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Variability of soil properties related to vegetation cover in a tropical rainforest landscape

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The variability of soil properties related to vegetation cover in Nnewi, a fast growing urban-industrial town, was studied to underscore the factors that predispose the soil to erosion menace. Twelve soil samples were purposively collected and analyzed to determine the soil properties. The results of soil properties analysis showed marked coefficient of variability ranging from low, moderate, high and very high variability for the physical, chemical and biological properties of the soil. This is as a result of poor vegetation cover associated with land use pattern. Positive and negative correlation coefficients were established within and between soil properties and vegetation cover. Principal components analysis identified soil organic matter content, soil moisture content, sand content of the soil, soil micro-organisms and cation exchange capacity as the main soil properties that explain 91.2% of the impact of vegetation cover on variability of soil properties. It is therefore advised that strict adherence to land use plans be enforced to reverse the trend towards unstable soil properties and high susceptibility of the soil to erosion menace in Nnewi.

Key words: Erosion, land use, soil properties, variability, vegetation cover.

INTRODUCTION

The soil of Nnewi, in Anambra state of Nigeria, is derived from the sedimentary rocks of middle cretaceous to lower tertiary age and is of ferralitic type, (Jungerius et al., 1964). Although it is rich in free iron, its low mineral reserve and deep porous red colour conveys an illusion of homogeneity of its properties across the town.

The objective of this study was therefore to examine if there is any significant variability between some selected soil properties and to relate them to differences in vegetation cover resulting from different land use types in this fast growing urban-industrial town.

Studies on the variability of soil properties have, over time, been related to myriad of factors such as land use (Crocker and Major, 1955; Langley-Turnbaugh and Keirstead, 2005; Eden et al., 1991; Amusan et al., 2001), slope disposition (Dowling et al., 1986; Riha et al., 1986; Huang et al., 2001), wetlands (Bruland and Richardson, 2005), and field crops (Cox et al., 1998). All the same, the relationship between soil and vegetation has generally continues to attract academic discourse from the 1950s to the present (Clayton, 1958; Wilde, 1958; Langdale- Brown, 1968; Trudgill, 1977; Eyre, 1968; Adejuwon and Ekanade, 1984; and Okeke, 2003).

However, the role of soil properties especially some aggregating agents on soil stability in Southeastern Nigeria studied by Igwe et al. (1995) indicated that organic matter and carbonates play minor roles while Fe and Al oxides play the most important clay aggregating roles in these soils. In a region of fragile and weakly consolidated sedimentary rocks such as Nnewi, the soils are less resistant to erosion and require effective cover of vegetation to enhance its stability. Where the vegetation is disturbed by human activity in exposing the soil, the soil properties and its aggregating agents, which ensure stability, are most likely to be altered as a result of direct impact of rainfall through infiltration and erosion. The consequence is therefore a predisposition and high susceptibility of the soil to erosion. In other words, land cover is a pre-requisite for the sustenance of soil properties and invariably acts as a stability and resistance to soil erosion as envisaged in the study area. The paper aims to underline if variations in soil properties, due to anthropogenic alteration of land cover, have in anyway contributed to observed soil erosion

Abbreviations: CEC, Cation exchange capacity; **N,** soil total nitrogen; **C,** soil total carbon; **O.M,** soil organic matter content; **P,** available phosphorus; **Kc,** soil potassium content; **CV,** coefficient of variability; **PCA,** principal components analysis.

