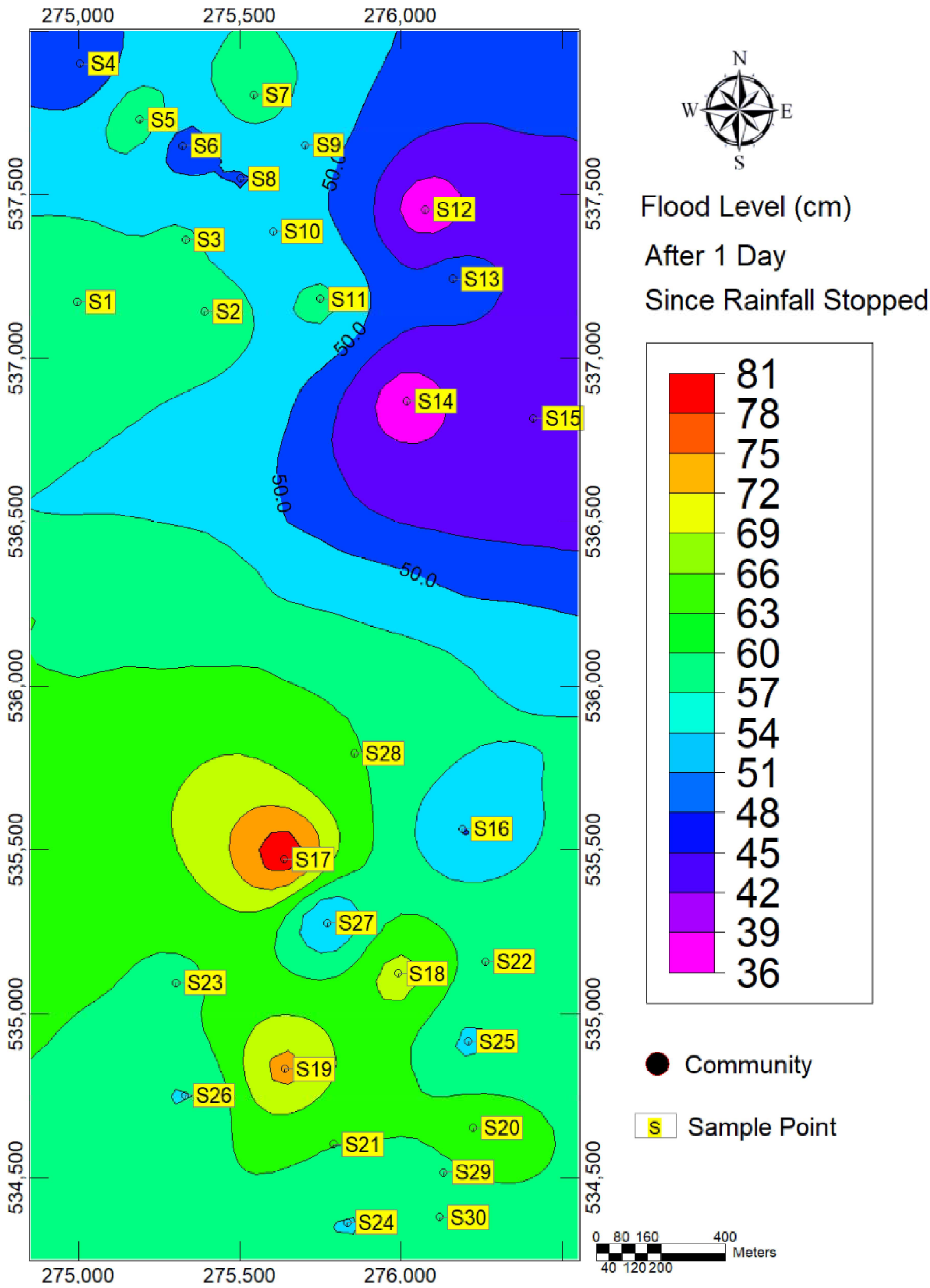

Fig. 7: Flood height after 1 day since rainfall stopped in the study area

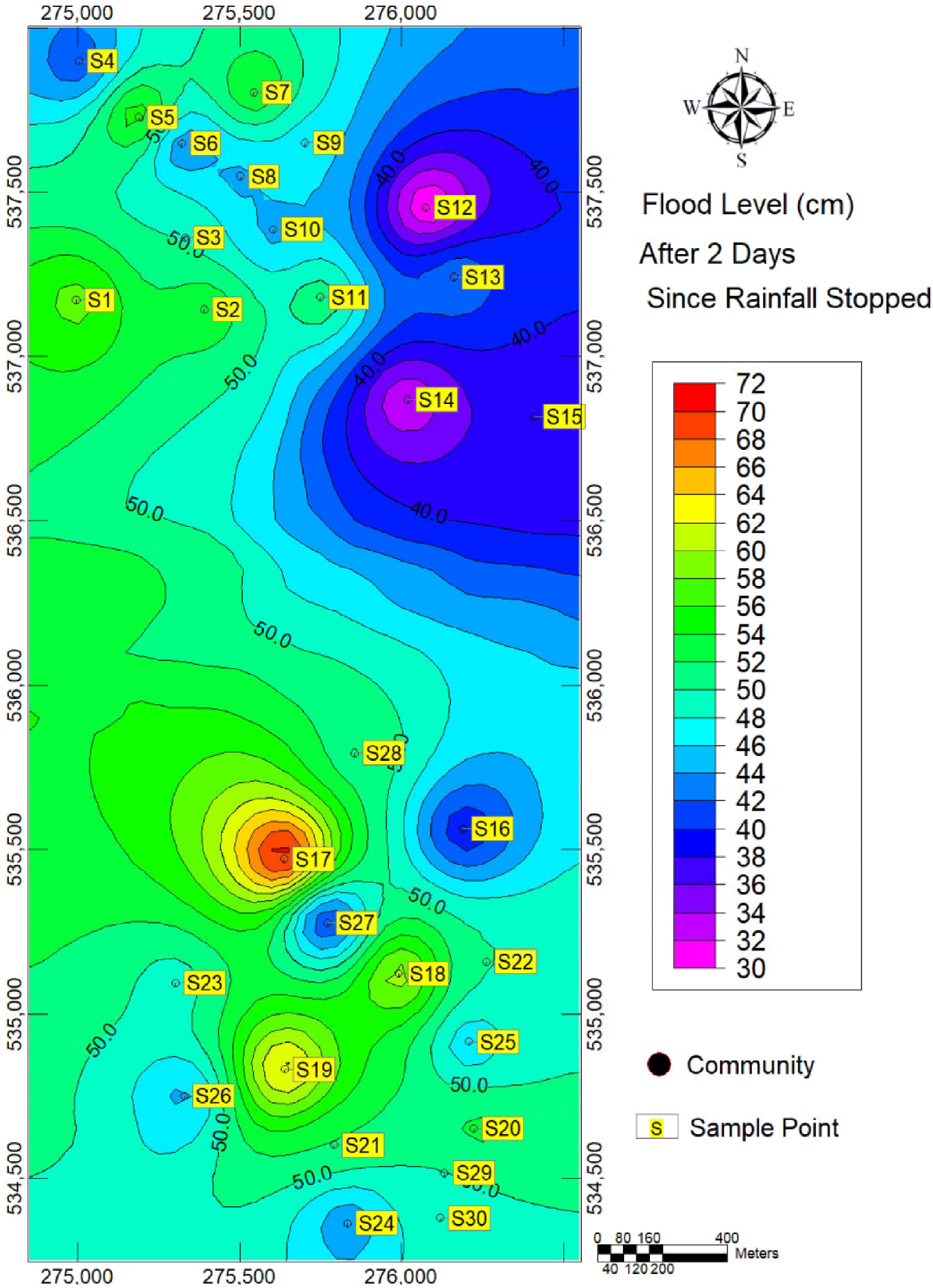

Fig. 8: Flood height after 2 days since rainfall stopped in the study area

