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# Soil Physico-chemical Properties at Different Habitat Types in Disturbed and Undisturbed Sites of the Takamanda Rainforest, Cameroon

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Authors EEA, NRN and EB designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors NRN and CFBL managed the soil chemical analyses of the study. Author NRN managed the literature searches. All authors read and approved the final manuscript.*

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## ABSTRACT

Soil fertility in tropical forest ecosystems is achieved by high and rapid circulation of nutrients, through nutrient cycling which is a function of climate variability. Decomposition is a key process in nutrient cycling and the formation of soil organic carbon. This study examines the physico-chemical properties of soils in different habitat types in the disturbed and undisturbed Takamanda rainforest. A total of 180 soil samples were collected from the different habitat types of the two forest sites. At each of the sites, soil samples were collected from the ridge tops (crest of a ridge), hilly slopes (side of a ridge), plains (low land), swamps (low land area saturated with water) and valley bottoms (trough surrounded by ridges). Soil samples were collected at 0-10 cm, 10-20 cm, 20-30 cm, 30-40

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cm, 40-50 cm and 50-60 cm soil depths. The results indicated that the bulk densities were highest in the habitats of hilly slope (1.43±0.35) and ridge top (1.21±0.11) in the disturbed and undisturbed forest respectively. The soil porosity was highest (73±50) in plain and valley bottoms (72±60) in the undisturbed forest. The electrical conductivity was highest (58.83±80, 57.00±4.50) in valley bottoms in both disturbed and undisturbed sites respectively. The soil textural classes noted in both top soil and subsoil in disturbed and undisturbed were loam, sandy loam, loamy sand, sandy clay loam and clay loam. The macro-nutrients (Nitrogen, Phosphorus, Organic Carbon, Sulphur, Calcium and Potassium) generally showed a decreased trend with soil depths across habitats in disturbed and undisturbed forests. The soil micronutrients (Manganese, Iron, Zinc, Copper and Nickel) showed an increased trend with soil depths across habitats in disturbed and undisturbed forest sites. Therefore, appropriate measures are necessary for conservation and management of the soils of Takamanda rainforest. This would enhance the growth and diversity of both flora and fauna of these rainforest sites.

*Keywords: Soil nutrients; soil physicalproperties; habitat types; Takamanda rainforest.*

## 1. INTRODUCTION

Soil is a non-renewable dynamic resource, comprising of unconsolidated minerals and organic matter including water and air in the uppermost layers of earth's surface. It plays an important role in maintaining the terrestrial ecosystem on which all life depends. It varies greatly in space and time; a single rainforest or agricultural field may contain many habitats and niches with identifiably different types of soil and nutrient contents [1,2,3], as a result of many biochemical and physical processes at various stages of the development [4].

Soils vary in their characteristics primarily because of topography and habitat types [4] which modify soil water relationships and to large extent influences on drainage, soil erosion, textural composition and other soil properties that affect plant growth within a forest [3]. The release of nutrients from decomposed litter is a fundamental process in the internal biogeochemical cycles of an ecosystem, and decomposers recycle a large amount of nutrients bounded in plant biomasses to the soil and atmosphere which becomes available for plant growth and development [4,5). Habitats variability is associated with plant growth and production which is an integrated reflection on soil properties and factors affecting growth and productivity in a forest ecosystem. Most of these nutrients are not readily available or they depleted due to anthropogenic and natural activities in the forest ecosystem.

The main threats to soils are increasing expansion of settlement; expansion of plantations, road construction, acidification, land slide, erosion, deforestation, forest degradation, and organic matter loss [5,6]. The decomposed litter is also the basis of many food chains in the tropical forests and it is a principal source of energy for the biota of the forest floor and soil, where the trophic chain of detritus predominates [6-10].

Extensive work has been done on the conversion of natural forests into agro-forests and cultivated land systems [11-14]. Presently, there is limited published work on the physico-chemical properties of soils in the Takamanda rainforest. This study therefore, examines the variation that occurs of the soil properties in different habitat types in the undisturbed and disturbed sites of the Takamanda rainforest.

## 2. MATERIALS AND METHODS

### 2.1 Study Site of the Area

The Takamanda Rainforest is located in Akwaya subdivision of the South West Region of Cameroon (Fig. 1). The National Park is part of the Guineo-Congolean forest, which encompasses approximately 2.8 million km$^2$ mostly below 600 m asl except where precambrian highlands such as the Jos Plateau of Nigeria and the Cameroon Highlands rise above 1000m above sea level [15]. The highest point is Mount Cameroon with 4,100 m.