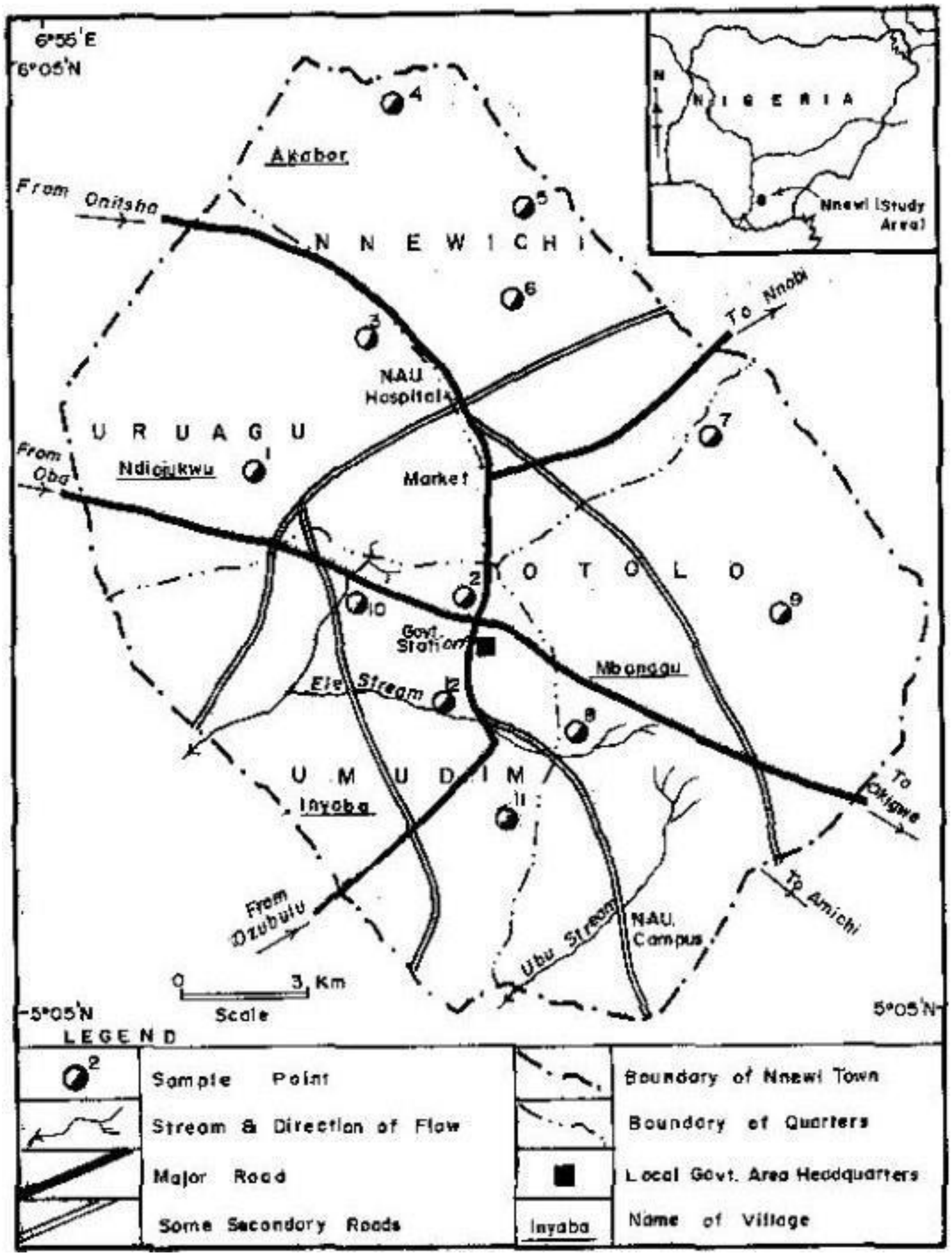

Figure 1. Map of Nnewi showing the soil sample points.

menace in Nnewi town in Anambra state of Nigeria.

The study area

The present study area, Nnewi, lies about 25 km south of Onitsha in Anambra state of Nigeria. It is located between latitudes 5° 05’N and 6° 05’N and longitudes 6° 55’E and 7° 00’E, (Figure 1), covering a total area of 72.52 km^2. The study area is bounded in the north by Nnobi, south by Utuh, east by Amichi and west by Ojoto. The climate is hot wet equatorial type characterized by mean monthly maximum temperature of 34°C and minimum temperature of 24°C. Total annual rainfall is 1900 mm, with most of precipitations between March and November. This large amount of precipitation ensures the maintenance of the natural tropical rainforest vegetation of Nnewi that is now degraded by over 30 years of aggressive industrialization and urbanization processes in the town. However, remnants of the pristine vegetation species are still found in parts typified by *Afzelia africana, Khaya grandifolia, Lophira alata, Antiaris africana, Ceiba pentandra, Millicia excelsa, Detarium macrocarpum, Elaeis guineensis* and *Brachystegia enguma.*

Land use within the town is not orderly and varies between residential, commercial, industrial and agricultural types with each type dominating according to the perceived interest of the landowners. The land use type has obvious implications on the vegetation cover within and around its area of influence and could affect the soil properties as envisaged in this study. Starting with a given population of Nnewi of 121,065 (NPC, 1991) and growing annually at a rate of 3%, the projected population in 2006 of approximately 188,861 exerted pressure on the vegetation cover exemplified by deforestation as demand for space increases in the face of competing needs.