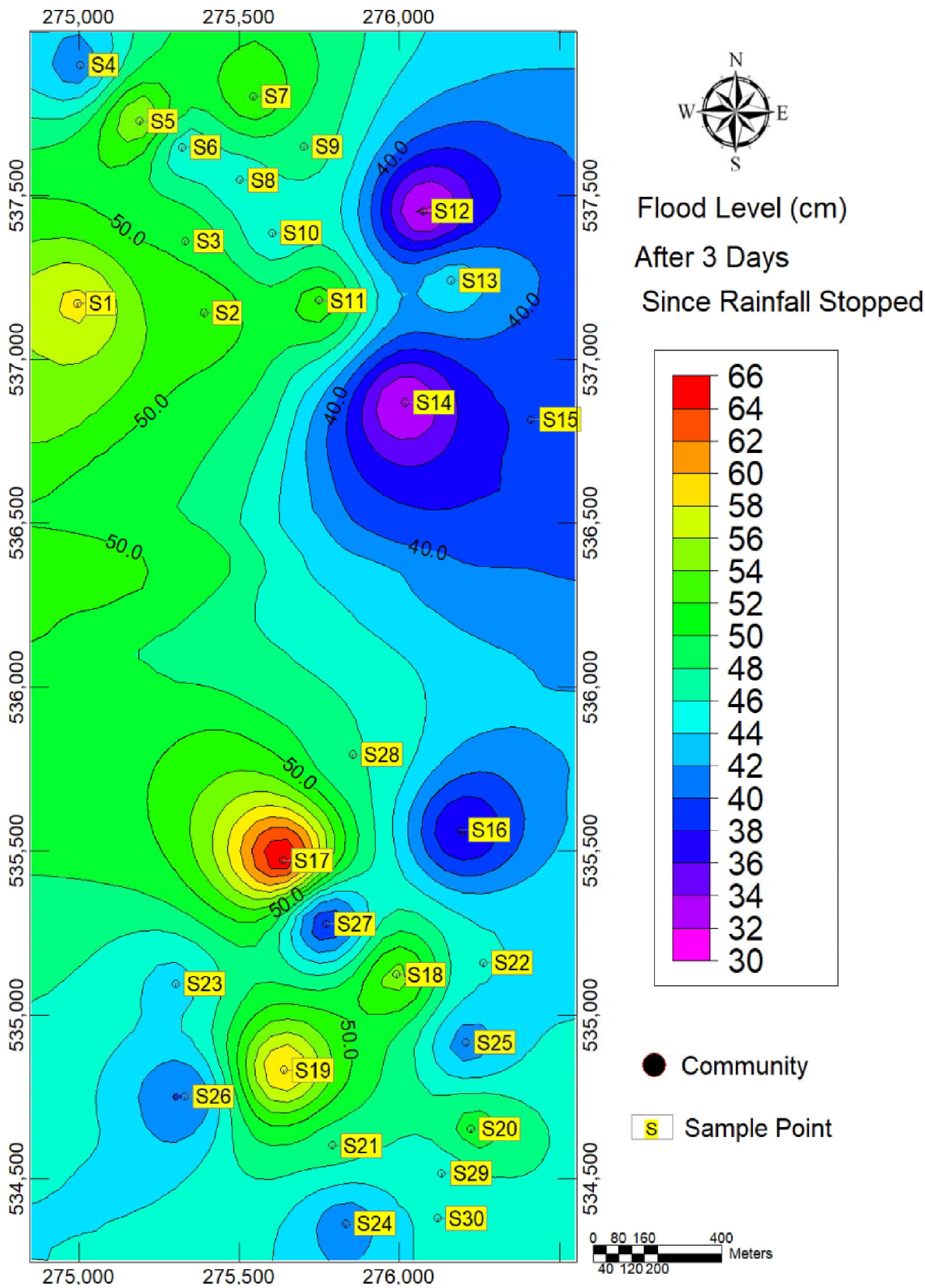

Fig. 9: Flood height after 3 days since rainfall stopped in the study area

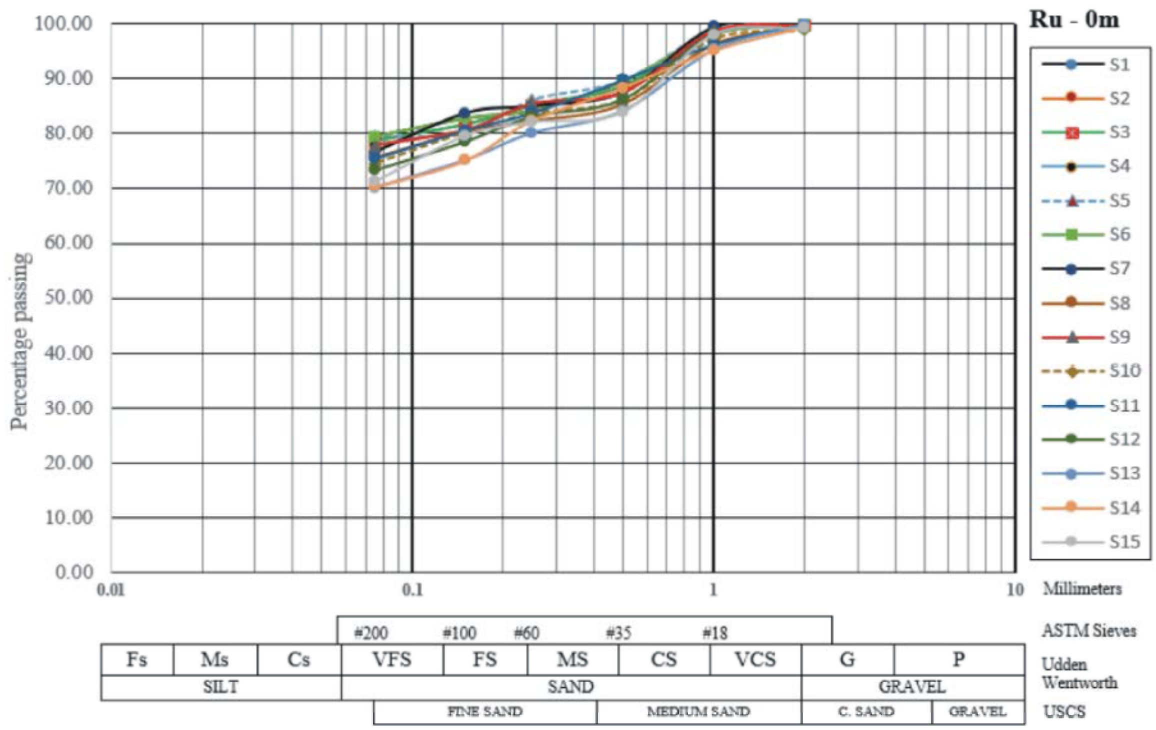

Fig. 10: Grain size analysis for top-soils (0 m) obtained from Rumuigbo flooded area

