Evaluation of Soil Quality in Relation to Landuse Effect in Akamkpa, Cross River State – Nigeria

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Abstract  Soil quality variation in the tropical rainforest zone of Akamkpa upon conversion from the natural vegetation to other landuse types (natural forest, reforested lands, cultivated upland soils, swamps, soils around quarry sites, built-up areas and fallow lands) was evaluated with a view to ascertain the changes in physical, chemical and biological characteristics of the soils and determine to what extent these changes affects soil quality degradation rates and vulnerability potential. Surface soil samples were collected from four points in each landuse type at the depth of 0-15cm and mixed to obtain a composite sample for routine laboratory analysis of selected soil quality parameters. The soils were generally sandy loam to clay loam on the surface and lateritic clay at the subsurface. Bulk density varied from 1.12-1.48mgcm⁻³, soil porosity was higher in cultivated soil (78.83%) and lower in the swamps (25.22%) water holding capacity was highest in swamps (72.9%) and lowest in the built-up areas (33.6%). Aggregate stability index was lower in the cultivated soils (0.44) and higher in the natural forest (0.69). pH value varied from 4.2-6.0, organic carbon levels were higher in the natural forest (9.84gkg) and lowest in built-up areas (4.16gkg⁻¹). Total nitrogen varied from 0.42-0.72gkg, the value was lowest in built-up areas and highest in the natural forest soils. C:N ratio varied from 8.63-13.12. these values were lowest in cultivated soils than natural forest and reforested soils. Available P was highest in fallow lands and lowest in built-up areas. Exchangeable bases show variability across landuse types with calcium, potassium, ECEC higher in natural forest soils. Al³⁺, SAR, Fe, Mn, Cu and S higher were in soils around quarry mines than any other landuse type. Reforested lands, cultivated uplands and fallow lands showed a slight variability in the selected chemical parameters. The biological properties were highly correlated with soil quality status in response to landuse change types. Total microbial biomass was higher in reforested lands and lowest in built-up areas, while active microbial biomass was higher in fallow lands. Higher rates of qCO₂:T for the cultivated soils, qCO₂:A rates was higher for fallow lands. Results revealed that built-up areas and soils around quarry mines has a significantly lower SDR/VP than any other landuse type. Percentage soil quality rating was higher in burned lands (88.0%), forested lands and reforested lands (83.3%), cultivated uplands (66.0%) swamps (56%), soils around quarry mines (44%) and built-up areas (33%). The findings suggest that the soils under fallow are slightly capable to resist degradation. Management practices such as planting leguminous crops, increased fallow period, organic manuring, planting of fast growing vegetative species and returning crop residues to the soil as a way of building up used carbon stocks.

Keywords: soil quality, landuse change, tropical rainforest, soil degradation and vulnerability potential

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1. Introduction

Landuse changes especially cultivation of deforested land may rapidly diminish soil quality, as ecologically sensitive components of the tropical rainforest ecosystem are not able to buffer the effects of agricultural practices and other landuse changes [28]. Population increase is the chief driving force for landuse change in Nigeria. [18] investigated the effects of landuse on soil quality and reported a 41-89% less dispersible clay in the forest than in cultivated areas. The study asvered that frequent cultivation leads to deterioration of soil quality.

Studies carried out by [22,35,40] reported a positive correlation between landuse changes and loss of soil quality especially chemical properties and soil aggregate stability which is considered a soil quality indicator that provides information on the soils ability to function as a basic component of the ecosystem. [39] reported a strong dependence of tropical rainforest soils. [4,19] also reported changes in soil properties such as porosity, soil organic matter, bulk density, due to changes in landuse practices. In another related study [33] & [34] reported correlation between reduced crop yields and decline in soil organic matter content and erodibility of the soils.

Soil microbial biomass has been reported by [2,3,27,44,45,47] as fundamental to maintaining soil
function because it is the main source of soil enzymes that regulates transformation processes in soils. It is a potent tool for detecting early indicator of changes in soil chemical and physical properties resulting from land use change and soil management. This study has not been investigated and reported in this area, assessment of soil properties upon conversion of natural forests for varying landuses is of great importance to food security and detecting early changes in soil quality. The study therefore assess and compare the changes in soil properties in response to landuse changes in the tropical rainforest area of Akamkpa.