MATERIALS AND METHODS

Field Techniques

The study area, Nnewi, has four major quarters namely Otolo, Umudim, Uruagu and Nnewichi. Three soil samples were purposively selected from each quarter for examination of vegetation cover, floristic composition and collection of soil samples at a depth of 0-30 cm. The samples were collected from areas of vegetation cover categorized as dense cover, moderate cover, light cover and no vegetation cover and the dominant land use of the sites were noted. At each sample site, soil samples were taken from locations that are 50 m apart and later bulked together in order to ensure adequate representation of each site. In determining sample selection, adequate care was taken to accommodate the inherent variability of soil materials, since insignificant spatial variability often exist over small areas. The bulking procedure for the soil samples was standardized by ensuring that samples collected were of equal volume. The enumeration of floristics was according to Hutchinson and Dalziel (1972) which described the flora of West Tropical Africa.

Laboratory analysis

The soil analysis was conducted at the Soil Science laboratory of the University of Nigeria, Nsukka in August 2005 to determine the following soil properties: particle size composition (sand, silt and clay), soil moisture content (moist), soil load of micro-organisms (Mco), soil total carbon (C), soil total nitrogen (N), soil pH, soil organic matter content (O.M.), available phosphorus (P), CEC, and soil potassium content (Kc). Soil particle size composition of the <2 mm sample was determined by the hydrometer method according to Gee and Bauder (1986). The soil pH was measured in 1:2 suspension of soil in 0.1 m Kcl using the pH meter. Soil organic carbon was determined by the Walkley and Black (1934) method as modified by Allison (1965), while soil organic matter content was determined by multiplying the value of soil organic carbon by Van Barnmelen factor of 1.724. Exchangeable potassium was measured by atomic absorption spectrophotometer; available phosphorus was determined by using the Bray and Kurtz (1945) No. 1 method as modified by Jackson (1964), while soil nitrogen content was determined by the macro Kjeldahl's method as described by Bremner (1965). Soil moisture was determined by saturating the soils and expressing moisture content at field capacity as a percentage of the oven-dried soil. CEC was determined by the summation method of Chapman (1965).

Soil microbial load was determined in cfu/gm at the Microbiology laboratory of the University of Nigeria, Nsukka. The samples (1gm each) were shaken for one hour in ten millilitre of sterile saline (0.95% w/v NaCl) at 150 rpm. 10-fold dilution of samples was then carried out with sterile saline. Enumeration of the total bacterial load of the soil samples was carried out by plating (pour-plating) of 0.1 ml of the appropriate soil dilution on nutrient agar plates. Inoculated plates were incubated for 24 h at 30°C and microbial load was determined as colony forming units (cfu/gm) in each sample.

RESULTS AND DISCUSSION

The results of the laboratory analysis of soil properties in Nnewi are presented in Table 1 which also shows the mean value, standard deviation and coefficient of variability of each soil property and vegetation cover. The vegetation cover was categorized into 4 groups ranging from No vegetation (1); Light vegetation cover (2); and Moderate vegetation cover (3), to Dense vegetation cover (4) as observed in the field with reference to land use.

In order to compare the variability of the soil properties among themselves across the study area, the coefficient of variability (CV) was used and the result was further categorized into four classes in a modified version after Aweto (1982). Less than 20% CV is regarded as low variability; between 21 and 50% CV is regarded as moderate variability; while between 51 and 100% CV is regarded as high variability. Any CV above 100% is regarded as very high variability.

The physical properties of the soil varied enormously from low CV for sand (6.19%), moderate for clay (40.54%) and very high for silt and soil moisture having CV of 121.36 and 300.30%, respectively. The very high variability for silt and soil moisture can be deduced from Table 1 where the proportion of silt and soil moisture ranged from 1.0 to 11.0 and from 0.40 to 96.85, respectively, across the study area. The very high variability for soil moisture is not surprising, due to the fact that one of the sample sites, Umudinsi is in a valley drained by Ele stream.