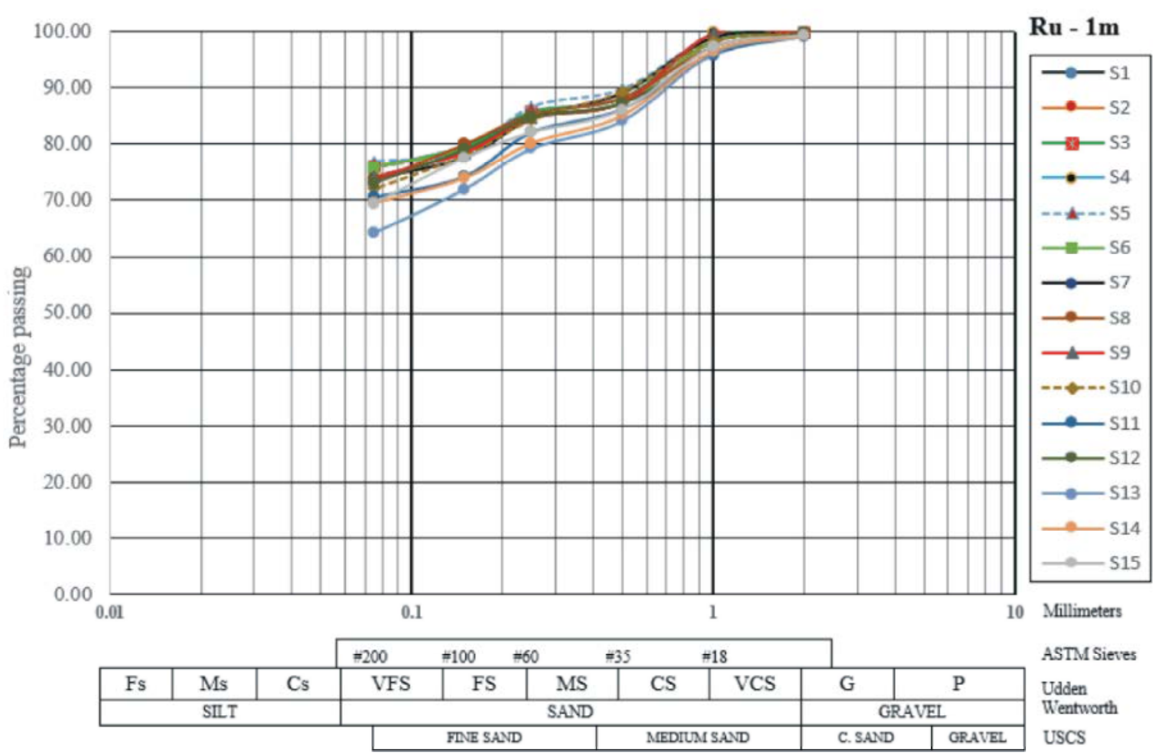

Fig. 11: Grain size analysis for top-soils (1.0 m) obtained from Rumuigbo flooded area

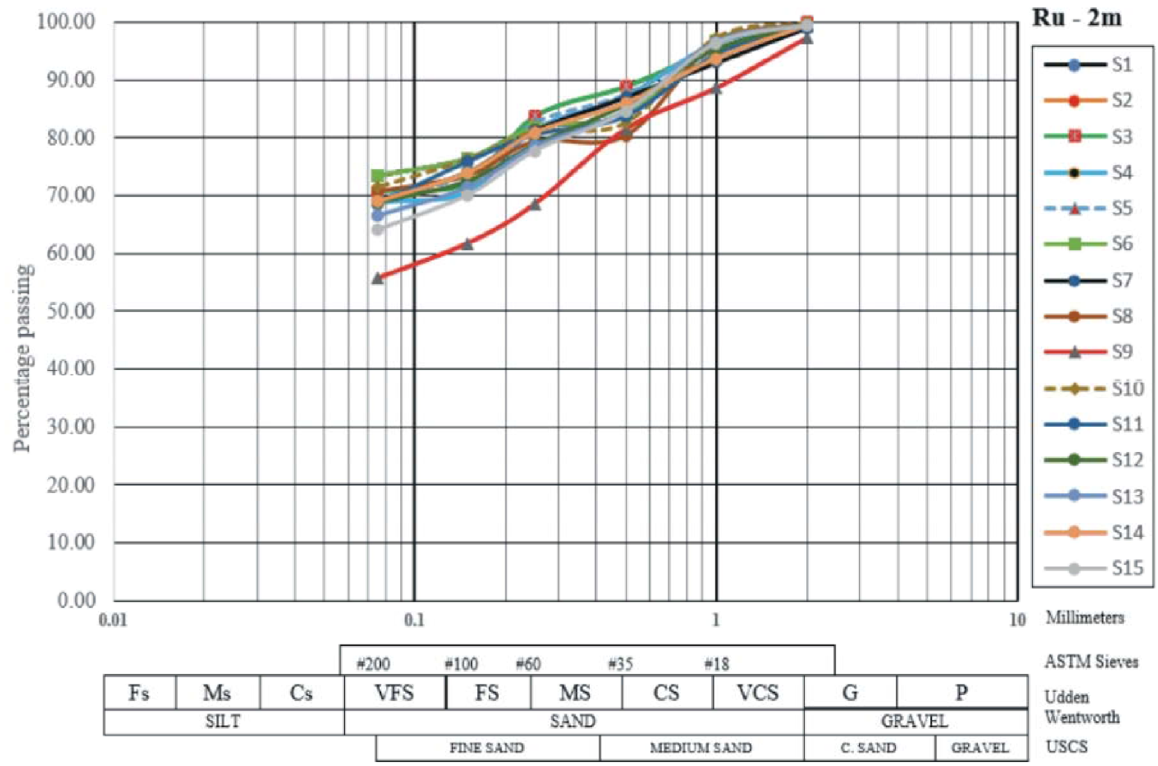

Fig. 12: Grain size analysis for top-soils (2.0 m) obtained from Rumuigbo flooded area

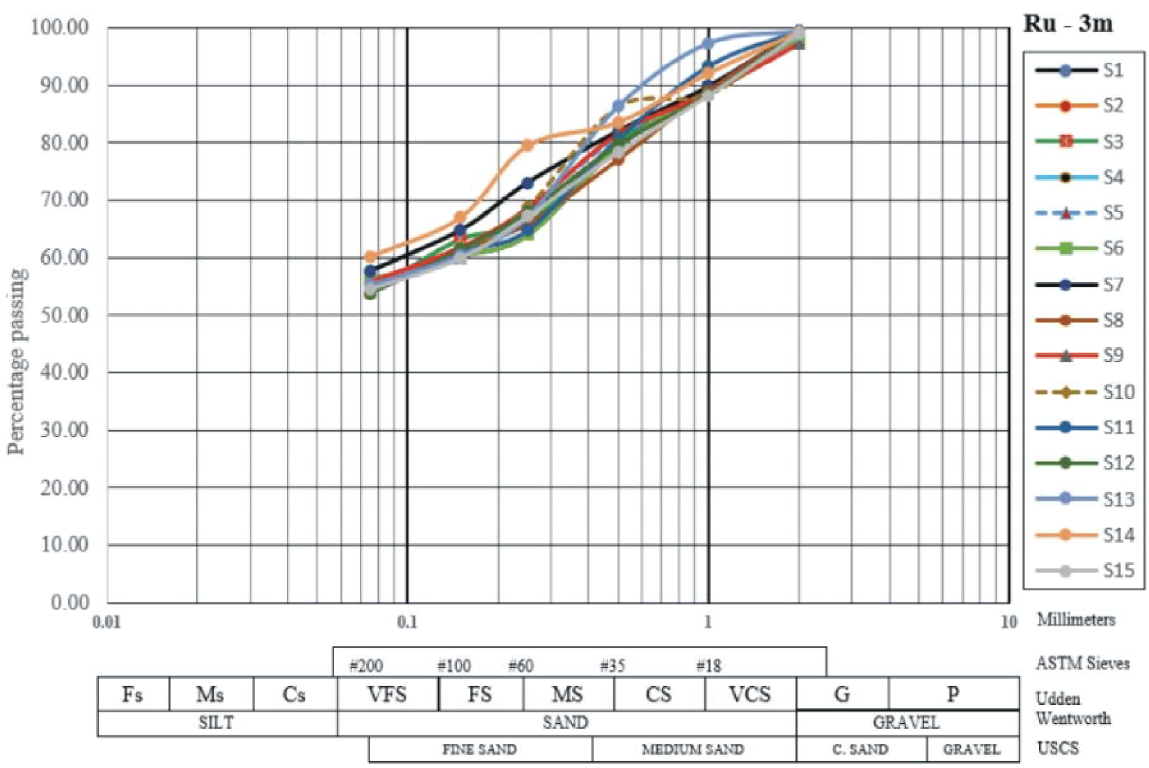

Fig. 13: Grain size analysis for top-soils (3.0 m) obtained from Rumuigbo flooded area

