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Application of Geographical Information Systems Technology in Soil Fertility Variation Analysis in South-eastern Nigeria

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Abstract

The study investigated the fertility status of soil around the River Otamiri watershed in Imo State of South-eastern Nigeria. A Geographical Positioning System was used to geo-reference the area and locate the soil samples, which were collected from 9 sampling points at 2 m depths each. The sample points were 210m, 110m and 10m away from the river channel. The soil samples were air-dried and passed through 2-mm sieves before they were subjected to routine laboratory analyses. Results showed that the soil area was predominantly made of loamy sand particles, with high values ± 98.7% which decreased progressively away from the river. There was increase in *available phosphorous upslope compared to downslope, steady decrease in aluminum and hydrogen downslope, while areas closer to the river have less acidic cations. The soil pH ranged from 4.67 ↔ 5.62. Surface soils comprised more of organic carbon content than subsurface soils which decreased from crest to footslope. The soil data also produced low values of total nitrogen and the total exchangeable bases. The results presented the soil as infertile and unfit for serious farming except with conscious enrichment efforts.*

Key words: soil fertility, surface soils, soil samples, geographical information systems, watershed

Introduction

Soils serve as a foundation for both natural and man-made resources, and as a medium for agricultural purposes [Smith, 2006]. Soil fertility level evaluation makes it possible to determine the best kind of use the soil can be put to. It is also possible to determine, through knowledge of the soil composition, the amount of resources to be applied to the soil to attain maximum yield (Verma, 1989 and Ajayi, et al 2003). Research on soil fertility evaluation and uses, in this area, has progressed over the years, such that new achievements have also been gained [see for example, Uzoho and Oti, 2005; Matthews-Njoku and Onweremadu, 2007; Onweremadu, et al 2007 and Onweremadu, et al, 2008]. For example, Ushie et al., [2005] reported the use of River Otamiri sands for the production of plain glass and the adoption of green fallows for cultivation purposes for soils along Otamiri River.

Soil fertility losses have been very rampant in southeastern Nigeria. Onweremadu et al [2008] observed that increased deforestation and resultant erosion damages of soil resources in central south-eastern Nigeria may be responsible for this development. The soil area along River Otamiri has been degraded by erosion, and by poor land planning and use. The erosive activities in the agro-ecological area have led to a decline in organic matter. As a result, there has been reduced biological activity, adverse changes in the soil physical and chemical properties, and also adverse changes in the soil nutrient content [Onweremadu et al, 2008]. This has led to a decrease in the value of the soil area around Otamiri River, and thus, a reduction in area suitable for agricultural purposes, as well as other uses. This paper evaluates the soil fertility status of a section of Otamiri River watershed using Geographical Information Systems [GIS]. The aim is to determine whether the fertility level flows towards or away from the river.

The research work was carried out on a section of the Otamiri River watershed in Owerri, south-eastern Nigeria. The study area was delineated to be the portion of the watershed found along Port-Harcourt – Owerri Road, adjacent to Federal University of Technology, Owerri, Nigeria. The area has mean annual rainfall ranging from 2250 to 3500mm with a mean annual temperature of 27^{o}C to 32^{o}C and rising [Njoku, 2006]. The study area is located between latitudes 5^{o}22'52.7"N to 5^{o}23'3.8"N and longitude 6^{o}59'34.3"E to 6^{o}59'17.2"E, with a mean elevation of 47m above sea level. The soils from the study area are derived from coastal plain sand (Benin formation) as described in Ezenwa [1987]. Varying and conflicting land uses such as farming, sand mining, fishing, waste disposal, recreational facilities and engineering activities are common in the area [Onweremadu et al, 2007].

Material and methods

A reconnaissance survey of the area was carried out. Soil data were collected using the Random Sampling Technique [RST]. A GPS was used to identify locations where the soil samples were collected. The samples were collected just after dawn on a clear, rainless day in August 2009. A soil auger was used to penetrate and scoop the soil sample at a depth previously measured. The samples were immediately put into clean polyethylene bag provided to avoid any contamination. A total of eighteen (18) samples were collected, separated into crest, mid-slope, and foot-slope. Three samples were collected horizontally at each slope, and at two depths of 0-15cm and 15-30cm each. The collected samples were air-dried, sieved using a 2mm mesh, and stored in a labeled polyethylene bag for laboratory analysis. The effects of physiography on fertility parameters were analyzed using geographical information systems technology. Prior to the analysis, the coordinates of sampling points were used to spatially geo-reference the area. The database were subsequently imported into an ArcView 3.2a GIS software for the analysis which interpolates grid on inverse distance weight and the data were presented in a spatial format.

Results and discussion

The physico-chemical properties of soils in the Otamiri River watershed area are presented on Tables 1 and 2.