2. Materials and Methods

2.1. Description of Study Area

This study area is Akamkpa (5°45'-8°21'N and 5°43' and 9°00'E) as a tropical rainforest. The natural forest has been exploited through cleaning and felling to meet demands for food, timber and fuel wood. Over the years this forest has witnessed intense human activities such as farming, lumbering and quarrying activities which has hampered regeneration. The geology of the study area is Oban Massif which is made up of basement complex rocks. Soil properties vary with topography and orientation of the hill-slope. The soils are generally sandy loam soil to lateritic clay soils. The climate of the area is humid tropical, characterized by double maxima rainfall, which starts from the month of April to October, reaching its climax in the month of June and September. The annual average is about 1500-3000mm. temperature ranges from 21°C-23°C in the wet season and 24°C-27°C in the dry season. The area records a relative humidity between 80-100% and vapour pressure in air average 29 millibars throughout the year (NAN, Weather Reports, 2014, CRBDA report 2006).

2.2. Soil Sampling and Processing

Surface soil samples were collected from four points in each landuse type (Natural forest, reforested lands, cultivated upland soils, Swamps, soils were sampled (0-15 depth) and mixed to obtained a composite sample that was sealed in a plastic bag. Field moist soil samples generally sieved to remove stones, big roots and organic residues and sealed in plastic bags and stored at 4°C. Soil biological analyses were carried out within 1 week of sampling.

2.3. Soil Physical and Chemical Properties

Soil particle size analysis was done by the hydrometer method. Soil bulk density (pb) was determined by the core method and total porosity was calculated, Gravimeter water holding capacity (WHC) of soil, was measured by tube method [49]. Aggregate stability (AS) was determined on 1-2mm sieved air-dried soil aggregates by a modified turbid metric method [50]. Soil pH was determined in 1:2.5 soil-water slurry, using a combination glass electrode. Total carbon (C_T) and Nitrogen (N_T) contents were determined by Walkley and Black method as modified by [37,48]. Exchangeable bases: Ca, Mg, Na, K, were extracted using normal ammonium acetate (Thomas, 1982). Exchangeable K and Na were determined by flame photometer while Ca and Mg were determined by atomic absorption spectrophotometer. Exchangeable sodium percentage (ESP) and sodium absorption ratio (SAR) were obtained by calculation.

2.4. Soil Degradation Rating (SDR)

The rating scheme for soil degradation (SDR) developed by [33] based on soil properties was applied in this study. Vulnerability potential (V_P) of the soil quality was added to the scheme. The critical levels of the soil properties were weighted on a scale of 1 to 5 (Table 4) In SDR, a weight of 1 was given when there were no limitations and 5 when limitation was extreme. Reverse was the case for V_P values. In this was good soils have least SDR and poor soils have the highest SDR, whereas in A (V_P) good soils have the highest value (5) and least value (1) for poor soils.

2.5. Soil Biological Properties

The microbial biomasses (GmB) was determined by chloroform fumigation incubation method (Jenkinson and Prolson, 1976). The GmB was calculated as follows:

\[
C_{TMB} = \frac{(CO_2-C_{fum}-CO_2-C_{unfum})}{KC} \times FC
\]

Where: \( C_{TMB} \) is the microbial biomass C mineralized as CO_2 for 10 days incubation at 25°C.

Active microbial biomass (CAMB) of soil was measured by the glucose – nutrient induced respiration method (Van de Werf and Verstrate, 1987). CAMB was measured as follows:

\[
C_{AMB} = \left[ (YCO_2-C_{10 amend} - YCO_2-C_{10 unamend} \right] \times AC
\]

Where: \( yCO_2 - C_{10 amend} \) and \( yCO_2 - C_{10 unamend} \) are the evolution of CO_2 from the glucose-nutrient amended and unamended soils during a 10hr incubation respectively and AC in the coefficient (0.283) to convert CO_2-C into CAMB. Basal respiration (BR) was measured as CO_2 evolution from unamended field-moist soil adjusted to 60% WHC for an incubation period of 10days at 25±1°C in the dark. The BR was calculated as follows:

\[
B_R = \frac{(CO_2 - C_{soil} - CO_2 - C_{air})}{10days}
\]

Where is the evolution of CO_2 from soil and is the atmospheric CO_2 absorbed by IM NaOH in a blank Mason jar.