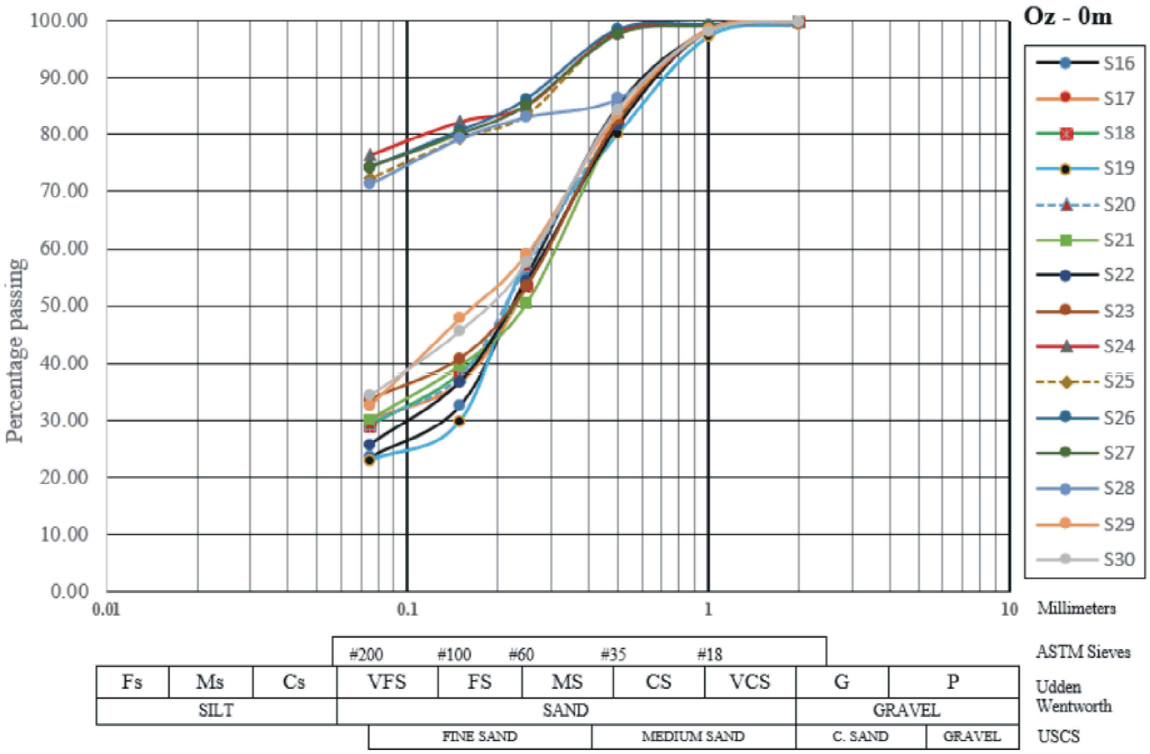

Fig. 14: Grain size analysis for top-soils (0 m) obtained from Ozuoba flooded area

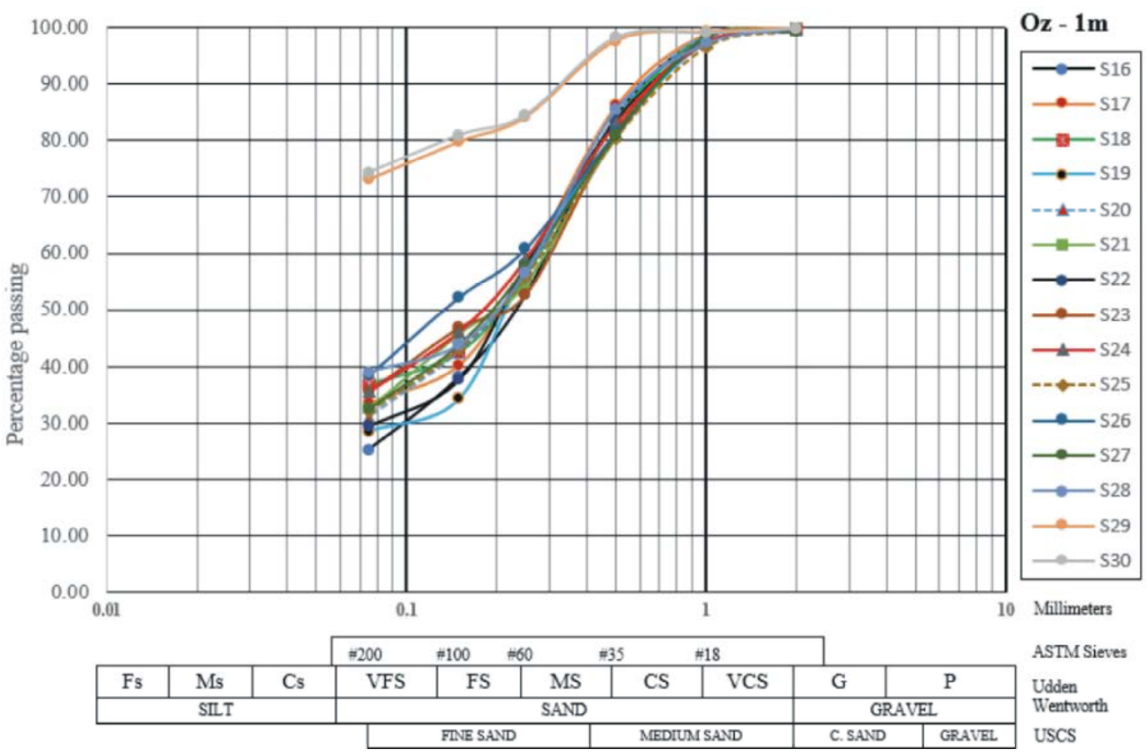

Fig. 15: Grain size analysis for top-soils (1.0 m) obtained from Ozuoba flooded area