Rainfall in the southern part of the Takamanda rainforest varies from 2500 to 4500 mm per year; giving rise to a variety of floristic habitat types [16]. The region contains 84% of known African primates, 68% of African passerine birds, and 66% of African butterflies [17]. For this reason, the Guineo-Congolian rainforest is an important focal point for conservation in Africa.

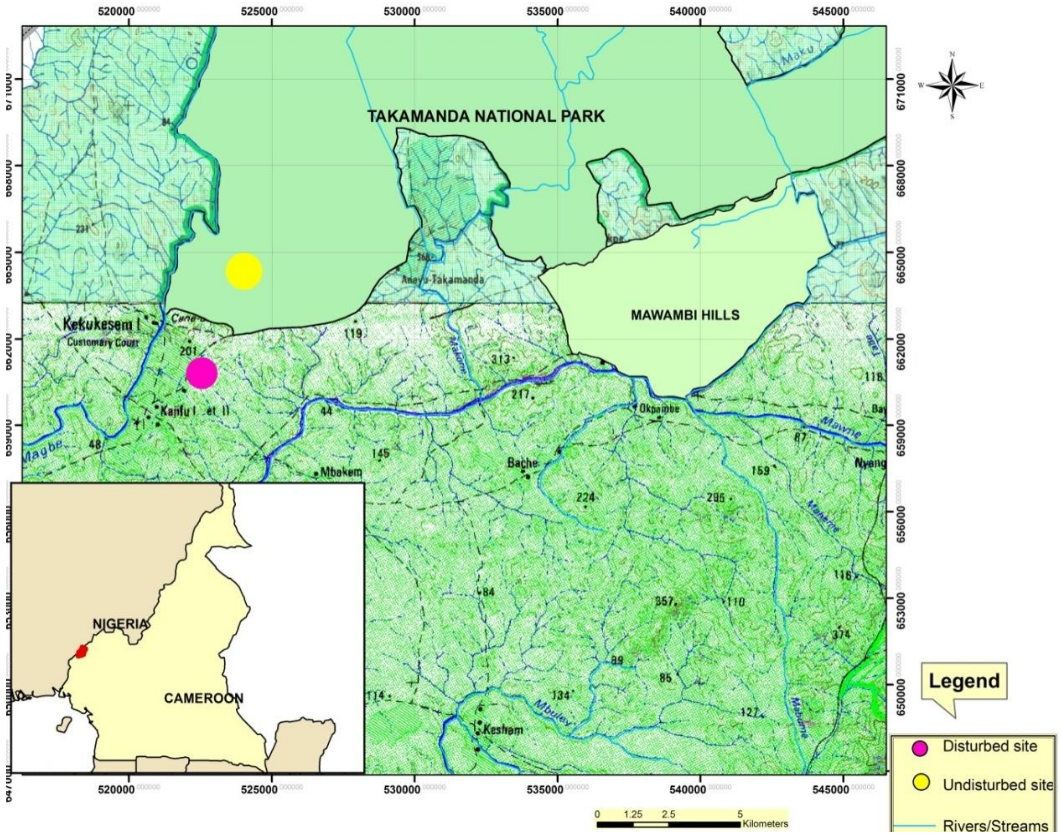

Fig. 1. Map of Akwaya subdivision showing the study sites

The terrain is undulating in the Southern and Central parts of the National Park, and ranges between 100 to 400 m asl (Fig. 2). The area rises sharply to an altitude of 1,500 m in the Northern part of the park [18]. A basement complex of granite, gneisses, schist, and quartzite underlies the region, leading to shallow sedimentary soils. Marine sediment deposition occurred during the Precambrian, resulting in ferrite derived from crystalline rock and large areas of alluvial soil toward the southern end of the Park [19].

The general direction of the drainage pattern is from north to south, with two major rivers, the Makone and Magbe, flowing through the Park [20]. The Makone drains through the Matene Highlands and runs southwest through the Park to meet the Munaya River. The Magbe flows from Matene through Nigeria and curves back into Takamanda; and it represents a portion of the park's western boundary and eventually drains into the Manyu River. The drainage pattern is mainly dendritic in the southern and centre part of the park and radial in the northern part of the park [20].

## 2.2 Soil Sampling and Preparation for Soil Analysis

Soil samples were collected from disturbed and undisturbed sites of the Takamanda rainforest using a soil auger. A total of 180 soil samples were collected in the two forest sites. At each of the sites, soil samples were collected from the various habitat types' ridge tops (crest of a ridge), hilly slopes (side of a ridge), plains (low land), swamps (low land area saturated with water) and valley bottoms (trough surrounded by ridges). Soil samples were collected at 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm and 50-60 cm soil depths. Six samples were taken randomly for each level and in each habitat type and bulked to have homogenized soil sample. From the bulked samples, representative samples for each level were put in a polythene bag and labeled. The soil samples were taken in such a way that the soils collected represented the whole sample areas adequately.