2.6. Statistical Analyses

The LSD procedure was used to separate the means of soil physico-chemical and biological properties at <0.05.
3. Results and Discussion

3.1. Physical Properties of Soils

The physical properties of soils are presented in Table 1. The soils generally have sandy loam to clay loam on the surface and lateritic clay at the subsoil. The sand content varied from 21.80-38.0%, silt (11.60-24.8) and clay (4.2-50.4). The sand content was highest in soils around quarry mines and cultivated uplands, the soils around quarry mines areas and swamps recorded the highest silt content while highest clay content was recorded in swamps and fallow lands. Generally, the silt-clay ratio of the soils was low (0.42-0.59) indicating the advanced stage of weathering of parent materials from which the soils are developed lower silt and slightly lower clay in other landuse types is probably due to the factor of toposequence as most of the natural forests and swamps are located at the two ends of land height (Upper slope and lower-slope), also preferential removal of silt by accelerated water erosion during high precipitation months [10,32,36,38]. The results of this study indicate high pedogenesis under intensive landuses.

Bulk density varied from 1.12-1.48mgcm$^{-3}$. The mean value of 1.30mgcm$^{-3}$ was regarded favourable for agronomic purposes, since it enhances root penetration, good aeration and infiltration. Bulk density was higher in soils under cultivation and fallow lands. These values observed in lands under cultivation and fallow may be associated with cultivation and seasonal flooding of lowlands leading to surface crusting and compaction. Soil porosity was higher in cultivated soils (78.83%) and lower in the swamps (25.22%), water holding capacity (WHC) of the soil was highest in the swamps (72.9%) and lowest in built-up area (33.6%). Aggregate stability index is lower in the cultivated soils (0.44) and higher in the natural forest (0.69). Thus enhanced aggregate stability reported in natural forest soils is consistent with findings as reported by [5,6,14,17,32].

3.2. Chemical Properties of Soils

Chemical properties of soils were presented in Table 2. The pH value in the soils varied significantly from 4.2-6.0. Natural forest and reforested areas planted with Gmelina and teak were more acidic than other landuse types. The pH value was highest in cultivated soils than the natural forests, but lower in the cultivated soils (0.44) and higher in the natural forest (0.69). Thus enhanced aggregate stability reported in natural forest soils is consistent with findings as reported by [2,7-13]. Available phosphorus (P) was highest in fallow lands and lowest in built-up areas. Available P is low taking into cognisance the critical value of 15g/kg reported for productive tropical soils by [12,13,16]. The low available P could probably be due to P-fixation by Iron and Aluminium sesquioxides under acidic conditions.

Exchangeable bases (Calcium, magnesium, sodium and potassium) showed variability across the land use change types as presented in Table 2. Calcium ranged from 3.0-6.6Cmolkg$^{-1}$. Calcium is not likely to be a limitation to agronomic practices in these soils. Magnesium (Mg) content varied from 0.6-2.8Cmolkg$^{-1}$. These values were above 0.3-1.4 Cmolkg$^{-1}$ regard as the critical value for Mg for tropical productive soils (FAO, 1976; Landon, 1991). Sodium (Na) content varied from 0.16-0.68Cmolkg$^{-1}$. The concentration of sodium is below the critical limit 1.0Cmolkg$^{-1}$ [23,26,31]. Thus the soil has sodicity problem. Exchangeable potassium (K) varied 0.08-0.54Cmolkg$^{-1}$. These values are lower than the critical limit of 0.2Cmolkg$^{-1}$ reported for different landuses in Nigeria [20,24,30]. Exchangeable hydrogen (H') ranged from 0.88-1.52Cmolkg$^{-1}$ their variation is not considered to be a limitation to areable crop production because values are lower than the critical limits [11,21,29,40]. The effective cation exchange capacity (ECEC) varied from 3.98-10.21Cmolkg$^{-1}$. These values is indicative of the low capacity of these soils to retain nutrient elements due to the insufficient amount of organic matter and soil pH chemistry [43,46-50]. The values of SAR and EA (Sodium Absorption Ration and Exchangeable Acidity) were considerably higher in the reforested lands than the natural forests. Sulphur (S) varied from 6.4-15.0mgk$^{-1}$. These levels of sulphur in the soils was considered not below the critical limit but still requires external supply to augment the amount of sulphur loss through crop removal and bush burning.

Micro-nutrients present in the soils (Zn, Fe, Mn, Cu) varied from Zn (1.4-3.4mgk$^{-1}$), Fe 121-263mgk$^{-1}$, Mn (43-80mgk$^{-1}$), and Cu (16.8-39.4mgk$^{-1}$). On the average, the observed levels were moderate, however, the reported variation across landuse change types may be probably due to lower organic matter content and the soil pH chemistry.

