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CHARACTERIZATION AND COMPARATIVE SOIL QUALITY ASSESSMENT OF SINKHOLE DEGRADED LAND, RESTORED LAND AND FORESTED UNDISTURBED LAND

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The study investigated the soil quality as well as characterization of a sinkhole degraded land, soil-filled restored land and a forested undisturbed land which served as control. Target sampling technique guided field studies. A profile pit was dug in each identified area except the sinkhole where its bank was scrapped to reveal fresh soils which were described using FAO guidelines. Soil samples were air dried and sieved for standard laboratory analysis. Data obtained were subjected to coefficient of variation and land degradation index (LDI). The results showed that the soils colour ranged from hue of 5YR and 10YR with chroma ≥3. The texture ranged from sandy clay loam in the sinkhole degraded and forested lands to clay (≥432g/kg) in the restored land. The structure ranged from weak, fine to strong massive angular blocky as depth increases. The soil pH (KCl) were slightly acidic (4.13 -4.31) and showed low variation (22.2%). The land degradation index (LDI) showed that the restored land (38.2-146.6) had higher appreciation in all soil chemical properties evaluated when compared with the forested soil (0) and sinkhole degraded soils (-1.4 – -46.0). The sinkhole soils were classified as Lithic Dystrudepts (Soil Taxonomy) and Technic Cambisol (World Reference Base). Restored land was classified as Typic Hapluderts (Soil Taxonomy) and Technic Vertisol (World Reference Base) while the forested soil was classified as Arenic Kandiudults (Soil Taxonomy) and Arenic Nitisol (World Reference Base). The restored land showed hastened resilience in regaining its lost quality through the soil filling method, hence recommended.

Key words: *Sinkhole, land degradation, land restoration, soil quality, soil characterization.*

Ernest C.I., Okafor M.J., Okoye A.I. Характеристика та порівняльна оцінка якості карстового деградованого ґрунту, відновленого та лісового ґрунту з непорушеною структурою

Е статті досліджено якість ґрунту, а також надано характеристику карстового деградованого ґрунту, заповненого відновленого ґрунту та лісового ґрунту з непорушеною структурою, які виступили е ролі зразка. Цільова методика вибірки визначила напрямок досліджень. Розріз був зроблений на кожному з вказаних ґрунтів, за винятком карстової вирви, де було взято зразок, щоб виявити свіжі ґрунти, які були описані згідно з рекомендаціями ФАО. Зразки ґрунту висушили повітрям і просіяли для стандартного лабораторного аналізу. Отримані дані трансформували у коефіцієнт варіації та індекс деградації земель (ІДЗ). Результати показали, що колір ґрунту коливався від відтінку 5YR та 10YR з насиченістю кольору ≥3. Текстура змінювалась від піщано-глинистих суглинок у деградованих і лісових ґрунтах до глинистих (≥432 г/кг) на відновлених ґрунтах. Структура змінювалась від слабкої, дрібної до сильної, масивної нерівно-глибистої через збільшення глибини. Рівень pH ґрунту (ОДК) був трохи кислим (4.13 -4.31) і показав низьку варіацію (22,2%). Індекс деградації ґрунтів (ІДЗ) показав, що відновлені ґрунти (38,2-146,6) мають вищу оцінку по всім хімічним властивостям ґрунту, порівняно з лісовим ґрунтом (0) та карстовими деградованими ґрунтами (-1,4 – -46,0). Карстові ґрунти були класифіковані як Lithic Dystrudepts (таксономія ґрунту) та Technic Cambisol (світова реферативна база), у той час як відновлений ґрунт як Typic Hapluderts (таксономія ґрунтів) та Technic Vertisol (світова реферативна база), а лісовий ґрунт як Arenic Kandiudults (таксономія ґрунтів) та Arenic Nitisol (світова реферативна база). Відновлений ґрунт показав стійкість у відновленні втраченої якості за допомогою способу заповнення ґрунту, який рекомендується до застосування.