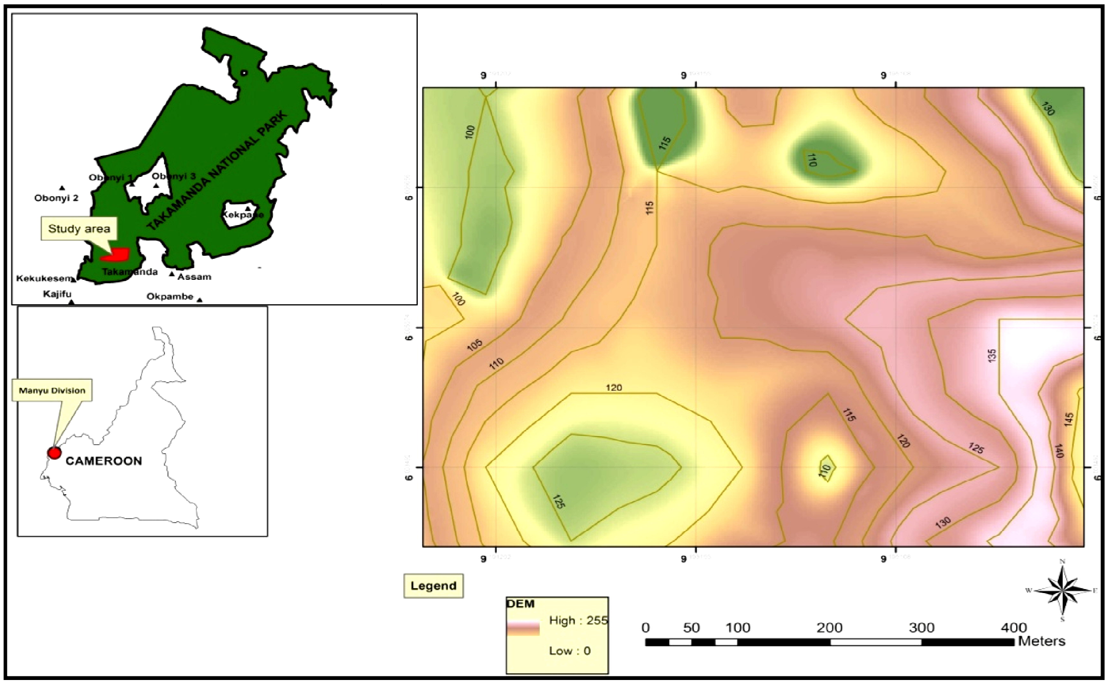

Fig. 2. Map showing the undulating nature of the study terrains

A kilogram of each soil sample was collected and air dried. Soil samples that are clumped were crushed in a porcelain mortar with a pestle and sieved with a 2 mm sieve in order to separate the soil from the gravels. Contamination was avoided by cleaning the mortar thoroughly using tissue papers. 500 grams of each of the sieved soil samples were used for the different routine soil analyses at the Soil Science laboratory of the University of Dschang, Cameroon.

## 2.3 Assessment of Soil Physical Properties

### 2.3.1 Soil bulk density and porosity

The bulk density of soil was determined by the core method [21]. This was done by collecting soil cores from the field from 0- 10 cm soil level, each metal core was weighed and labeled. Weighed samples were oven dried at $105^0$C for 72 hours. The oven-dried cores were allowed to cool in desiccators and then weighed. The bulk density was calculated from the formula:

Bulk density = weight of oven dry soil/ volume of dry soil (1)

Soil porosity was determined using the bulk density [22]. Soil porosity was calculated as:

Soil porosity (%) = 1- (soil bulk density/2.65) (2)

The default value of 2.65 is a reflection of the parent material.

### 2.3.2 Soil electrical conductivity

10 g of each sample was put in a 100ml vial container and 25 ml of distilled water added. An electrical conductivity meter was used to read the EC of the soil volume

### 2.3.3 Soil particle size analysis

Particle size was determined by the hydrometer method [23]. The soil samples were treated with sodium hexametaphosphate complex in order to separate cations that bind clay and silt particles into aggregates. Organic matter was suspended in this solution. The density of the soil suspension is determined with a hydrometer calibrated to read in grams of solids per litre after the sand settles out and again after the silt settles.