The soil chemical properties across the study area showed considerable variation for each element. Whereas CEC and pH have low CV of 10.10 and 16.17%, respectively, soil N varied moderately at 48.17%. High CVs were recorded for C, O.M., Kc and P as 53.87, 53.56, 82.41 and 68.56%, respectively. No soil chemical property recorded very high variability.

The only measured biological property was soil load of micro-organisms which showed very high CV of 123.50% across the study area. The proportion of soil load of micro-organisms ranged from 8 cfu/gm in Obi Umudim to 6170 cfu/gm in Okpunoeze. It is indicative of the variability in the physiological requirements of the different soil micro-organisms in the soil of the study area as

Table 1. Soil Properties and Vegetation categories obtained from the field.

S/No.	Locations	Sand	Silt	Clay	Moist	Mco	C	N	O.M	CEC	Kc	P	pH	Veg.
X1	Ndi Ojukwu	93.00	1.00	6.00	1.22	230.00	1.75	0.070	3.02	19.60	0.07	150.80	5.10	4.00
X2	Ememono	93.00	1.00	6.00	1.01	2170.00	0.64	0.028	1.10	20.40	0.05	57.10	5.20	1.00
X3	Okpunoeze	91.00	1.00	8.00	0.60	6170.00	0.81	0.070	1.40	19.60	0.10	77.40	5.80	2.00
X4	Obiofia	89.00	1.00	10.00	0.40	2460.00	1.62	0.112	2.79	22.80	0.11	65.20	5.00	3.00
X5	Okpunoeze Abuo	83.00	1.00	16.00	0.40	432.00	0.68	0.056	1.17	18.40	0.14	16.30	5.10	3.00
X6	Abubo	81.00	1.00	18.00	0.81	410.00	0.38	0.042	0.66	21.60	0.45	36.70	5.40	2.00
X7	Ogwugwu	89.00	3.00	8.00	0.81	530.00	2.22	0.098	3.83	23.60	0.12	53.00	4.50	2.00
X8	Obiuno	87.00	1.00	12.00	0.40	30.00	1.49	0.070	2.57	17.60	0.12	32.60	3.90	2.00
X9	Ebenator	83.00	3.00	14.00	0.60	8130.00	1.45	0.112	2.50	21.60	0.07	81.50	5.30	4.00
X10	Obi-Umudim	79.00	1.00	20.00	0.40	8.00	0.38	0.028	0.66	20.00	0.03	12.30	3.00	2.00
X11	Mbanagu	77.00	3.00	20.00	3.73	83.00	0.94	0.042	1.62	24.00	0.13	130.40	4.80	3.00
X12	Umudinsi	81.00	11.00	8.00	96.85	5610.00	1.58	0.112	2.27	19.20	0.28	154.90	4.90	4.00
Mean(X)		84.82	2.45	12.73	9.64	2366.64	1.11	0.070	1.87	20.80	0.15	65.22	4.81	2.55
Std Dev.		5.25	2.98	5.16	28.94	2922.86	0.60	0.034	1.00	2.10	0.12	44.71	0.78	0.93
C. Var.		6.19	121.36	40.54	300.30	123.50	53.87	48.17	53.56	10.10	82.41	68.56	16.17	36.70

Source: Field work and laboratory analysis, 2005.

influenced by vegetation cover.

When the CV of mean values of the soil properties in different vegetation cover in the study area was computed as shown in Table 2, one could notice that only soil moisture recorded very high CV at 176.67%. Soil silt content, micro-organisms and available P recorded high CV of 77.18, 74.63 and 58.75%, respectively, while low CV was recorded for CEC and pH as 4.94 and 4.04%, respectively. Other soil properties in Table 2 recorded moderate CV.

The result of these variability indices, obtained from the mean values of soil properties under different vegetation cover, was at variance with that obtained directly from the raw data shown in Table 1. This brings to limelight the loss of vital statistics when average values are computed and used for further analysis especially with reference to the raw data. For this reason, the next step was therefore to correlate the different soil properties with one another and the vegetation cover in order to establish the relationship among them.