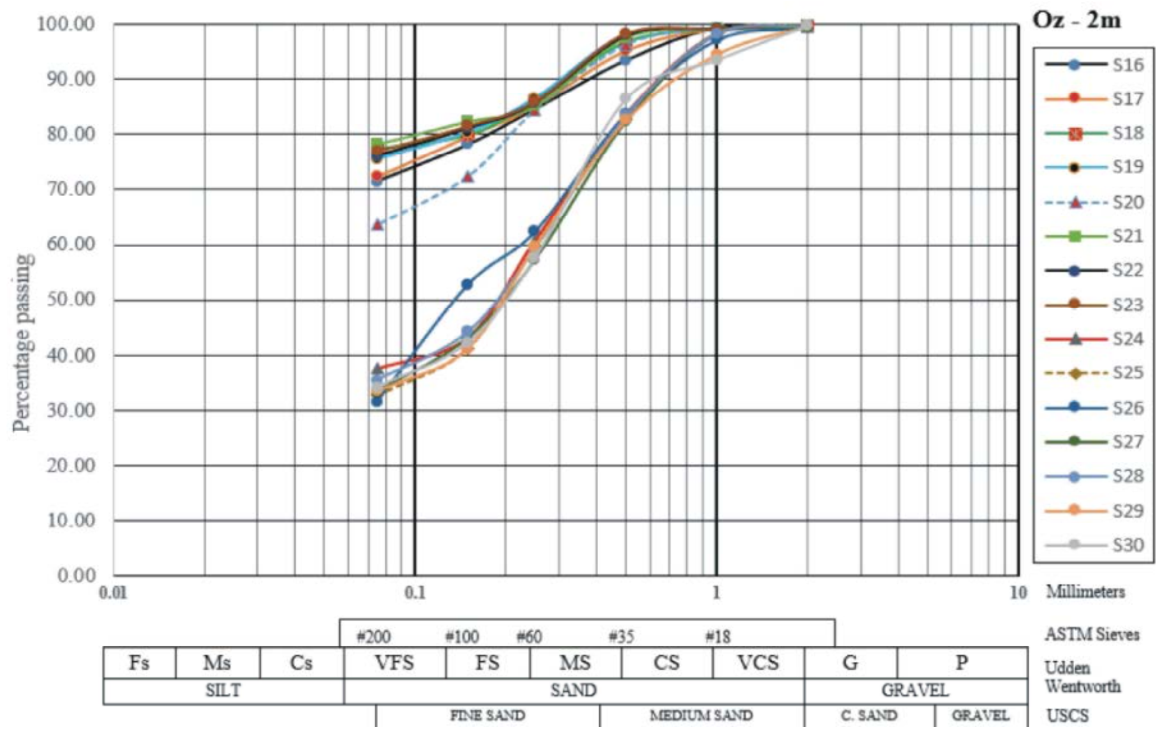

Fig. 16: Grain size analysis for top-soils (2.0 m) obtained from Ozuoba flooded area

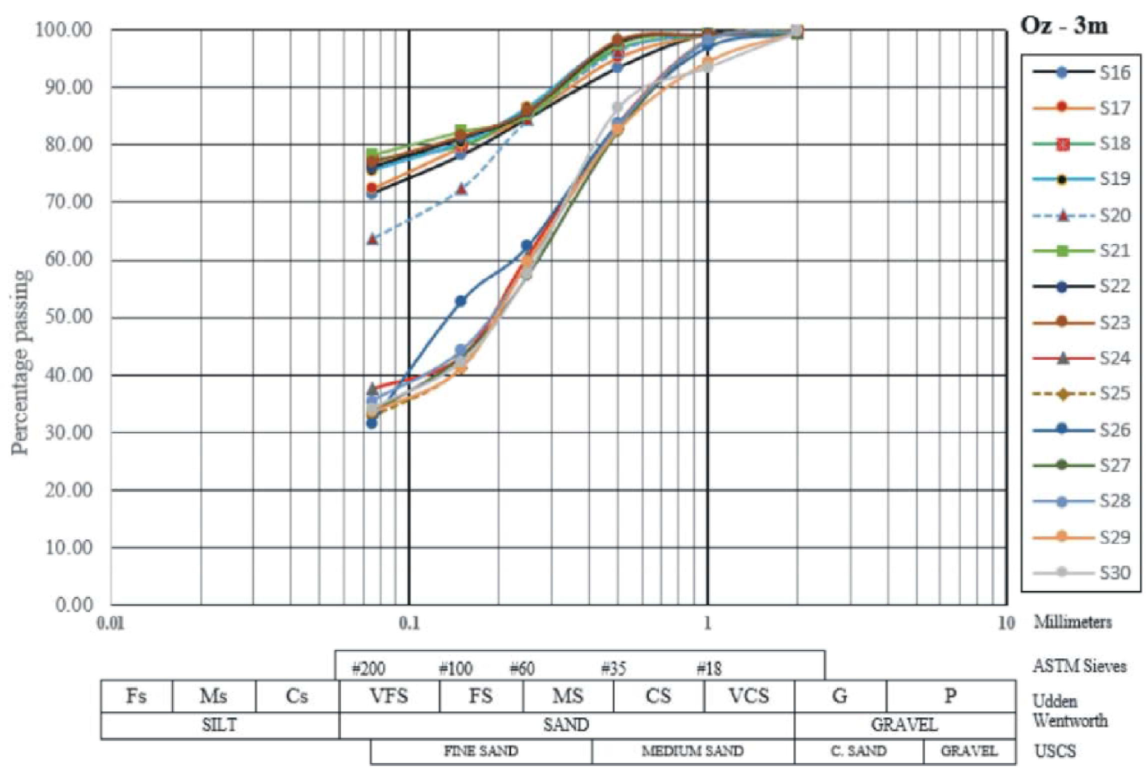

Fig. 17: Grain size analysis for top-soils (3.0 m) obtained from Ozuoba flooded area

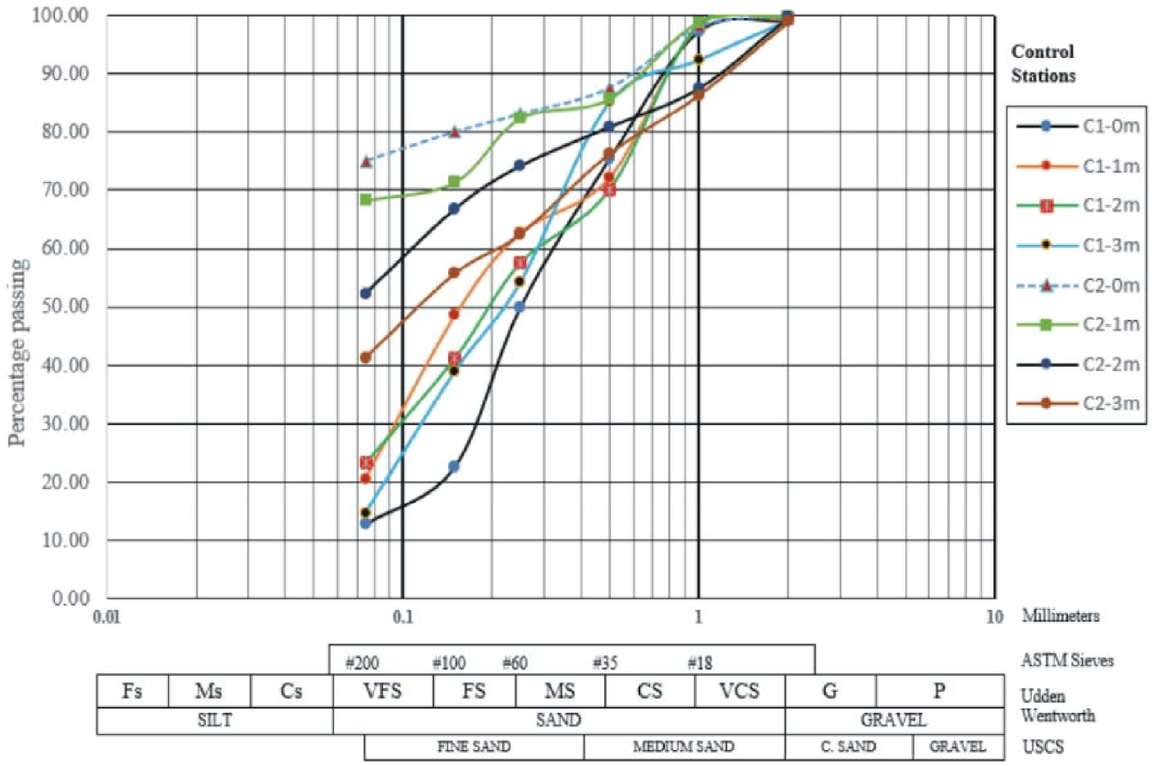

Fig. 18: Grain size analysis for soils obtained from control site

Table 5: 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

Table 5: Continued

Sample Code	Sample Depth (m)	% Silty clay	% Medium Sand	% Fine Sand	Soil description	Moisture Content (%)	D10	D60	Hydraulic conductivity
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 6: 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