Table 1: Physical properties of soils in the area

Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	***Scr***
Crest					
A1	0 - 15	87.7	3.3	9	0.366
A2	16 - 30	83.7	4.3	12	0.35
B1	0 - 15	85.7	7.3	7	1.043
B2	16 - 30	85.7	5.3	9	0.588
C1	0 - 15	89.2	4.8	6	0.8
C2	16 - 30	83.7	5.3	11	0.482
Mean		85.95	5.03	9	0.6048
Midslope					
D1	0 - 15	95.7	0.3	4	0.075
D2	16 - 30	89.2	1.8	9	0.2
E1	0 - 15	91.8	3.2	5	0.64
E2	16 - 30	89.2	4.8	6	0.8
F1	0 - 15	87.7	3.3	9	0.367
F2	15 - 30	91.7	3.3	5	0.66
Mean		90.88	2.78	6.3	0.457
Footslope					
G1	0 - 15	93.7	3.3	3	1.1
G2	16 - 30	95.7	2.3	2	1.15
H1	0 - 15	91.7	3.3	5	0.66
H2	16 - 30	87.7	3.3	9	0.367
I1	0 - 15	97.7	1.3	1	1.3
I2	16 - 30	98.7	0.3	1	0.3
Mean		94.2	2.3	3.5	0.8128

Horizon/ Sample	Depth (cm)	O.C (%)	pH (H_20)	TN (%)	Av.P (ppm)	Ca (meq/100g)	Mg (meq/100g)	K (meq/100g)	Na (meq/100g)	ECEC (meq/100g)	Ca/Mg	Al (meq/100g)
Crest												
A1	0–15	1.207	5.04	0.058	22.4	0.4	0.17	0.002	0.032	1.054	2.35	Trace
A2	15-30	0.938	5.08	0.028	18.9	0.6	0.25	0.001	0.032	1.383	2.4	0.34
B1	0-15	1.736	4.99	0.068	25.2	2.5	0.83	0.002	0.032	3.764	3.01	Trace
B2	15-30	1.337	4.67	0.048	19.6	2.7	1.00	0.001	0.023	4.274	2.70	Trace
C1	0-15	1.257	5.11	0.059	16.1	2.6	0.67	0.002	0.032	3.554	3.88	Trace
C2	15-30	0.818	5.02	0.024	13.3	0.47	0.18	0.001	0.023	1.074	2.61	Trace
Mean		1.2155		0.0475	19.25	1.545	0.51667	0.0015	0.029	2.517	2.83	
Midslope												
D1	0-15	0.958	4.98	0.03	14	0.8	0.33	0.001	0.023	1.604	2.43	Trace
D2	15-30	0.618	4.97	0.02	8.4	0.18	0.08	0.0008	0.023	0.534	2.25	0.27
E1	0-15	0.998	5.13	0.024	16.1	0.26	0.07	0.001	0.023	1.204	3.72	Trace
E2	15-30	0.459	4.95	0.018	11.9	0.17	0.05	0.0002	0.023	0.643	3.40	Trace
F1	0-15	0.599	4.94	0.019	12.9	0.08	0.03	0.001	0.015	0.676	2.67	Trace
F2	15-30	0.898	4.72	0.024	14.7	0.42	0.13	0.0002	0.023	1.173	3.23	Trace
Mean		0.755		0.0225	13	0.3183	0.115	0.0007	0.02167	0.972	2.95	

Footslope												
G1	0-15	0.608	5.52	0.011	11.9	1.7	1.00	0.001	0.032	2.883	1.7	Trace
G2	15-30	0.359	5.45	0.014	9.80	0.8	0.33	0.0009	0.015	1.296	2.43	Trace
H1	0-15	0.189	5.31	0.008	8.40	0.49	0.18	0.002	0.032	0.954	2.72	Trace
H2	15-30	0.118	5.33	0.015	10.50	0.42	0.13	0.002	0.023	0.875	3.23	0.35
J1	0-15	1-037	5.47	0.032	13.30	1.6	0.67	0.0009	0.023	0.964	2.39	Trace
J2	15-30	0.638	5.62	0.021	12.60	0.8	0.55	0.0009	0.023	1.304	2.43	Trace
Mean		0.4915		0.0168	11.08	0.9683	0.44	0.0013	0.02467	1.379	2.48	
Where OC = Organic Carbon; pH = Potential Hydrogen; T.N = Total Nitrogen; Av.P = Available Phosphorus; ppm = part per million; meq = milliequivalent												

Table 3: The spatial locations of the longitude and latitude of the sample locations