Correlation and principal components analysis (PCA)

The results of the correlation analysis presented in Table 3 show that the soil properties and vegetation cover exhibit both negative and positive correlation of diverse magnitude. A high negative correlation was established between sand and clay content of the soils (-0.836) only and moderate negative correlation was obtained between sand content of soil and vegetation cover (-0.508) and clay content and C (-0.517). In a few instances, the correlation coefficients established were significantly and positively high especially for silt and soil moisture (0.951), silt and available P (0.777), Carbon content and soil O.M. (0.991), Carbon and N (0.835) and N and soil O.M. (0.801).

Moderate positive correlation was noticed between vegetation cover and soil silt content (0.621), micro-organisms (0.516), soil N (0.502), available P (0.566) and soil moisture (0.520). Elsewhere, moderate relationship was noticed between silt and N (0.502), available P and soil moisture (0.684), micro- organisms and N (0.593), available P (0.503), and soil pH (0.532).

The observed relationships from the correlation analysis were indicative of the intricate connections among the various soil properties and vegetation cover which can be hardly observed physically. To determine the over-arching influence of vegetation cover on the variability of these soil properties, PCA was applied with

Table 2. Mean Values of soil properties under different vegetation cover in Nnewi.

Variables	Soil properties	No veg. cover (1)	Light cover (2)	Moderate cover (3)	Dense cover (4)
X1	Sand	93.00	85.40	83.00	85.70
X2	Silt	1.00	1.40	2.00	5.00
X3	Clay	6.00	13.20	15.00	9.30
X4	Moist	1.01	0.64	1.15	32.89
X5	Micro.	2170.00	1430.00	992.00	4960.00
X6	C	0.64	1.06	1.08	1.59
X7	N	0.028	0.061	0.070	0.095
X8	O.M.	1.10	1.82	1.89	2.59
X9	CEC	20.40	20.48	18.40	20.13
X10	Kc	0.05	0.16	0.13	0.14
X11	P	57.10	42.40	70.93	9.40
X12	pH	5.20	5.40	4.90	5.10

Table 3. Soil properties – vegetation cover correlation matrix.

	Sand	Silt	Clay	Moist.	Micro.	C.	N	O.M.	CEC	Kc	P	pH	Vegetation
Sand	1.00												
Silt	-0.314	1.00											
Clay	-.0836	-0.258	1.00										
Moist	-0.957	0.256	-0.292	1.00									
Micro.	0.190	0.410	-0.431	0.361	1.00								
C	0.276	0.410	-0.431	0.259	0.593	1.00							
N	0.174	0.502	-0.467	0.404	0.593	0.835	1.00						
O.M	0.315	0.291	-0.489	0.130	0.181	0.991	0.801	1.00					
CEC	-0.109	-0.038	-0.234	-0.234	-0.808	0.276	0.142	0.319	1.00				
Kc	-0.335	0.311	0.373	0.373	-0.093	-0.130	0.028	-0.183	0.022	1.00			
P	-0.208	0.777	0.684	0.684	0.503	0.342	0.420	0.260	0.291	0.166	1.00		
pH	0.329	0.054	-0.366	0.042	0.532	-0.021	0.240	-0.028	0.154	0.326	0.353	1.00	
Veg.	-0.508	0.621	0.158	0.520	0.516	0.361	0.667	0.299	0.082	0.140	0.566	0.171	1.00

varimax rotation to do away with the problem of autocorrelation and reduce the contributing factors of soil property variation to orthogonal principal components. The result of the PCA is presented in Table 4.

Five principal components were extracted explaining 91.2% of observed variation in the soil vegetation data. Component I with high positive loading on carbon, Nitrogen and organic matter content of the soil has eigen value of 3.23 and explains 24.87% of the observed variation in the data set.

Table 4. Varimax rotated component loadings of soil – vegetation data set.