3.3. Soil Biological Properties

The values of most of the measured biological properties were significantly lower in built-up areas, soils around quarry mines and swamps than cultivated uplands and natural forest (Table 3). The Total micronial biomass ($C_{TMB}$) was higher in fallow lands (380.4mg/Ckg$^{-1}$) and lowest in built-up areas (92.7mg/Ckg$^{-1}$). Active microbial biomass $C_{AMB}$ also followed some trend. This results may be due to the sensitive response of microbial biomass C to conversion of natural forest and cropping areas. Higher proportion of microbial biomass ($C_{TMB}$ and $C_{AMB}$) is an indication of aggregation of available organic carbon in soils [41-51]. The respond pattern of $C_{TMB}$ and $C_{AMB}$ to landuse change types were highly congruent, Basal respiration (BR) rates vary significantly among landuse change types, but was higher in soils under fallow and reforested lands and lower in built-up areas and soils around quarry mines. High rate of BR can occur either as
a result of large pools of liable substrates or rapid oxidation of smaller pool. Thus high BR may indicate a high level of ecosystem productivity [6]. Higher ratio of $q_{CO_2}$ was observed for the cultivated upland and fallow lands. Although it has been used to express growth efficiency in agricultural systems and also as indicator of microbial stress [19]. Furthermore, it may also connote intense competition for the available C as a result of cultivated soils and fallow lands favours bacteria based food webs which have low C assimilation efficiencies and faster turnover rates than the more efficient fungal-based food webs dominant in undisturbed or natural forest ecosystems [42].

Table 1. Land use change effect on selected physical properties

| Landuse types       | Soil texture   | Sand % | Clay % | Soil % | Silt/Clay ratio | Porosity % | WHC (%) | Aggregate Stability index | Bulk density |
|---------------------|----------------|--------|--------|--------|-----------------|------------|---------|--------------------------|-------------|
| Natural forest      | Clay loam      | 29.8   | 44.0   | 26.20  | 0.59            | 50.51      | 68.8    | 0.69                     | 1.12        |
| Reforested lands    | Clay loam      | 30.2   | 44.8   | 25.00  | 0.56            | 53.93      | 68.5    | 0.63                     | 1.26        |
| Cultivated uplands  | Sandy clay loam| 33.9   | 46.2   | 19.90  | 0.43            | 78.83      | 50.6    | 0.44                     | 1.48        |
| Swamps              | Silty clay     | 21.80  | 50.4   | 27.8   | 0.55            | 23.22      | 72.9    | 0.57                     | 1.32        |
| Soils around quarry mines | Lateritic clay | 45.60  | 45.0   | 11.60  | 0.26            | 57.02      | 47.4    | 0.45                     | 1.39        |
| Built-up areas      | Sandy clay     | 38.0   | 41.2   | 20.80  | 0.50            | 76.00      | 33.6    | 0.56                     | 1.44        |
| Fallow lands        | Sandy clay loam| 29.60  | 49.7   | 20.70  | 0.42            | 70.48      | 59.2    | 0.68                     | 1.46        |

WHC=Water holding capacity.