Sampling Points	Proximity to the River (m)	Altitude (m)	Latitude (Northing)	Latitude in metres	Longitude (Easting)	Longitude in metres
A	210	57	5^{O} 22' 54.0"	153157	6^{O} 59' 36.3"	507123
B	210	58	5^{O} 22' 52.7"	153149	6^{O} 59' 34.3"	506839
C	210	59	5^{O} 22' 51.8"	153149	6^{O} 59' 33.8"	506576
D	110	46	5^{O} 23' 0.1"	153567	6^{O} 59' 24.3"	507113
E	110	47	5^{O} 23' 1.6"	153560	6^{O} 59' 25.3"	506832
F	110	47	5^{O} 23' 17"	153568	6^{O} 59' 26.3"	506577
G	10	38	5^{O} 23' 3.9"	153925	6^{O} 59' 19.6"	507109
H	10	39	5^{O} 23' 3.8"	153925	6^{O} 59' 17.2"	506846
I	10	39	5^{O} 23' 3.2"	153922	6^{O} 59' 16.6"	506585

The digital elevation model of the study area shows the progressive change in different variables from the foot-slope upwards. The study revealed that the study area comprised mainly of sand particles (majorly loamy sand), and also more of clay than silt. It was also observed that there was an increase in the ratio of silt to clay particles with progression down the slope. These are shown in Figures 2 and 3 below.

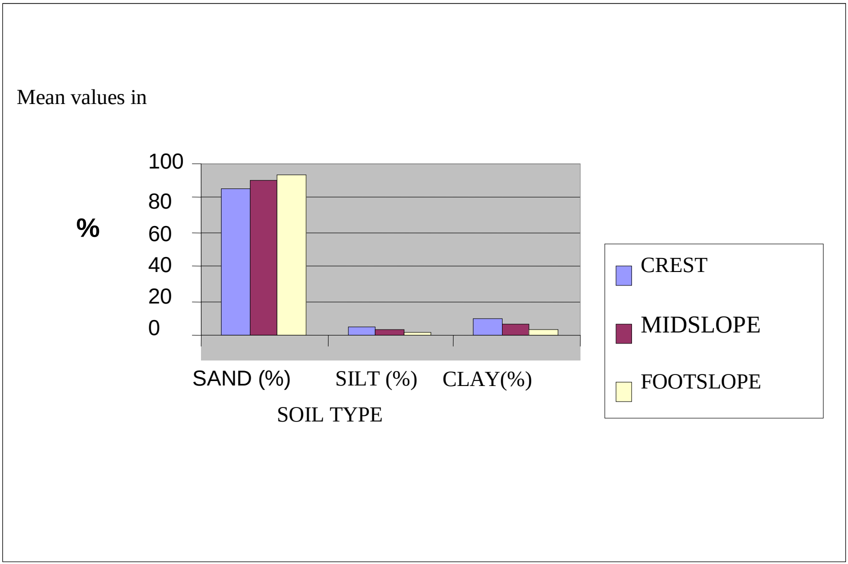

Figure 1: Particle size distribution in the study area

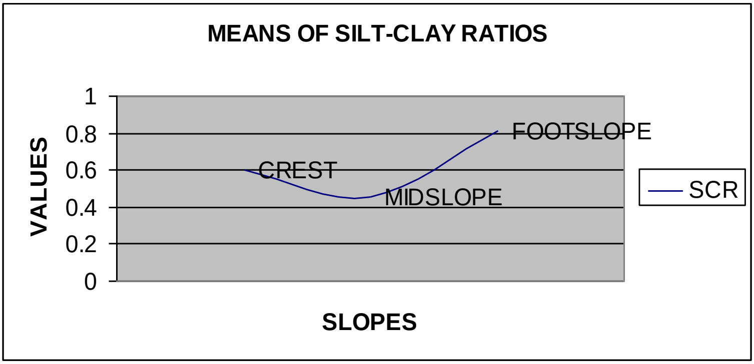

Figure 2: Ratio of sand particles to silt particles

The distribution of organic carbon in the watershed indicates a steady decrease from the crest to the footslope. It was noticed that the crest has about twice the amount of organic carbon found at the mid and footslope. This suggests that there may be more biological activity occurring at the crest, and also that the river plays a vital role in the availability of organic carbon in the soil. The spatial variation of organic carbon at 0 – 15 depths were from 0.177% to 1.734% from the top, down.

Besides, subsurface soils were seen to have generally lesser organic carbon than surface soils, with values ranging from 0.118 – 0.722 towards the surface and 0.723 – 1.337 as the depth increases.

The soils around the Otamiri river watershed are generally strongly acidic, with a pH range from 4.7 to 5.62. The leaching of aluminum along partly causes this high pH by the release of hydrogen ions into the soil. The middle horizons of soil profiles, however, tend to show more acidity than other profiles.