Ключові слова: *Карстова вирва, деградований ґрунт, відновлений ґрунту, якість ґрунту, характеристика ґрунту.*

Ernest C.I., Okafor M.J., Okoye A.I. Характеристика и сравнительная оценка качества карстовой деградированной почвы, восстановленной почвы и лесной почвы с ненарушенной структурой

В статье исследовано качество почвы, а также охарактеризована карстовая деградированная почва, заполненная восстановленная и лесная почва с ненарушенной структурой, которые выступили в роли образца. Целевая методика выборки определила направление исследований. Разрез был сделан на каждой из указанных почв, за исключением карстовой воронки, где был взят образец, чтобы выявить свежие почвы, которые были описаны согласно рекомендациям ФАО. Образцы почвы высушили воздухом и просеяли для стандартного лабораторного анализа. Полученные данные трансформировали в коэффициент вариации и индекс деградации почв (ИДП). Результаты показали, что цвет почвы колебался от оттенка 5YR и 10YR с насыщенностью цвета ≥3. Текстура менялась от песчано-иловатых суглинок в деградированных и лесных почвах до глинистых (≥432 г/кг) на восстановленных почвах. Структура менялась от слабой, мелкой к сильной, массивной неровно-глыбистой из-за увеличения глубины. Уровень pH почвы (ОДК) был немного кислым (4,13 – 4,31) и показал низкую вариацию (22,2%). Индекс деградации почв (ИДП) показал, что восстановленные почвы (38,2-146,6) имеют высшую оценку по всем химическим свойствам почвы по сравнению с лесной почвой (0) и карстовыми деградированными почвами (-1,4 – -46,0). Карстовые грунты были классифицированы как Lithic Dystrudepts (таксономия почвы) и Technic Cambisol (мировая реферативная база), в то время как восстановленную почву классифицировали как Typic Hapluderts (таксономия почв) и Technic Vertisol (мировая реферативная база), а лесную как Arenic Kandiudults (таксономия почв) и Arenic Nitisol (мировая реферативная база). Восстановленная почва показала устойчивость в восстановлении утраченных качеств с помощью способа заполнения почвы, который рекомендуется к применению.

Ключевые слова: *Карстовая воронка, деградированная почва, восстановленная почвы, качество почвы, характеристика почвы.*

Introduction

Environmental quality is an important direct and indirect determinant of soil health. Deteriorating environmental condition is a major contributory factor to poor soil quality [15]. Environmental disasters especially sinkholes are often neglected wreck havoc to communities by gradually and constantly dissecting the landscape. Sinkhole is a depression in the ground caused by collapse of surface layer which vary in size from 1-600m both in diameter and depth [10]. The formation of sinkholes involves natural process such as erosion, suffusion, collapse of cave roof or lowering of water table [5]. Human induced sinkholes popularly referred to as artificial sinkholes result through activities such as drilling, mining, construction, broken water or drain pipes, improperly compacted soil after excavation work.

In Nigeria, most sinkholes are formed due to change in land surface activated by intensive quarrying or sand mining. Searching, locating and extracting materials used for construction activities pose some problems to the environment which normally result in the damaging of the immediate environment and atmosphere [19]. Quarrying carried out excessively without considering the impact on the environment most likely leads to over-exploitation of soil leaving deep pits (sinkholes) on bare ground while rivers are widening daily. Soil mining has become a daily sight with tipper trucks carrying pit sand, river sand and gravel from rivers and open fields. Deep and wide pits are left when pit sand and gravel are collected, riverbeds widen and deepen after removing river sand, affecting aquatic while gravel removal destroy ecosystems, forests and agricultural land [12].

P. Bagchi exposed illegal sand mining going on in India, mostly done on rivers [1]. The environmental impacts noted were changes in fluvial morphology, deep tunnels on river beds and increase in velocity of flowing water resulting in erosion on river banks. In some cases there is depletion of water resources leading to food shortages and hardships for people. The obvious potential negative effects of soil extraction are that habitats are lost, together with the species that they support [3]. They can be lost through direct removal by excavation, or indirectly through some of the environmental impacts [14].

P. Lawal noted that sand mining in Nigeria is rapidly becoming an ecological problem as demand for gravel and sand increases [11]. The resources are used in construction of strong structures which improves the socio economic lives of most Nigerians though with notable negative environmental impacts through formation of induced sinkholes.