Table 2. Land use change effects of selected chemical properties

| Landuse change type       | pH | OC (gkg⁻¹) | Total N (gkg⁻¹) | C:N ratio | Ca (Cmol/kg) | Mg (Cmol/kg) | K (Cmol/kg) | Na (Cmol/kg) | Al³⁺ (mg/kg) | H⁺ (mg/kg) | ECEC | EA | SAR | Zn | Fe | Mn | Cu | S (mg/kg) |
|---------------------------|----|------------|-----------------|-----------|--------------|--------------|-------------|--------------|--------------|-------------|------|-----|----|----|----|----|----|----|-----------|
| Natural forest            | 4.2| 9.84       | 0.72            | 13.12     | 5.50         | 6.6          | 2.5         | 0.54         | 2.02         | 1.32        | 1.20 | 0.059 | 2.68 | 188 | 43 | 22.7 | 8.1 |
| Reforested lands          | 4.5| 7.50       | 0.64            | 11.72     | 6.05         | 5.8          | 2.8         | 0.41         | 0.59         | 2.16        | 1.48 | 0.268 | 3.44 | 134 | 50 | 20.4 | 8.5 |
| Cultivated uplands        | 5.0| 6.90       | 0.60            | 11.50     | 4.62         | 6.0          | 2.0         | 0.38         | 0.46         | 1.72        | 1.52 | 0.224 | 2.00 | 166 | 52 | 28.0 | 11.6|
| Swamps                    | 5.2| 5.39       | 0.55            | 9.80      | 3.12         | 4.54         | 1.8         | 0.19         | 0.48         | 1.96        | 1.47 | 0.725 | 1.65 | 185 | 66 | 36.0 | 15.0|
| Soil around quarry mines  | 6.0| 4.10       | 0.42            | 9.76      | 5.80         | 5.70         | 1.3         | 0.12         | 0.21         | 4.18        | 1.35 | 2.37  | 0.081 | 2.22 | 77 | 39.4 | 13.8|
| Built-up Areas            | 4.8| 4.06       | 0.46            | 8.83      | 2.44         | 3.0          | 0.6         | 0.08         | 0.16         | 1.04        | 0.08 | 3.98  | 2.04 | 0.071 | 1.4 | 121 | 45 | 16.8 | 6.4 |
| Fallow lands              | 4.6| 7.09       | 0.68            | 10.40     | 6.12         | 6.3          | 2.6         | 0.41         | 0.52         | 2.64        | 1.38 | 9.55  | 2.16 | 0.061 | 2.9 | 160 | 80 | 34.5 | 10.2|

GTMB=Total microbial biomass; CAMB=Active microbial biomass; BR=Basal respiration; Corg=Total Organic Carbon; $q_{CO_2}$:T and $q_{CO_2}$:A=Specific maintenance respiration rates for GTMB and CAMB.

Table 3. Land use change effect on selected biological soil properties

| Landuse type | $C_{TMB}$ (mgCkg⁻¹) | $C_{AMB}$ (mgCkg⁻¹) | $C_{TMB}/C_{org}$ (%) | % | BR (mgCO₂ C/kg/d) | $q_{CO_2}$:T (mgCO₂ – C/mg biomass/d) | $q_{CO_2}$:A (mgCO₂ – C/mg biomass/d) |
|--------------|----------------------|----------------------|------------------------|---|------------------|----------------------------------------|----------------------------------------|
| Natural forest| 273.9                | 81.2                 | 2.78                   | 0.83 | 33.49           | 6.4                                   | 0.068                                  | 0.218                                  |
| Reforested lands| 324.6               | 66.5                 | 4.33                   | 0.89 | 48.81           | 8.8                                   | 0.072                                  | 0.244                                  |
| Cultivated uplands| 176.6              | 51.4                 | 2.55                   | 0.74 | 34.24           | 6.2                                   | 0.070                                  | 0.262                                  |
| Swamps        | 298.2                | 43.0                 | 5.53                   | 0.79 | 69.34           | 5.5                                   | 0.056                                  | 0.158                                  |
| Soil around quarry mines | 155.0            | 37.4                 | 3.78                   | 0.91 | 41.44           | 4.0                                   | 0.049                                  | 0.109                                  |
| Built-up Areas| 92.7                 | 17.8                 | 2.27                   | 0.44 | 52.08           | 2.6                                   | 0.031                                  | 0.076                                  |
| Fallow lands  | 380.4                | 102.6                | 5.36                   | 0.14 | 37.07           | 9.1                                   | 0.080                                  | 0.252                                  |

Table 4. Scheme for soil degradation rating (SDR) and vulnerability Potential (VP)

| SDR Limitation | Relative weighting Scale (RWS) | Vulnerability potential (Vp) | RWS |
|----------------|--------------------------------|-------------------------------|-----|
| None           | 1                              | None                          | 5   |
| Slight         | 2                              | Low                           | 4   |
| Moderate       | 3                              | Moderate                      | 3   |
| Severe         | 4                              | High                          | 2   |
| Extreme        | 5                              | Very High                      | 1   |