## 2.4 Routine Soil Chemical Analyses

### 2.4.1 Soil pH, organic carbon and macronutrients

Organic Carbon was determined by chromic acid digestion and spectrophotometric analysis [24].

Ten grams of air-dried soil sample was weighed using a sensitive scale into plastic cups and 25ml of distilled water was added using a 1: 2.5, and it was stirred using a stirrer and allowed for an hour. The pH of soil solution was determined with a pH meter [25]. Total nitrogen was determined by wet acid digest [26] and analyzed by colorimetric analysis [27]. Exchangeable calcium, magnesium, potassium, and sodium were extracted using the Mehlich-3 procedure [28] and determined by atomic absorption spectrophotometry. Available phosphorus was extracted by Bray-1 procedure and analyzed using the molybdate blue procedure described by [29]. CEC was determined by ammonium acetate method at pH 7.

### 2.4.2 Soil micronutrients analyses

0.5 M ammonium acetate, 0.5 M acetic acid and 0.02 M ethylenediaminetetra acetic acid (EDTA) was added in a conical flask containing 5 g of soil and this was shaken and water filtered through whatman 42 pore sizes. Atomic absorption spectrophotometer (WFX-130B, RAYLEIGH) was used with Acetylene gas using the following standard solutions: Mother commercial products of Fe, Cu, Mn, Zn and Ni at 1000 ppm were used to prepare the different standard solutions in 1M $HNO_3$ acid as solvent in a 200 ml flat bottom flask [30].

## 2.5 Data Analysis

An analysis of variance (ANOVA) was used to test differences in soil physical and chemical properties across the different habitat types and forest sites. Significance level of $P<0.05$, $P<0.01$ and $P<0.001$ were generated for the different habitat types, soil depths and forest sites by one way ANOVA was carried within the site. Data analyses were done using a statistical software package (Genstat version 16).

# 3. RESULTS

## 3.1 Physical Properties

### 3.1.1 Soil bulk density

The bulk densities showed variations in the different habitat types in both undisturbed and disturbed forest sites (Table 1). In the undisturbed forest the highest bulk density (1.21 g/ $cm^3$) was noted on the ridge top while the lowest bulk density (0.71g/ $cm^3$) was observed in the valley bottoms (Table 1). In the disturbed forest the highest bulk density (1.43g/ $cm^3$) was observed on hilly slopes while the lowest bulk density (0.96 g/$cm^3$) was at the plain (Table 1).

### 3.1.2 Soil porosity

The soil porosity varied greatly across habitat types in the undisturbed and disturbed forests. In the undisturbed forest the highest percentage soil porosity (73%) was noted in plain while the lowest percentage soil porosity (51%) was observed in the swamp (Table 1). It was noticed in the disturbed forest that the highest percentage soil porosity (64%) was recorded in plain while the least percentage soil porosity (46%) was observed in the hilly slope (Table 1).

### 3.1.3 Soil electrical conductivity

The electrical conductivity of soil in the undisturbed and disturbed was highest in the valley bottom while the least was noted in swamps. It was 57.0mol/L for valley bottoms and 36.50mol/L for the swamps (Table 1). In the disturbed forest the highest electrical conductivity was 58.83mol/L for valley bottoms and 16.17mol/L for swamps (Table 1).

### 3.1.4 Soil texture

The soil textural classes varied significantly ($P< 0.001$) across habitat types in the top soil (0-30 cm) and subsoil (40-60 cm) in the undisturbed and disturbed Takamanda rainforest (Table 2). For the disturbed site soil texture were as follows in the 0-30cm depth. Silt loam was noted on hilly slope, sandy loams for the plain, loamy sand for the ridge top, sandy clay in swamps and silty clay for the valley bottoms. In the subsoil level (40-60 cm) in the disturbed forest, the soil textural classes varied greatly across the different habitat types (Table 2). The soil texture was observed as follows; sandy loam soil for the hilly slope, sandy clay loam soil for the plain, clay loam for the ridge top, loamy sand for the swamp and sandy clay loam for the valley bottom.

In the top soil level (0-30 cm) in the undisturbed forest the soil textural classes showed major variation across habitat types. We observed silt loam for the hilly slope, sandy clay loam were for the plain, swamp and valley bottom and sandy loam for the ridge top (Table 2). In the subsoil level (40-60 cm) in the undisturbed forest, soil textural classes showed variation across habitat types. It was observed as follows; Clay loam for hilly slope and ridge top, sandy loam for plain and valley bottoms and silt loam for the swamps.