Materials and Methods

The study was conducted in Aboh-Mbaise local government of Imo State, located in the southeast region of Nigeria and lies between latitudes $5^0 27^1$N, and longitude $7^0 14^1$E. The land area covers over 184 km^2 with a population of 195,652. The major parent material of the study area is the coastal sands and flood plains (Benin formation and deltaic deposits) and marine deposits. The study area lies within the humid tropics. The mean temperature range is from $26\text{-}29^0$C. The relative humidity is high throughout the year especially in rainy season averaging 85%. The mean annual rainfall over years ranges from 2500-3000mm which is attributed within a 9 month period which starts from March and ends September, while the dry season is from November to February [18]. The natural vegetation of the study area is tropical rainforest. The plant species are arranged in tiers with the forest floor harbouring a great category of sun heating species. The rain forest is highly depleted of plant species due to anthropogenic activities.

Field Studies

A reconnaissance visit was carried out with the aid of a location map of the study area to identify the areas to be studied. Target sampling technique guided field studies. A sinkhole degraded land of about 5m in depth and 25m wide, 8 year old restored land (soil-filled sinkhole) and an undisturbed secondary forest were identified. A profile pit was dug in each identified area except the sinkhole where its bank was scrapped to reveal fresh soils. Samples were collected from the bottom to the top according to horizon differentiation and described using FAO (2006) procedures. Identifiable morphological characteristics were determined for each profile. These will include: profile depth, depth of individual horizons, root-room system, drainage, texture, structure, colour, consistence, presence or absence of clay skins. Soil samples were air-dried, crushed, sieved using 2-mm sieve and analyzed in the laboratory.

Laboratory Analysis

Soil samples were collected and tested for some physical and chemical properties using standard laboratory procedures. Core soil samples were also collected from each study site to determine bulk density using the Grossman and Reinsch method [8]. Particle size distribution was determined by hydrometer method according to the procedure of [7]. Organic carbon was determined using wet oxidation method described by [22; 16]. Exchangeable bases (magnesium, calcium, sodium and potassium). Exchangeable Na and K were extracted using 1N NH4OAc using flame photometer [9], while Ca and Mg were determined using ethelene diamine tetracetic acid (EDTA) [21]. Exchangeable acidity was determined titrimetrically [13]. Effective cation exchange capacity (ECEC) was calculated from the summation of all exchangeable bases and exchangeable acidity [20]. Percentage base saturation (%BS) was determined by computation.

Soil Classification

Based on the results obtained from the laboratory analysis and field morphological properties, the soils were classified according to soil taxonomy (Soil Survey Staff, 2014), and correlated with world reference base (2014).

Land degradation determination

Status of land degradation was computed from results of laboratory analyses of samples from the sinkhole degraded land, restored land and compared with forest undisturbed soils, using the land degradation index [2]. The LDI is given as follows:

$$\text{LDI}=\left\{\frac{D}{ND}x100\%\right\}-100 \quad Egn$$

Where:

LDI = Land degradation index

D = Value of soil parameter from the sinkhole and restored land

ND = Value of soil parameter in the forest plot

100% = Percentage grade

100 = Constant representing ideal soil state

Statistical Analysis

Data collected from the study site were subjected to summary statistics. Also, Coefficient of variation (CV) was used to estimate the degree of variability existing among soil properties in the study site. Coefficient of variation is ranked as follows; low variation ≤ 15%, moderate variation 15%≤ 35% and high variability >35% [23].