Variables	Components				
	I	II	III	IV	V
Sand	0.194	-0.320	0.919	0.060	-0.061
Silt	0.320	0.869	-0.130	0.247	-0.129
Clay	-0.382	-0.176	-0.860	-0.204	0.137
Moist	0.154	0.921	-0.013	0.192	-0.250
Micro.	0.148	0.155	0.172	0.910	-0.117
C	0.960	0.159	0.163	0.050	0.080
N	0.769	0.254	0.019	0.459	0.035
O.M.	0.965	0.014	0.170	0.021	0.106
CEC	0.346	-0.162	-0.210	0.008	0.807
Kc	-0.313	0.674	0.008	-0.144	0.466
P	0.263	0.617	-0.010	0.478	0.216
pH	-0.211	0.125	0.446	0.639	0.520
Veg.	0.354	0.382	-0.535	0.598	-0.028
Eigen value	3.233	2.875	2.234	2.200	1.317
% of var. explain	24.870	22.112	17.188	16.921	10.133
Cum. %	24.870	46.983	64.170	81.091	91.224

This component reflects soil richness in terms of its fertility as influenced by vegetation cover. Component II has positive loadings on two variables (silt and soil moisture) which accounts for additional 22.1% of observed variation in the data set. Component II is indicative of the soil erodibility. Component III has high loading on two variables only. It has high positive loading on sand content of soil (0.919) and high negative loading on clay content of soil (-0.860). This component explains additional 17.19% of observed variation in the raw data and together with component I and II explain a total of 64.17% of the variation in the variables. The implication of this component is that variations in the sand and clay content of soil in Nnewi are indirectly related according to the nature of the vegetation cover. This component therefore reflects soil susceptibility to erosion as a result of adequacy or lack of vegetation cover. Component IV explains 16.9% of the variation in the soil and vegetation data making the cumulative percentage of explained variation 81.1%. It has high loading on one variable, soil micro- organisms (0.910). This is indicative of the nature of the soil habitat for micro-organisms as influenced by vegetation cover. Component V has high loading on CEC (0.807) and contributes 10.13% to the total of 91.2% of the cumulative observed variation in the soil variation. This component is indicative of the soil absorption capacity of cat ions and nutrients based on the nature of vegetation cover.

Since the five indices of soil variability identified by PCA cannot be observed physically, the component defining variables (CDV) as representative of each index was used. The five CDV are soil organic matter content, soil moisture content, sand content of the soil, soil micro-organisms and soil CEC. In other words, the variations in these five indices of the soil are significantly related to the nature of the vegetation cover in the study area. This is not surprising given the nature of land use in the study area. This finding, although at variance with Aweto's (1982) result in Western Nigeria, agrees with the result obtained by Fearnside (1980) and Amusan et al. (2001). The result equally highlights the importance of vegetation cover towards the susceptibility of the soil to erosion, soil habitation by micro-organisms and recycling of nutrients within the ecosystem. For example, the emergence of sand as a significant soil variable is a testimony that the finer particles have been removed by sheet erosion in areas under inadequate cover of vegetation as reported elsewhere by Adejuwon and Ekanade (1984). Also, areas under dense vegetation cover are sure to have large population of soil micro-organisms to facilitate the decomposition of organic matter for soil enrichment. This translates to mean that poor vegetation cover are adversely impacted on soils through erosional and degradational processes that cause significant alteration in their physical and chemical properties as against areas under dense cover of vegetation. Areas under no vegetation cover in Nnewi are therefore at the risk of not only high susceptibility to soil erosion but also poor crop yield due to inadequate recycling of nutrients and lack of soil micro-organisms, that are the decomposing agents of the ecosystem.

The analysis of the spatial distribution of O.M. and CEC against vegetation cover in the study area by comparing their distribution diagrams (Figures 2 a, b and c) shows that variation is non-directional. Whereas the trend in variation increased from west to east for CEC, it was multi-directional for O.M. The distribution for O.M. showed peripheral concentration especially around Ndi