## 3.2 Some Chemical Properties of Habitat Types in the Disturbed Takamanda Rainforest

### 3.2.1 Percentage soil organic carbon in the disturbed forest

The percentage organic carbon varied significantly ($P<0.001$) across habitat types and soil depths in the disturbed forest (Table 3). The soil organic carbon decreases with depths across habitat types in the disturbed forest. The highest percentage organic carbon was at valley bottoms (3.12 %) at soil depth 0-10 cm while the least was observed in the swamp at soil depth 30-40cm. Soil organic carbon generally decreased with soil depth for all the habitat types.

### 3.2.2 Soil pH in $H_2O$ in the disturbed forest

The soil pH was not significantly different at $P=0.05$ across habitat types and soil depths in the disturbed forest (Table 3). The soil pH showed variability for hilly slopes, plains, and ridge top while for swamps and valley bottoms the pH the increases with soil depth (Table 3).

### 3.2.3 Percentage total nitrogen

The total nitrogen decreases with depths across habitat types in the disturbed forest and showed significant ($P= 0.005$) (Table 3). The highest percentage N was observed in valley bottom (2.28 %) at soil depth 0-10 cm while least (0.46%) was observed in the swamps at soil depth 50-60cm.

### 3.2.4 Soil available phosphorus in the disturbed forest

The soil available P showed significant differences ($P=0.05$) across habitat types in the disturbed site (Table 3). The trend in available P concentration decreases with depths across habitat types in the disturbed forest. The highest available P concentration was recorded in valley bottom (15.85 mg/kg) at soil depth 0-10 cm (Table 3) while the least was noted at the hilly slope at soil depth 50-60 (4.7mgkg) in the ridge top at soil depth 50-60 cm.

### 3.2.5 Soil total phosphorus in the disturbed forest

The total P showed significant difference ($P=0.05$) across habitat types in the disturbed forest (Table 3). The highest total P was recorded in valley bottoms (442.5mg/kg) at soil depth 0-10 cm while the least total P was observed in the swamp at 30-40 cm soil depth (238.7mg/kg). Total Phosphorus levels decreases with depths for the hilly slope and plain habitats while it shows variability with depths for the other habitats.

### 3.2.6 Percentage soil sulphur in the disturbed forest

The percentage Sulphur decrease significantly $P =0.05$) across soil depths for the different habitat types in the disturbed forest (Table 3). The highest concentration of Sulphur was observed in plain (4.62 %) at soil depth 0- 10 cm while the least concentration was observed at ridge top and valley bottom (1.36%) at soil depth 20-30 cm and 50-60cm respectively.

### 3.2.7 Soil Calcium, Mg and K in the disturbed forest

Calcium, Mg and K varied significantly ($P< 0.001$) across habitat types and soil depth in the disturbed forest (Table 3). There was no observed trend in the concentration of these nutrients across depths and habitat types in the disturbed forest (Table 3). The highest Ca concentration was recorded in swamps (0.92 cmol/kg) at soil depth 50-60 cm while the least concentration of Ca was obtained in valley bottoms (0.22 cmol/kg) at soil depths 10- 20 cm and these were not significantly different at $P=0.05$.

The highest concentration nutrient of Mg was in valley bottom (2.80 cmol/kg) at soil depth 0-10 cm while the least was reported on ridge tops (0.04 cmol/kg) at soil depth 0-10cm (Table 3) and they were significantly different at $P=0.05$.

The highest K concentration was observed in plain and valley bottom (0.18 cmol/kg) at soil depths 0-10cm. while the least nutrient concentration was recorded on ridge tops (0.01cmol/kg) at soil depths 30-60 cm (Table 3). The highest Na concentration was in plain (0.19 cmol/kg) at soil depths 0-10 cm while the least Na concentration was noted on ridge tops (0.06 cmol/kg) at soil depths 40-60 cm.

**Table 1. Some soil physical properties**

| Habitat types | Undisturbed site | | | Disturbed site | | |
|---|---|---|---|---|---|---|
| | Bulk density (g /$cm^3$) | Porosity (%) | Electrical conductivity (mol/L) | Bulk density (g /$cm^3$) | Porosity (%) | Electrical conductivity (mol/L) |
| Plain | 0.73±0.12 | 73±50 | 56.00±3.10 | 0.96±0.12 | 64±50 | 34.17±3.20 |
| Ridge top | 1.21±0.11 | 58±40 | 37.33±5.40 | 1.33±0.11 | 50±40 | 40.33±5.40 |
| Valley bottoms | 0.71±0.15 | 72±60 | 57.00±4.50 | 1.04±0.15 | 61±60 | 58.83±3.80 |
| Hilly slope | 0.74±0.35 | 72±13 | 41.00±3.80 | 1.43±0.35 | 46±13 | 36.33±4.50 |
| Swamp | 1.10±0.09 | 51±30 | 36.50±3.10 | 1.12±0.09 | 56±30 | 16.17 ±3.10 |