Results and Discussion

Soils studied were characterised with reddish brown, weak red, red, yellowish brown and yellowish red of hue 5YR and 10YR respectively. The surface soils of all areas studied showed brown colour except in the sinkhole with dark red. The colours observed could be attributed to soil darkening by organic matter while that of sinkhole was due to the exposure of sub surface soils by mining activities. The subsurface soils of the areas studied showed red to yellowish red pigments which indicates high amount of iron oxide which may be due to the parent material and intense rainfall associated with the area. The structure of the soils studied ranged between weak, fine to massive, strong angular blocky structure. The soils also showed friable-firm consistence in all soils studied except in the restored land where all soil layers were firm and massive due to compaction from soil filling and high clay content. The soils of the study area were well drained and the presence of root decreased as soil depth increased. Sand played a significant role in the particle size distribution of the soils studied having high content except in restored land. However clay content was significant with the textural class of the soils studied identified as sandy clay loam, sandy clay, sandy loam, loamy sand and clay. Although soils of the sinkhole had higher sand content in all horizons (558.0-648.0 g/kg), sand and clay were irregularly distributed while silt content (80 g/kg) was static in all horizons. The forest soil recorded very high sand content (828 g/kg) at the epipedon and decreased irregularly with depth increase. The clay and silt contents were inversely distributed as clay content increased, silt content decreased as soil depth increased. Soils of the forest area were categorised as loamy sand at the epipedon and sandy clay loam in subsequent sub surface horizons. Soils of restored land were dominated by clay (432.0-632.0 g/kg) which increased as depth increased while sand (168.0-328.0 g/kg) and silt (120.0-30.0 g/kg) were not significant in the particle size distribution of the area and was classified as clay. Soil information on previous activities of the area indicated that the area was once excavated and refilled with sub soil which explains the high clay content of the soils of the area. The bulk density of all soils studied showed an indication of the predominance of mineral soil component as it ranged between 1.19-1.50g/cm3. Soils of the restored land recorded the highest due to subsoil filling of the area and compaction while and forest soils recorded the least. Sinkhole recorded high bulk density due to compaction resulting from heavy duty trucks which could lead to poor movement of water and air, lodging and rotting of plant root, reduce crop emergence, impede root growth and limits soil exploration by roots. High bulk density in the subsurface horizons could be attributed to clay migration and filling of poor spaces while the lower bulk density on the top soil was due to organic matter content. The average soil porosity of all soils studied ranged between 43.4-56.2%. Porosity increased at the epipedon of all soils studied due to the presence of organic matter and increased soil specific surface area. There were decline of porosity as depth increased. Soils of the forest area had the highest porosity due to the high percentage of sand while the restored land had the least porosity due to high clay content and compaction due soil filling. Soils of the sinkhole also recorded low porosity resulted from anthropogenic activities which lead to top soil removal, compaction and surface sealing. The moisture content of the soils studied varied between 21.53-24.16%. This is an indication of the dry moisture status of the soil and dry surface humidity at the time of sample collection. However, the restored land recorded more moisture at the epipedon due the high tenacity to which clay bind moisture. Soils of all areas studied showed strongly acidic reaction which ranged between 5.33-5.49 in H_20 and 4.31-4.13 1N KCl. Acidic soil reaction in the areas studied indicates the dominance of Al3+ and H+ ions in the soil exchange complex. Low acidity recorded in soils of sinkhole and forest could be attributed to leaching of basic cations out of the soil solum and corresponding increase in H+ ions on the exchange sites, while the restored land could be as a result of formation of carbonic acid through CO_2 released by roots and micro organisms. Soils of the forest area recorded high organic matter value at the epipedon which decreased gradually as horizon increased. The high organic matter recorded at the epipedon was due to the forested nature and high litter fall associated with the area. Restored land recorded very high organic matter values which ranged between 2.52-6.01%, which were irregularly distributed within the soil profile. High organic matter recorded in restored land could be attributed to the high clay of the soil which reduced leaching and tightly held organic matter to its colloid due to its high specific surface area. Others were due to the densely populated grasses and tree canopies which increased litter fall and inhibited direct impact of sun rays thereby slowing decomposition and mineralization of organic matter. Sinkhole also recorded an irregular distribution of organic matter with the top soil having organic matter value of 1.41%. Low organic matter recorded at the epipedon of sinkhole soils was as a result of mining and excavation activities, hence the removal of the surface soil. The total nitrogen levels observed in all soils studied were low which ranged between 0.11-0.15%. Although, top soil recorded higher N values compared to subsequent horizons. The low N may be attributed to the sandy texture of the soils and resultant high mineralization and leaching through the soil profile. In soils of the restored land with high clay content and organic matter, loss of N could be attributed to the extreme competition between the soil micro organisms for the limited amount of soil N. These micro organisms not only compete between themselves for N, but also against crops. More so, recalcitrant organic residues may be difficult to decompose organic N, these include cellulose, lignin, oils, fat and resins. The amines and amino acids released by the process of aminization during the N mineralization process could be tied up to clays. Soils of sinkhole recorded available P values which was moderate at the epipedon (5.00ppm), which decreased irregularly. The restored land had available P values which were very low and were irregularly distributed. Low available P observed in all soils studied could be attributed to the acidic nature of the soil as P may be chemically bounded as phosphates of Fe and Al. Other reasons include low organic matter and the nature of the parent material which encouraged mobility of P and disposed them to leaching in the forest area. The sinkhole recorded a very low, irregular distribution of calcium which ranged between 1.26-4.12 cmol/kg. Forest area recorded the reverse where calcium content decreased as depth increased with minimum and maximum values of 1-10 and 3.40cmol/kg respectively. Restored land recorded the highest value (4.82 cmol/kg) while forest area recorded the least (1.10 cmol/g).