Table 6: Continued

Sample Code	Sample Depth (m)	% Silty clay	% Medium Sand	% Fine Sand	Soil description	Moisture Content (%)	D10	D60	Hydraulic conductivity (cm/sec)
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 7: 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	C1-0m	12.7	22.6	64.7	Medium-Fine Sand	14.34	0.06	3.5	0.0036
(Rumu-Oparali)	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	C2-0m	75	10.4	14.6	Silty Clay	18.6	6E-06	0.009	3.6E-11
(Rumuadaolu)	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 8: 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

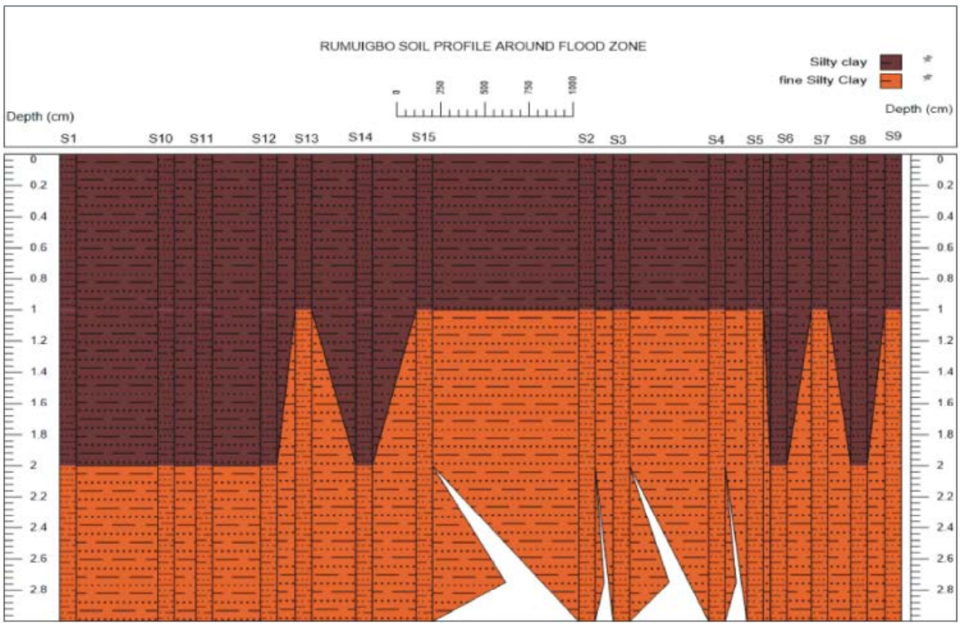

Fig. 19: Soil profile around Rumuigbo flood risk area

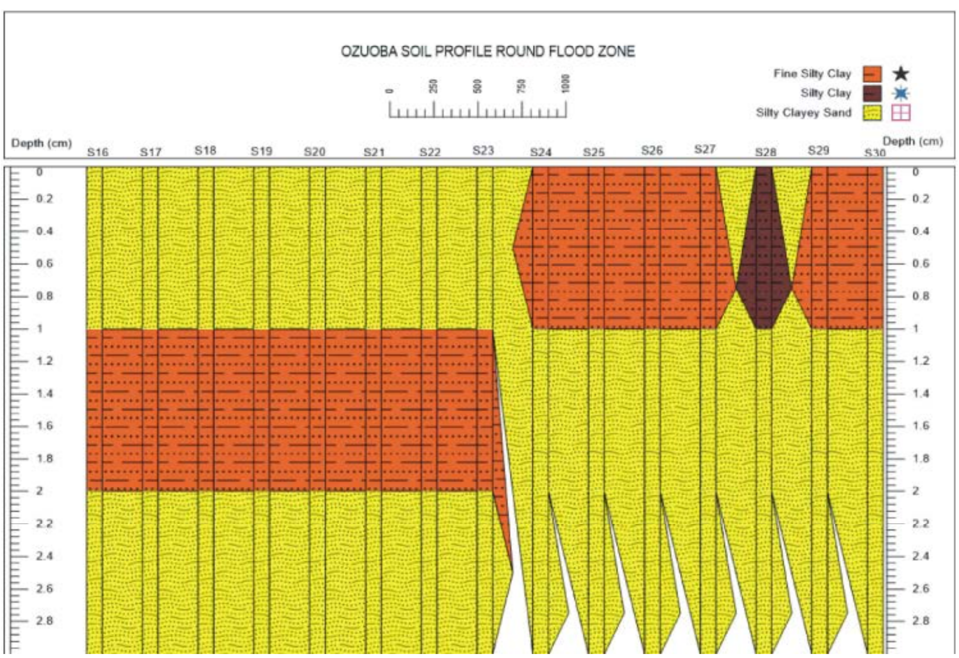

Fig. 20: Soil profile around ozuoba flood risk area

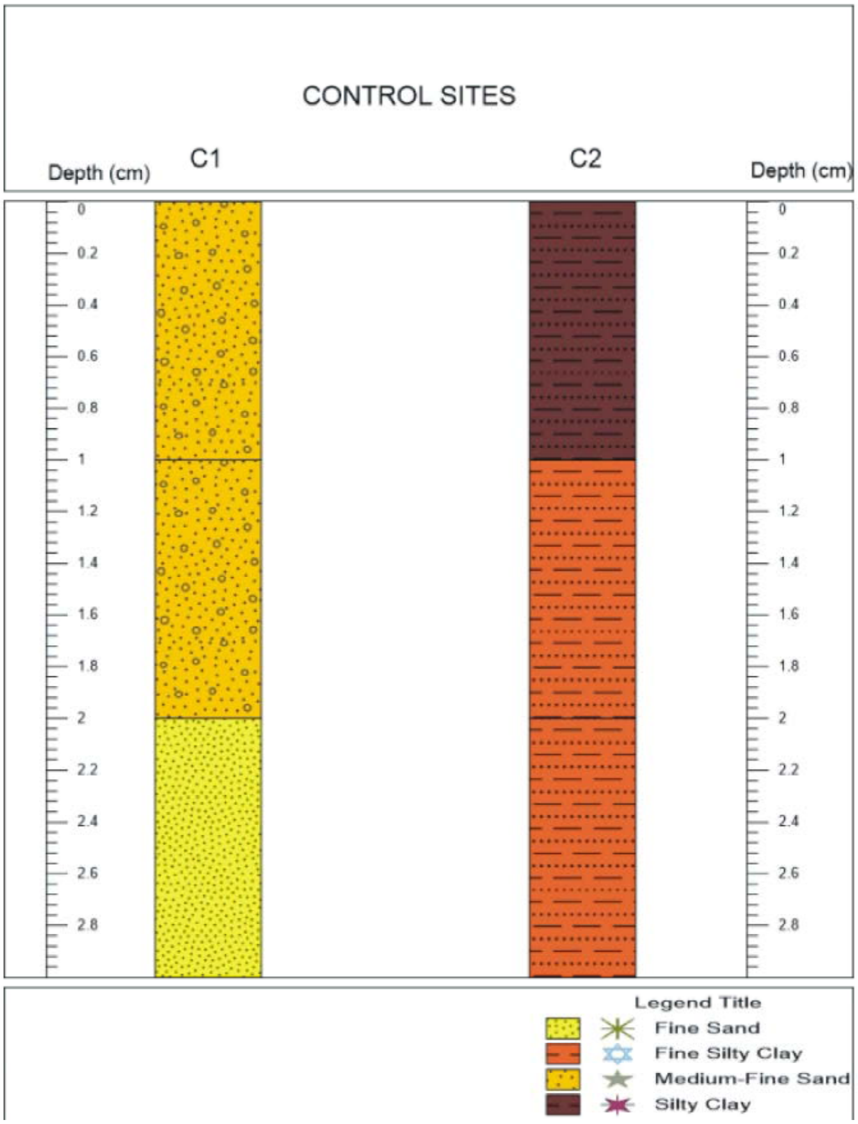

Fig. 21: Soil profile around control sites. C1-Rumuadaolu; C2-Rumu-Oparali

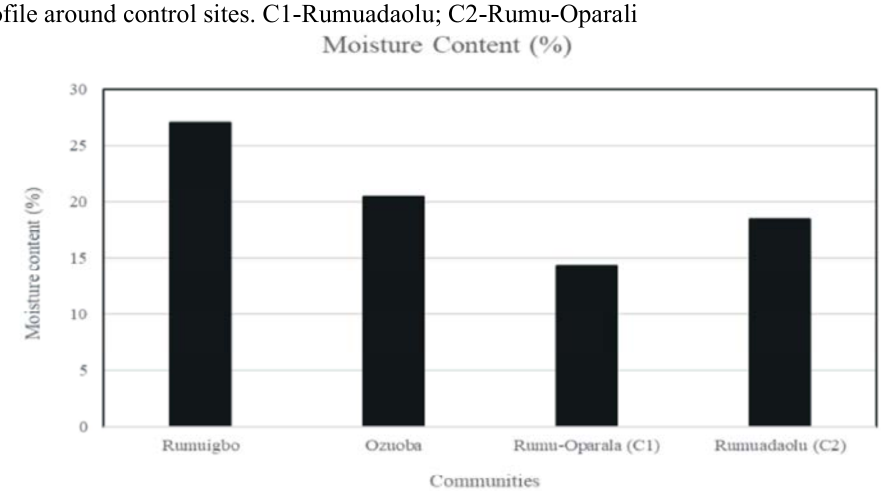

Fig. 22: Average moisture content compared with control sites

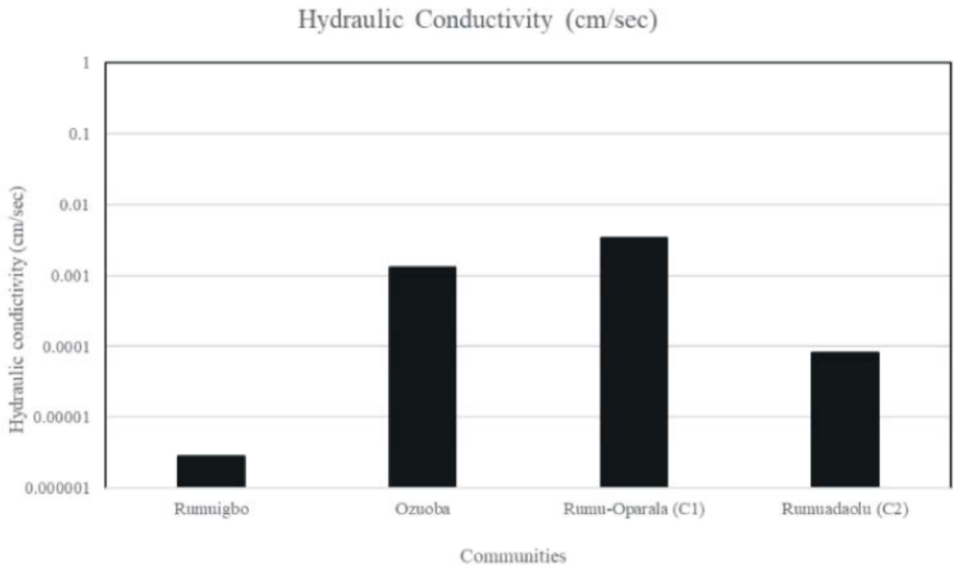

Fig. 23: Average hydraulic conductivity compared with control sites

Table 9: Properties utilized for development of groundwater vulnerability maps for the area

S/No	Surface Elevation	Lithology	Moisture Content	Hydraulic Conductivity	Highest flood marking on wall	Flood Encroachment rate	Flood Recede Rate
S1	13.00	Silty clay	27.00	8.46E-07	104.00	17.50	1.50
S2	14.00	Silty clay	26.60	7.2565E-07	101.00	15.00	4.00
S3	13.00	Silty clay	23.22	1.0078E-06	102.00	15.00	3.00
S4	15.00	Silty clay	25.81	7.5555E-07	97.00	9.50	3.50