Source: Lal, (1994).
Table 5A. Critical limits for interpreting levels of soil chemical properties from literatures

| Soil properties | Very low | Low | Moderate | High |
|-----------------|----------|-----|----------|------|
| pH              | <3.0     | 4.0-5.0 | 5.5-7.5 | >7.5 |
| Organic carbon (gkg⁻¹) | <2.0 | 2.0-5.0 | 5.5-10 | >10 |
| Total nitrogen (gkg⁻¹) | <1.5 | 1.5-2.0 | 2.0-5.0 | >5.0 |
| Available phosphorus (gkg⁻¹) | <2.0 | 2.0-5.0 | 8.0-20 | >20 |
| Potassium (Cmolkg) | <2.2 | 0.2-0.5 | 0.6-0.90 | >1.10 |
| Calcium (Cmolkg) | 2.0 | 2.0-5.0 | 5.0-10 | >10.0 |
| Magnesium (Cmolkg) | <0.5 | 0.5-3.0 | 3.0-5.0 | >10.0 |
| Iron (mgkg⁻¹) | <50 | 55-75 | 75-105 | >105 |
| Zinc (mgkg⁻¹) | <2.0 | 2.0-3.0 | 3.0-5.0 | >5.0 |
| Manganese (mgkg⁻¹) | <10 | 20-40 | 40-100 | >100 |
| Copper (mgkg⁻¹) | <10 | 10-20 | 25-40 | >40 |
| ECEC (Cmolkg⁻¹) | <10 | 10-15 | 15-2x0 | >20 |

Source: Hazelton & Murphy, (2007); Kparmwang & Malgwi, (1979); Isirima et al., (2003); Abe et al., (2010); FAO (1996); Holland et al., (1989); Uquetan, (2013).

Table 5B. Critical limits for interpreting levels of soil physical properties

| Critical levels | Rwf | Light texture | Heavy texture | Morphology | Consistence | Texture |
|-----------------|-----|---------------|---------------|------------|-------------|---------|
| None            | 1   | 1.3           | 1.2           | Sb to c    | Loose       | Loam    |
| Slight          | 2   | 1.3-1.4       | 1.2-1.3       | Sb         | Very friable| Sil, Si, Sicl |
| Moderate        | 3   | 1.4-1.5       | 1.3-1.6       | Msb        | Friable     | Cl, Si |
| Severe          | 4   | 1.5-1.6       | 1.4-1.5       | Wsb        | Hard        | Scl, Ls |
| Extreme         | 5   | >1.6          | >1.5          | M or sg    | Harsh/extreme hard | C, S |

N/B: Rwf = relative weighing factor, Sb to c = subangular to crumb, Sb = subangular blocky, Msb = Moderate subangular blocky, Wsb = weak subangular blocky, Silt = Silt loam, Si = Silt, Sicl = silt clay loam, Cl = clay loam, Si = sandy loam, Sc = silt loamy sand, C = clay, S = sand. pH, EC= Electrical conductivity, Al=Aluminium, Mn=Manganese, SOC=Soil Organic Carbon. Rwf 1 = none, Rwf 2 = slight, Rwf 3 = moderate, Rwf 4 = Severe, Rwf 5 = extreme.

Source: Lal, 1994; Landon, 1984.

Table 6. Soil degradation rates (SDR) and vulnerability potential (VP) rating scheme of selected soil qualities in the study area

| Parameters | Landuse change types |
|------------|----------------------|
| Soil physical properties | NF | RF | CL | SW | Sqm | BUA | FL |
| Texture    | 3(3) | 3(3) | 3(3) | 3(4) | 3(3) | 3(2) | 3(3) |
| Bulk density | 2(4) | 2(4) | 2(4) | 2(4) | 2(4) | 2(3) | 2(4) |
| Porosity   | 2(5) | 2(5) | 3(2) | 2(4) | 2(4) | 3(2) | 4(2) |
| Aggregate stability | 1(5) | 1(5) | 2(3) | 3(2) | 2(4) | 2(4) | 2(4) |
| Soil Chemical Properties |   |   |   |   |   |   |   |
| Soil pH     | 1(5) | 1(5) | 2(4) | 2(3) | 2(4) | 2(4) | 1(5) |
| Organic Carbon | 3(2) | 3(2) | 2(3) | 2(3) | 2(4) | 2(4) | 3(3) |
| Total Nitrogen | 3(3) | 3(3) | 2(3) | 2(3) | 2(4) | 2(4) | 3(3) |
| Available P  | 2(4) | 2(3) | 2(4) | 2(4) | 2(4) | 2(4) | 3(3) |
| Carbon : Nitrogen ratio | 1(5) | 1(5) | 2(4) | 2(4) | 4(2) | 2(3) | 1(5) |
| Potassium   | 4(2) | 4(2) | 2(3) | 2(4) | 2(4) | 2(4) | 3(3) |
| Calcium     | 2(4) | 2(4) | 2(4) | 2(4) | 2(4) | 2(4) | 3(3) |
| Magnesium   | 2(3) | 2(3) | 2(3) | 2(3) | 2(4) | 2(4) | 4(2) |
| ECEC        | 2(3) | 2(3) | 2(4) | 2(4) | 2(4) | 2(4) | 3(3) |
| Iron        | 2(4) | 2(4) | 2(4) | 2(4) | 2(4) | 2(4) | 2(4) |
| Zinc        | 1(5) | 1(5) | 2(4) | 2(4) | 3(3) | 1(5) | 1(5) |
| Manganese   | 2(4) | 2(4) | 2(4) | 3(3) | 3(3) | 1(5) | 2(4) |
| Copper      | 2(3) | 2(3) | 2(3) | 2(3) | 2(4) | 2(4) | 3(3) |
| Sulphur     | 3(3) | 3(3) | 2(3) | 3(2) | 4(2) | 2(4) | 3(3) |