The exchangeable bases were higher in the epipedon than other horizons in all soils studied except in sinkhole. The accumulation of organic matter at the soil surface could have led to the increase in exchangeable bases recorded at the epipedon. Decrease in organic matter within the profile led to the decrease of basic cations. However, the irregular distribution of the basic cations within the profile was due to illuviation of these basic cations in the lower horizons. Also the acidic nature of the soils studied could have displaced the basic cations and replacement with Al and Mn.

Table 1

Mean Values of Selected Soil Physical Properties

Land Type		**Sand** →	**Silt g/kg**	**Clay**	**Textural Class**	**MC (%)**	**BD g/cm^3**	**Porosity (%)**
Sinkhole		610.0	80.0	304.0	SCL	24.16	1.19	55.1
Restored Land		248.0	227.0	525.0	C	21.53	1.50	43.4
Forest/Control		692.0	60.0	265.6	SCL	23.60	1.16	56.2
CV (%)		45.7	74.5	38.4		6.0	14.7	13.8

B.D= Bulk density, Texture: SL=Sandy loam, SCL= Sand Clay Loam., S=Sand, MC=Moisture content

Exchangeable acidity values observed in all soils studied were very high above the critical value of 2.0 cmol/kg. This is an indication that soils of the study area were strongly acidic which may affect sensitive crops. The Al3+ ions and H+ ions which make up the exchangeable acidity were irregularly distributed within all profiles studied. Soils of sinkhole recorded the highest exchangeable acidity values which ranged between 1.2-3.5cmol/kg. This was followed by the forest area (1.30-2.90 cmol/kg) and restored land (1.2-2.3 cmol/kg).

Soils of the restored land recorded the highest %BS of 69.9-88.8% due to the fallow state of the area as well as high clay content which gave rise to high organic matter and reduced leaching of nutrients. The forest area recorded %BS between 59.0-84.8% while the sinkhole recorded 46.5-83.5%. The low %BS value recorded in sinkhole was as a result of surface soil removal, deforestation and soil disturbance, exposure of bare soil to direct temperature and rainfall and leaching of basic cation. Generally, soils of the study area recorded moderate ECEC values with soils of the restored land recording the highest (7.64-10.68cmol/kg), which was irregularly distributed within the profile. Forest area recorded decrease in ECEC with soil depth increase which ranged between 4.53-8.62cmol/kg. ECEC values in the sinkhole were also irregularly distributed and ranged between 5.52-8.52cmol/kg. ECEC value of 8-10cmol/kg has been stated as the minimum ECEC value of top soils for effective crop production. ECEC is higher in heavy, fine textured soil than in coarse textures soils, hence the higher ECEC values in restored land than other soils studied. The quantity of ECEC of a soil is determined by the kind amount of clay and organic matter.