± = *standard error*

**Table 2. Variation in soil texture classes in the different habitats in the disturbed and undisturbed Takamanda rainforest**

| Soil depths (cm) | Habitats types | Disturbed forest site | | | | Undisturbed forest site | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | % Sand | % Silt | % Clay | Texture Class | % Sand | % Silt | % Clay | Texture Class |
| **Top soil (0-30 cm)** | Hilly slope | 41.37 | 55.87 | 2.76 | Silt Loam | 34.56 | 43.42 | 22.02 | Silt clay loam |
| | Plain (low land) | 59.47 | 38.58 | 1.95 | Sandy Loam | 62.91 | 16.14 | 20.95 | Sandy loam |
| | Ridge top | 80.66 | 14.64 | 4.70 | Loamy sand | 67.40 | 28.67 | 3.93 | Sandy loam |
| | Swamp | 92.52 | 6.65 | 0.83 | Sandy | 53.71 | 17.28 | 29.1 | Sandy clay loam |
| | Valley bottom | 11.48 | 54.33 | 34.19 | Silty clay loam | 58.00 | 14.61 | 27.39 | Sandy clay loam |
| **Sub soil(40-60 cm)** | Hilly slope | 64.08 | 17.44 | 18.48 | Sandy loam | 39.15 | 30.41 | 30.42 | Clay loam |
| | Plain (low land) | 51.22 | 30.49 | 18.29 | Sandy loam | 57.94 | 19.56 | 22.50 | Sandy clay loam |
| | Ridge top | 44.84 | 27.83 | 27.33 | Sandy Clay | 38.83 | 5.32 | 55.85 | clay |
| | Swamp | 82.84 | 10.51 | 6.64 | Loamy sand | 36.61 | 58.49 | 4.90 | Silt loam |
| | Valley bottom | 60.98 | 15.72 | 23.30 | Sandy clay loam | 74.99 | 13.74 | 11.27 | Loamy sand |
| | **Mean** | **58.95** | **27.21** | **13.84** | | **52.41** | **24.77** | **22.82** | |
| | **LSD** | **NS** | **NS** | **NS** | | **NS** | **0.05** | **NS** | |