S5	14.00	Silty clay	27.99	5.9345E-07	100.00	16.00	2.50
S6	16.00	Silty clay	30.22	9.001E-06	89.00	12.50	1.50
S7	13.00	Silty clay	25.66	1.5661E-06	103.00	17.50	4.50
S8	18.00	Silty clay	30.33	4.0029E-06	90.00	13.00	3.00
S9	17.00	Silty clay	25.37	2.2465E-06	92.00	16.50	2.00
S10	14.00	Silty clay	28.19	9.0025E-06	98.00	16.50	3.50
S11	19.00	Silty clay	31.18	2.2582E-06	86.00	16.00	2.50
S12	18.00	fine Silty Clay	27.20	3.0794E-06	88.00	11.00	3.50
S13	18.00	Silty clay	22.65	4.8375E-07	90.00	12.50	1.50
S14	15.00	Silty clay	27.03	2.7125E-07	92.00	15.00	4.50
S15	17.00	Silty clay	26.96	6.2603E-06	88.00	15.00	1.50
S16	24.00	Silty-Clayey Sand	20.97	0.00035728	92.00	6.50	9.50
S17	22.00	Silty-Clayey Sand	21.73	0.00011026	98.00	5.50	9.50
S18	26.00	Silty-Clayey Sand	18.83	0.00016925	90.00	7.00	10.00
S19	22.00	Silty-Clayey Sand	21.42	4.875E-05	98.00	6.50	8.50
S20	26.00	Silty-Clayey Sand	19.99	0.00013606	92.00	7.50	8.50
S21	25.00	Silty-Clayey Sand	20.70	0.00021825	98.00	7.00	9.00
S22	22.00	Silty-Clayey Sand	20.24	0.017206	95.00	12.00	10.50
S23	26.00	Silty-Clayey Sand	19.52	9.275E-05	91.00	6.50	11.00
S24	25.00	Silty-Clayey Sand	20.09	7.2577E-05	91.00	7.50	9.00
S25	24.00	Silty-Clayey Sand	19.57	0.0001115	98.00	7.50	9.50
S26	26.00	Silty-Clayey Sand	21.31	0.0003235	87.00	6.50	10.50
S27	24.00	Silty-Clayey Sand	20.35	0.0001115	90.00	7.50	8.00
S28	23.00	Silty-Clayey Sand	20.98	0.0003235	95.00	10.00	9.50
S29	24.00	Silty-Clayey Sand	20.23	0.00023025	96.00	7.00	10.50
S30	26.00	Silty-Clayey Sand	20.22	0.00011275	84.00	11.50	9.00
C1	45.00	Medium-Fine Sand	14.30	0.00027525			
C2	53.00	Fine-Silty Clay	18.48	0.0001425			