Table 2

Mean Values of Selected Soil Chemical Properties

Land Type	**pH H_2O**	**pH KCl**	**O.M %**	**TEA cmol/kg**	**T.N %**	**TEB cmol/kg**	**ECEC cmol/kg**	**BS %**	**AV.P ppm**
Sinkhole	5.33	4.13	0.94	2.7	0.05	3.73	6.43	58.3	2.1
Restored Land	5.49	4.31	4.29	1.8	0.21	7.18	9.01	79.3	4.0
Forest/Control	5.46	4.17	1.74	2.1	0.09	4.42	6.52	66.2	2.4
CV (%)	1.6	2.2	75.3	20.8	71.4	36.0	20.0	15.6	36.1

OM = Organic matter, TEA=Total exchangeable acidity, T.N= Total nitrogen, TEB= Total exchangeable bases, ECEC= Effective cation exchange capacity, BS= Base saturation, Avail. P= Available phosphorus

Land Degradation Index

Table 3 displayed Land Degradation Index (LDI) of selected soil properties studied. Negative LDI values indicate degraded soil properties while positive LDI values indicate non degraded soil properties. The forested soil with zero LDI values is a separating index between degraded and non degraded soil properties. Soil properties was observed to be highly degraded in soils of sinkhole degraded land while soil properties appreciated greatly in the restored land more than the forested area used as the control. Organic matter was observed to be highly degraded in the sinkhole (-46.0) while the restored land recorded (146.6) high appreciation. Total exchangeable bases was moderately degraded (-15.6) in the sinkhole and highly appreciable (62.4) in the restored land. Base saturation (-11.3) and available P (-12.5) were minimally degraded in the sinkhole while the restored land recorded base saturation (19.8) and available P (66.7) of minimally and highly appreciable. Total nitrogen was highly degraded in the sinkhole (-44.4) and high appreciable (133.3) in the restored land.

Table 3

Land Degradation Index (LDI) of Selected Soil Properties

Location	**O.M**	**TEB**	**ECEC**	**BS**	**T.N**	**Av. P**
Sinkhole	-46.0	-15.6	-1.4	-11.3	-44-4	-12.5
Restored Land	146.6	62.4	38.2	19.8	133.3	66.7
Forest/Control	0	0	0	0	0	0

Soil Classification

The soils of the study area were classified according to soil taxonomy (Soil Survey Staff, 2014) and correlated with world reference base (2014). The mean annual soil temperature of the soil and study area was above 25^0 C, therefore isohyperthermic and located in an udic moisture regime. The sinkhole degraded soils had anthropic epipedon and cambic subsurface horizon, the restored land recorded an anthropic epipedon and a fragipan subsurface horizon while the forest soils had an ochric epipedon and kandic subsurface horizon.

The sinkhole degraded soils were characterized with human induced physical changes and had lithic contact and cambic horizon within the mineral surface. The sinkhole degraded soils were classified as Lithic Dystrudepts (Soil Taxonomy) and

Technic Cambisol (World Reference Base). Soils of the restored land were human induced and characterized with clay of above 30% in all horizons and consequent shrink and swell properties hence classified asTypic Hapluderts (Soil Taxonomy) and Technic Vertisol (World Reference Base). The Forested soil was characterized with chroma of 4 or more, the organic carbon content decreased irregularly within the soil profile. The soils were sandy and had a kandic subsurface horizon. It does neither had clay increase in depth of more than 20% nor had a densic, lithic or paralithiic contact, thus were classified as Arenic Kandiudults (Soil Taxonomy) and Arenic Nitisol (World Reference Base).

Conclusion

Sinkhole poses severe threat to the landscape and environment which are in most cases are induced by intense and uncontrolled anthropogenic activities. The impact of soil mining and excavation has greatly affected the natural ecology. The removal of organic rich surface soils required for agricultural and human settlement results in change in land use. The absence of natural vegetation as well as uncontrolled land exploitation has greatly increased the menace of land degradation in mining areas. Restoration of lands by soil filling according to the study would hasten its resilience in regaining its lost quality. It is therefore recommended that sinkholes should be used for sanitary landfill and layered with soil of 30cm thickness daily. Also soil filled sinkholes especially with subsoil (clay) can be utilized for upland/irrigated rice production.

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АГРОЕКОЛОГІЧНІ ОСОБЛИВОСТІ ВИКОРИСТАННЯ САПРОПЕЛІВ НИЖНЬОГО ДНІПРА

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У статті викладені матеріали щодо підвищення продуктивності деградованих темно-каштанових ґрунтів степових агроландшафтів півдня України із застосуванням сапропелів Нижнього Дніпра. Під час досліджень встановлений механізм сучасного утворення сапро-