**Table 3. Variation of soil chemical properties in the different habitat types in the disturbed Takamanda rainforest**

| Habitat types | Soil depths (cm) | OC (%) | pH$H_2$O | Total N (%) | AvailP(mg/kg) | TotalP (mg/kg) | S (%) | Ca (cmol/kg) | Mg (cmol /kg) | K (cmol /kg) | Na (cmol /kg) | CEC (cmol/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Hilly slope** | 0-10 | 2.44 | 5 | 1.72 | 11.17 | 431.79 | 3.53 | 0.28 | 0.56 | 0.09 | 0.08 | 43.36 |
| | 10-20 | 2.13 | 4.8 | 1.26 | 10.31 | 421.06 | 3.42 | 0.32 | 0.24 | 0.09 | 0.14 | 35.20 |
| | 20-30 | 1.95 | 4.9 | 0.91 | 10.25 | 399.62 | 3.13 | 0.36 | 0.16 | 0.04 | 0.08 | 34.40 |
| | 30-40 | 1.45 | 5.2 | 0.82 | 6.65 | 346.00 | 2.72 | 0.64 | 0.20 | 0.04 | 0.14 | 31.44 |
| | 40-50 | 0.96 | 5.3 | 0.90 | 6.62 | 331.70 | 2.04 | 0.48 | 0.12 | 0.09 | 0.14 | 28.64 |
| | 50-60 | 0.28 | 5.2 | 0.84 | 4.71 | 306.68 | 2.04 | 0.36 | 0.04 | 0.09 | 0.14 | 23.68 |
| **Plain (low land)** | 0-10 | 2.01 | 5.1 | 1.22 | 11.77 | 285.24 | 4.62 | 0.40 | 0.24 | 0.18 | 0.19 | 32.80 |
| | 10-20 | 1.82 | 5.1 | 1.11 | 11.54 | 299.54 | 4.45 | 0.56 | 1.00 | 0.16 | 0.14 | 45.60 |
| | 20-30 | 1.64 | 5.4 | 0.95 | 9.24 | 278.09 | 3.26 | 0.36 | 0.36 | 0.16 | 0.14 | 35.20 |
| | 30-40 | 1.45 | 5.2 | 0.90 | 8.41 | 270.94 | 2.31 | 0.48 | 0.48 | 0.09 | 0.14 | 30.40 |
| | 40-50 | 1.20 | 5.4 | 0.82 | 7.79 | 256.64 | 2.62 | 0.32 | 0.32 | 0.09 | 0.14 | 30.80 |
| | 50-60 | 1.17 | 5.5 | 0.79 | 6.13 | 245.92 | 2.18 | 0.40 | 0.28 | 0.09 | 0.14 | 27.84 |
| **Ridge top** | 0-10 | 2.50 | 5.3 | 2.21 | 8.89 | 270.94 | 2.18 | 0.56 | 0.04 | 0.01 | 0.14 | 32.00 |
| | 10-20 | 1.20 | 5.4 | 1.19 | 8.84 | 253.07 | 2.14 | 0.60 | 0.10 | 0.01 | 0.14 | 29.60 |
| | 20-30 | 0.90 | 5.4 | 1.07 | 8.04 | 360.30 | 1.36 | 0.72 | 0.08 | 0.02 | 0.14 | 41.60 |
| | 30-40 | 0.83 | 5.7 | 0.70 | 7.96 | 413.92 | 1.90 | 0.28 | 0.72 | 0.01 | 0.08 | 31.60 |
| | 40-50 | 0.77 | 5.8 | 0.61 | 7.54 | 342.43 | 1.63 | 0.60 | 0.08 | 0.01 | 0.06 | 32.40 |
| | 50-60 | 0.40 | 5.4 | 0.50 | 5.70 | 356.73 | 1.63 | 0.28 | 0.32 | 0.01 | 0.06 | 32.80 |
| **Swamp** | 0-10 | 1.27 | 5.3 | 1.34 | 10.44 | 331.70 | 2.77 | 0.24 | 1.28 | 0.09 | 0.14 | 26.40 |
| | 10-20 | 1.76 | 5.2 | 1.05 | 7.61 | 238.77 | 2.18 | 0.28 | 0.36 | 0.09 | 0.14 | 30.80 |
| | 20-30 | 1.27 | 5.8 | 0.71 | 7.16 | 342.43 | 2.31 | 0.40 | 0.20 | 0.09 | 0.14 | 28.96 |
| | 30-40 | 0.65 | 6.1 | 0.65 | 6.30 | 238.77 | 1.90 | 0.76 | 0.12 | 0.09 | 0.14 | 30.40 |
| | 40-50 | 1.64 | 6.2 | 0.57 | 6.15 | 256.64 | 1.77 | 0.52 | 0.84 | 0.09 | 0.14 | 33.92 |
| | 50-60 | 1.20 | 6.3 | 0.46 | 5.85 | 399.62 | 1.61 | 0.92 | 0.16 | 0.09 | 0.08 | 26.40 |
| **Valley bottoms** | 0-10 | 3.12 | 5.8 | 2.28 | 15.85 | 442.15 | 3.94 | 0.52 | 2.80 | 0.18 | 0.14 | 32.00 |
| | 10-20 | 2.07 | 5.6 | 1.33 | 10.00 | 353.15 | 3.80 | 0.22 | 0.72 | 0.04 | 0.08 | 30.40 |
| | 20-30 | 1.64 | 6.3 | 1.20 | 8.11 | 317.41 | 3.54 | 0.36 | 0.52 | 0.16 | 0.14 | 30.80 |
| | 30-40 | 0.59 | 6.4 | 0.70 | 7.92 | 285.24 | 1.90 | 0.44 | 0.24 | 0.04 | 0.08 | 28.40 |
| | 40-50 | 0.53 | 6.3 | 0.63 | 7.71 | 306.68 | 1.63 | 0.36 | 0.72 | 0.04 | 0.08 | 28.40 |
| | 50-60 | 0.28 | 5.9 | 0.49 | 7.16 | 285.24 | 1.36 | 0.40 | 0.16 | 0.01 | 0.14 | 29.20 |
| | **Mean** | **1.39** | **6** | **1.02** | **9.00** | **322.29** | **2.42** | **0.45** | **0.45** | **0.08** | **0.12** | **31.85** |
| | **LSD** | **0.03** | **NS** | **0.05** | **0.04** | **0.04** | **0.05** | **NS** | **0.04** | **0.05** | **0.05** | **0.05** |

## 3.3 Soil Cation Exchange Capacity (CEC) in the Disturbed Forest

The cation exchange capacity (CEC) varied significantly different ($P < 0.001$) across depths and habitat types in the disturbed forest (Table 3). Cation exchange capacity showed no trend across soil depth and habitat types in the disturbed forest (Table 3). The highest CEC concentration was observed in plain (45.60 cmol $kg^{-1}$) at soil depth 0- 10 cm while the least concentration noted in swamp (26.40 cmol $kg^{-1}$) at soil depth 0-10cm.