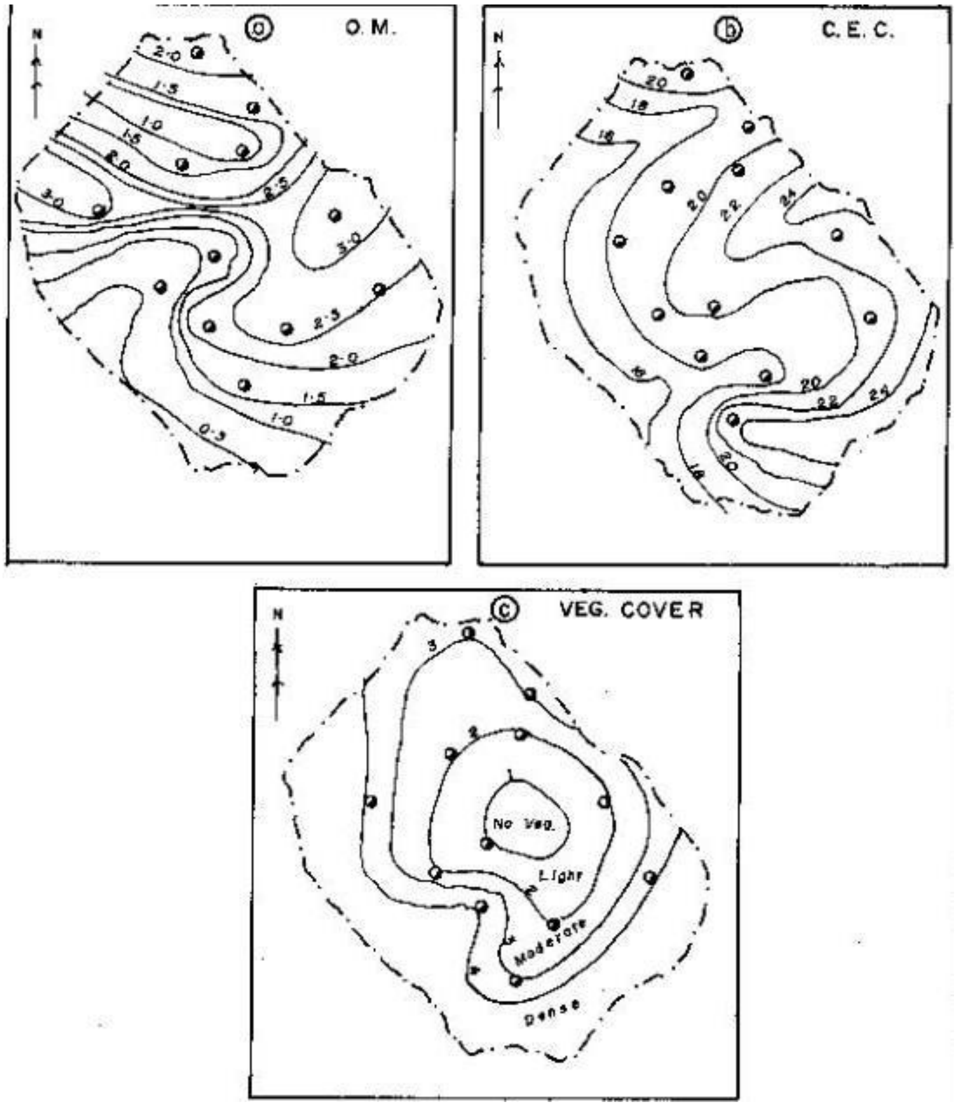

Figure 2. Spatial distribution of O.M, CEC and vegetation cover in Nnewi.

Ojukwu and Abubor which all had dense cover of vegetation while Ememono had the least amount of O.M., with no cover of vegetation at all. This is to be expected since there is no visible pattern of land use in the study area or any attempt to enforce existing plan by the Town Planning Authority (Onweluzo, 2005) . Consequently, variation in soil properties is found to be as stochastic as the nature of the vegetation cover which is determined by the prevailing land use in any given place. This results in the widespread nature of different types of soil erosion (sheet, rill and gully) in the study area which makes it difficult to design and/or undertake holistic preventive/ remedial measures.

Conclusion

This study has highlighted that in spite of the apparent homogeneity of soil origin, variations in the physical, chemical and biological properties are largely influenced by the nature of the vegetation cover. The soil properties most affected by variations in vegetation cover are sand content of the soil, soil moisture content, soil micro-organisms, soil organic matter content and soil cation exchange capacity (CEC). The implication of the finding is that the soil of the area is pre-disposed or susceptible to erosion as the vegetation cover is lost. The explanation could be that nutrient cycling declines through weak CEC following reduction in soil microbial activities that generate humus, a binding/aggregating agent in the soil, crop yield declines and the soil becomes highly susceptible to erosion. Contrary to the findings of Igwe et al. (1995), O.M. plays a significant role in aggregating the soil particles here and makes it more resistant to soil erosion. If vegetation cover continues to be depleted to the detriment of O.M. and CEC, Nnewi as a town will be undergoing a directional trend towards irreversible erosion menace unless the present land use pattern is checked.

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