NB: 1=none; 2=slight; 3=moderate; 4=severe; 5=extreme – for SDR, 5=none; 4=low; 3=moderate; 2=high; 1=very high – for VP (values in bracket), Ratings based on mean soil quality and critical limits established in Table 5 and literature, [52]
Soil degradation rate (SDR) and vulnerability potential (VP) results are presented in Table 6 while the critical limits for interpreting limits of soil properties are presented in Table 5A and B. The results generally show that the soil qualities have varied potentials for degradation. The results in Table 6 indicates that soil pH is a better quality SDR=1; VP=5) for natural forest. Reverted and fallow lands while soils under cultivation swamps, around quarry mines and built-up areas had SDR-2; VP=4 had more. Potential vulnerability to erosion than soil in the natural forest, reforested and fallo lands. C:N ratio aggregate stability and availability of Zinc follow the same trend. Bulk density recorded SDR/VP of 2(3) – 2(4) implying that the soils have better structural conditions for crop production. The bulk densities obtained in these soils are in tandem with findings reported by [12,24-47]. Organic carbon and Total Nitrogen generally follow a similar SDR trend with built-up areas and soils around quarry mines showing high soil quality rating shows that soil qualities in the various percent). From the results presented above, the percentage obtained in these soils are in tandem with findings reported by [28] to determine the percentage soil quality rating:

\[
\% Q\text{ Rating} = \frac{\text{no. of Indicators that attain CL}}{\text{no. of Indicators assessed}} \times 100
\]

Where Q = Soil quality, CL = Critical limit;

The indicators were transformed on the basis of their ability to attain a critical level or range. Any indicator that is equal to or above the critical level for crop production is scored 1 and any below the critical level is scored zero. These later is integrated into percentage quality rating. Results from the analysis show that built-up areas and soil around quarry mines had a significant lower SDR/VP and percentage soil quality rating of 33 percent and 44 percent while swamp and cultivatable upland soils had (56 and 66 percent, soil under natural forest and reforested areas had 83.3 percent, and soil under fallow for (5-10 years) had 88 percent). From the results presented above, the percentage soil quality rating shows that soil qualities in the various landuse type have varied potentials for degradation with built-up areas and soils around quarry mines showing high susceptibility to degradation, while swamps and cultivatable upland soils indicating moderate potential degradation or vulnerability. Soil in the fallow areas appear to be slightly more capable to resist degradation.

4. Conclusion

The removal of native vegetation through agronomic production results in a significant reduction in soil quality of tropical rainforest of Akamkpa. The results in this study have shown spatial variability of soils under different landuse types (natural forested, reforested lands, cultivated uplands, swamps, soils around quarry mines, built-up areas and fallow lands) and their soil property vulnerability potentials. The results of this study indicate high pedogenesis under intensive landuses. Bulk density was regarded as favourable for agronomic purposes. Aggregate stability index was higher in the natural forest and lower in the cultivated uplands. Chemical soil properties variation was reported and values were compared with reported critical liits for soil quality rating across landuse types in the study area. Measured biological properties were significantly lower in built-up areas, soil around quarry mines and swamps than cultivated uplands and natural forest. The biological properties were highly correlated with soil quality status in response to different landuse types. Based on the findings of the study, it can be suggested that biological properties has a more promising potential to predict future changes in soil quality compared to the physico-chemical properties.

The study therefore recommends management practices that will reduce indiscriminate destruction of vegetation cover and protection of the top soils.

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