Since the study area comprises mainly sand which is highly permeable, there tends to be easy passage of air and water carrying acid cations thus increasing the pH of the subsurface soils. Thus, the subsoil exhibits more acidity with soils having a pH of as low as 4.67 for depths of 15 – 30cm. This high pH is generally unsuitable for the growth of many kinds of crops, and needs treatment so as to reduce the soil's acidity.

The study area also showed unusual low values of total nitrogen. This could be as a result of the incapability of the soils to hold one another tightly, thus leading to the loss of nutrients through runoff. Low organic carbon could also be responsible for the low values of total nitrogen obtained at all slopes. This is because low organic carbon results from insufficient organic matter in soil, and thus little or no acting microbes. Nitrogen is one of the most important nutrients needed by crops. Its deficiency here makes the soil generally unfit for agricultural purposes. Figure 9 below shows the relative distribution of total nitrogen in soils in the study area; that total Nitrogen varies retrogressively from crest, midslope to footslope.

The distribution of available phosphorus in the watershed revealed that there is an increase in available phosphorus up slope, that is, the crest has more phosphorus available for use than the midslope, which in turn has more available phosphorus than the footslope. Generally the top-slope has almost optimum available phosphorus requirements, thus making that area advantageous for agricultural purposes than the other slopes.

It was observed that there was a steady decrease in aluminum and hydrogen ions down the slope. Thus, the areas closer the river has lesser acidic cations, and this increases up the slope. The relative abundance of exchangeable bases is in decreasing order of calcium, magnesium, sodium, and potassium. All the bases tend to decrease down slope, except for Sodium which displays no significant trend. Total exchangeable bases in the area shows that Calcium presented higher values at crest, midslope and footslope than Mg, Na and K respectively.

The ECEC was categorized into surface ECEC and subsurface ECEC. The ECEC of soils in Otamiri River watershed is generally low, however with surface soils showing higher values than subsurface soils. The curve in the trend of variability of the effective cation exchange capacity of the soil in the study area shows that both the crest and the footslope have higher values of ECEC than the midslope. This could be due to the higher values of pH recorded at both crest and the footslope. The spatial variation of ECEC at 0 – 15 cm showed that both the crest and footslope soils contain more values of ECEC than the midslope soils. This could be as a result of soils leaching at the top of the slope and going down to its foot through natural means. The study also indicate that ECEC at 15 – 30 cm depth varied between 0.534 – 4.274 meq/100g progressively between the crest, midslope and footslope

Table 4: Chi square values showing soil fertility level

SOIL PPTY	UNIT	OBS VALUE	EXP VALUE	OBS - EXP	$(Oi – Ei)^2$	$(Oi – Ei)^2$ / Ei
Total Nitrogen	%	0.029	0.1	-0.071	0.005	0.05
Av. Phosphorus	Ppm	14.45	25	-10.55	111.3025	4.4521
Potassium	meq/100g	0.0012	0.25	-0.2488	0.0619	0.2476
pH		5.13	6.5	-1.37	1.8769	0.2888
Organic Carbon	%	0.821	1.5	-0.679	0.4611	0.3074
Ca / Mg ratio		2.75	3	-0.25	0.0625	0.0208
TOTAL						**5.3667**

From above, $\chi 2_{calc}$ = 5.3667 and $_{tab}\ \chi 2$ = 11.070, thus since, $X_{calc} < X_{tab}$, the null hypothesis is accepted, meaning that, soils in the area are infertile.

Conclusion

The following findings were made based on analysis of results obtained. Firstly, results of the particle size distribution test showed that the area is predominantly sandy (values ± 98.7%), and clay particles having more occurrence than silt particles. The soil is characteristically loose, thus allowing penetration of air and water, prone to erosion due to their looseness and usually low in nutrient status. Secondly, the value of organic matter content in the soil was generally low, showing a decreasing trend in organic carbon content from the slope down to the river. Thirdly, the pH of the soil recorded was generally, strongly acidic. Fourthly, total nitrogen (%) values were observed to be very low, and this could be as a result of the washing away of the top layer of the soil by overland flow into the river. Finally, the overall soil region in the study area is infertile for agricultural use.

The results showed that soil of the area comprise very low values of relatively important qualities that influence its fertility. According to Treloges and Chuasavathi [2002] the appropriate soil management and conservation technique here would imply steady monitoring of the study area to avoid the impacts of external factors, which would further deteriorate the fertility of the soil. Following, therefore, the Otamiri River watershed should be delineated into areas to be used for agricultural purposes, as distinct from areas used for other activities such as construction and quarrying, while fertilizers and organic manure should be used to regenerate the soil for agricultural purposes.

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