Table 10: Flood vulnerability rating for the various flood vulnerability indices

Vulnerability Indices	Surface Elevation (m)	Lithology	Moisture Content (%)	Hydraulic Conductivity (cm/sec)	Highest flood marking on wall (cm)	Flood Encroachment rate (cm)	Flood Recede Rate (cm)
High	<20	Silty Clay to Silty-Clayey Sand	>30	$<10^{-5}$	>80	>10	<4
Moderate	20-40	Medium-Fine Sand	20-30	10^{-5} - 10^{-1}	50-80	5-10	4-8
Low	>40	Coarse-Grain Sand	<20	$>10^{-1}$	<50	<5	>8

Table 11: Vulnerability indices and ratings adopted in this study

Vulnerability Rating	Vulnerability Index
Low	1-7
Moderate	8-14
High	15-19
Very High	20-21

Table 12: 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

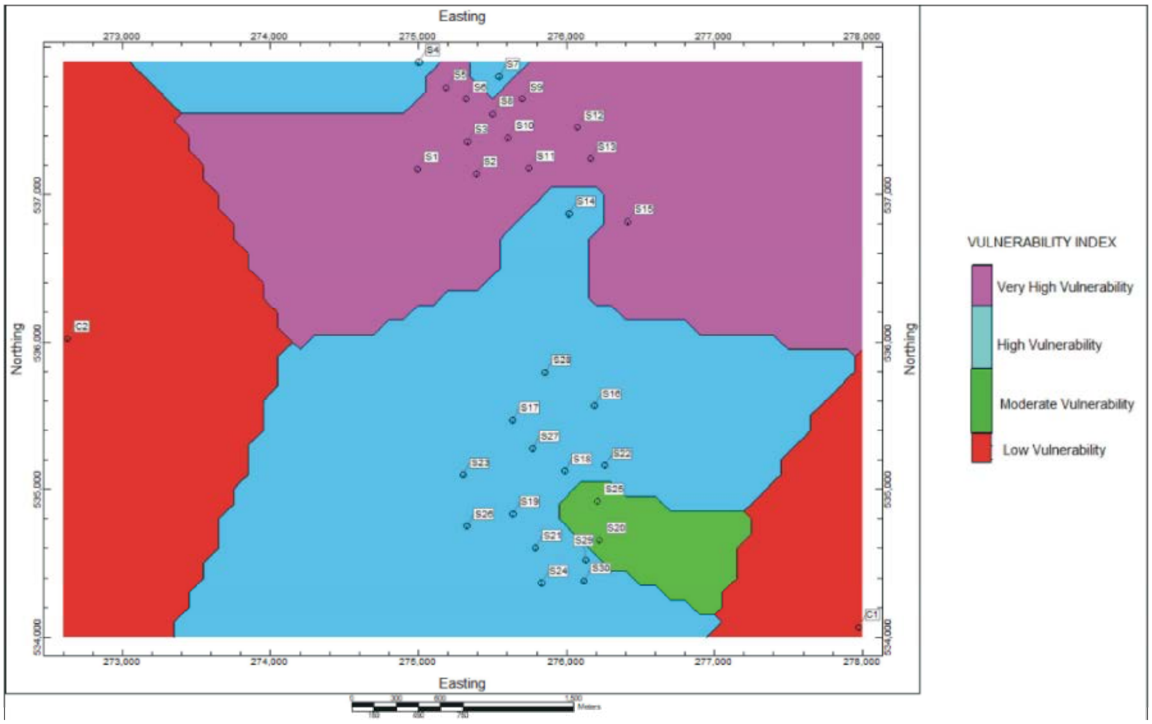

Fig. 24: Flood vulnerability index map for the study area showing areas prone to flooding

RESULTS AND DISCUSSION

Results of grain size analysis revealed that Rumuigbo soils, around the flood prone areas are predominantly silty clay, underlain by fine sandy silty clay. In Ozuoba, the soils are predominantly silty clayey sands and fine sandy silty clay. The soil types in both flood prone areas are similar, although more sandy sands are recorded from soils around Ozuoba area. The presence of silts and clays in the soil fabric are responsible for the slow percolation of water into the subsurface realms. At Rumuadaolucontrol site (C1), the soils fine silty clay capped by silty clay, while at Rumu-Oparali control site, the soils are 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 as adopted [10], 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 are having low to medium hydraulic conductivities.

The study areas; Rumuigbo and Ozuoba communities are situated on a lower slope (< 26.0 m) compared to the surrounding communities (> 45.0 m), thus, rainfall will always drain into these communities from surrounding communities and causing flooding because they act as a sink due to their low-lying topographies. Highest flood marks on walls, fences, gates and buildings in Rumuigbo and Ozuoba communities are relatively much higher than the current flood levels recorded, suggesting that they were periods in the past when flood incidents were much more intense in the area. In an earlier study conducted [20], flood marking on walls in Ozuoba area ranged from 70 to 150 cm as opposed to a range of 84-98 cm recorded in this study. This results as compared with earlier studies conducted in the area suggests that the flood incidents that caused the highest flood marks occurred in 2007.

The average flood encroachment rate recorded in this study showed that flood water levels rises by about 14.57 cm/day in Rumuigbo and 7.73 cm/day in Ozuoba area. This indicates that Rumuigbo stands a greater risk of being flooded compared to Ozuoba area because it will take roughly twice the amount of rainfall that floods Rumuigbo to cause flooding to occur in Ozuoba at significant levels. Based on these recorded encroachment rate, it becomes easy to quantify the flood heights after any given time, provided that the rains are continuous and heavy during this period.

Average flood recede rates recorded are 2.4 cm/day and 6.5 cm/day for Rumuigbo and Ozuoba communities. The slow recede daily rate recorded by Rumuigbo area is related to the lithology, moisture content and hydraulic conductivity. The soils are 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 are having 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 are having very low permeability (2.8×10^{-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 are 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 (1.3×10^{-3} cm/sec) is much higher than those recorded in Rumuigbo area. These characteristics of Ozuoba soils are responsible for the higher daily flood recede rates. The soils at Rumuadaolucontrol site have similar characteristics as soils within the flood risk zones but Rumuadaolu is 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 are 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 are not vulnerable to flooding.

The inhabitants aged between 25 and 70 years in the area all fall within the educated class. The residents all have either radio/television/phones and can easily comprehend information shared through these various media. The buildings in these flood prone areas are predominantly blocks and concrete which can easily be damaged over time when constantly subducted in water. A minor shaking or trembling of the earth surface will result in complete destruction of the buildings. Flood incidents experienced in these flood prone areas are often perceived by respondents as moderate to severe. The respondents revealed that flooding occurs in the area only when rainfall is heavy and continuous all through the year. Most of the respondents in the area revealed that no relief material/assistance comes to their aid during times of flood incidents and every man/woman must have to fend for himself/herself. Most respondents in the area agree to the fact that there have been significant flood incidents in the past six months leading to water levels rising to different levels (ankle level, knee level and waist level) depending on the residence. The significant flood incidents occurring in the area is related to the very high rainfall that occurs in the area.

CONCLUSION

The study has 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.

The study recommends the following:

- Large sloping gutters should be constructed within strategic places in the area in order to properly transport flood water to the nearby rivers.
- Dumpsites around flood prone areas should be evacuated to prevent waste contaminated water to recharge our aquifers.
- Proper sensitization should be conducted for residents of flood prone areas so they can know what to do in the event of another flood incident.

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