## 3.4 Soil Chemical Properties across Habitat Types and Soil Depths in the Undisturbed Forest

### 3.4.1 Percentage soil organic carbon in the undisturbed forest

The percentage organic carbon varied across soil depths and habitat types in the undisturbed forest and this was not significantly different at P= 0.05(Table 4). It was noticed that the % C decreases with soil depth in the various habitat types (Table 4). The highest % C was noted in plain (3.38 %) at soil depth 0-10 cm while the least % C was reported in ridge top (0.46%) at soil depth 50-60cm.

### 3.4.2 Soil pH in $H_2O$ in the undisturbed forest

The soil pH varied across soil depths and habitat types in the undisturbed forest and was not significantly different at P= 0.05. The highest soil pH in $H_2O$ was observed in swamp (6.00) at soil depth 10-20 cm while the lowest soil pH was recorded in valley bottoms (4.1) at soil depth 0-10 cm.

### 3.4.3 Total percentage soil nitrogen in the undisturbed forest

The total percentage nitrogen concentration decreases with soil depths across the habitat types in the undisturbed forest (Table 4). The highest total % N concentration was observed in plain (2.42 %) at soil depth 0-10 cm while the least concentration was noted at the hilly slope (0.74%) at soil depth 50-60cm).

### 3.4.4 Soil available phosphorus in the undisturbed forest

Available P showed significant differences (P=0.05) across habitat types in the undisturbed forest (Table 4). Available P showed a decrease with soil depths across habitat types and highest available P levels was obtained in plain (34.86 mg/kg) at soil depth 0- 10 cm while the least available P levels at that same soil depth was observed at the ridge top (5.82 mg/kg) at soil depth 50-60cm.

### 3.4.5 Soil total phosphorus in the undisturbed forest

Total P showed significant differences (P= 0.05) across habitat types in the undisturbed forest (Table 4). Total P decrease with depths across habitat types in the undisturbed forest. The highest total P was in valley bottom (771.36 mg/kg) at soil depth 0- 10 cm while the least total P was observed at the ridge top (274.51mg/kg) at 50-60cm soil depth.

### 3.4.6 Percentage soil sulphur in the undisturbed forest

Percentage Sulphur varied significantly ($P < 0.05$) across soil depths and habitat types in the undisturbed forest (Table 4). There was no trend noted in respect to soil depths and habitat types. The highest % S was recorded in valley bottom (2.18 %) at soil depth 0-10 cm while the least was observed at the swamp (0.52%) at 50-60cm soil depth.

### 3.4.7 Soil Ca, Mg, K and Na in the undisturbed forest

Calcium, Mg and K varied significantly ($P < 0.001$) across habitats in the undisturbed forest (Table 4). Generally, the concentrations of Ca, Mg, K and Na were decreasing with soil depths in the undisturbed forest.

The highest concentration of Ca was observed on ridge top (0.74 cmol/kg) at soil depth 0-10 cm (Table 4) while the least Ca concentration was observed at the swamp (0.68 cmol/kg) at soil depth 50-60cm. The highest concentration of Mg was noticed on hilly slope (0.52 cmol/kg) at soil depth 0-10 cm while the least was observed in the swamps (0.04cmol/kg) at soil depths 40 – 60cm (Table 4).

The highest K was observed in plain (0.05 cmol/kg) at soil depth 0- 10 cm while the least was observed at the plains, ridge top, swamps and valley bottom (0.01cmol/kg) at soil depths 30-60cm.

The highest Na concentration was observed in plain (0.20cmol/kg) at soil depth 0-10 cm while the least concentration was noted at hilly slope and plains (0.01 Cmol/kg) at soil depths 30-60cm.

**Table 4. Soil chemical properties in different habitat types in the undisturbed Takamanda rainforest**

| Habitat types | Soil depths (cm) | OC (%) | pH($H_2O$) | Total N(%) | Avail P (mg/kg) | TotalP (mg/kg) | S (%) | Ca (cmolkg$^{-1}$) | Mg (cmol Kg$^{-1}$) | K (cmol kg$^{-1}$) | Na (cmolkg$^{-1}$) | CEC (cmol/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hilly slope | 0-10 | 2.13 | 4.6 | 1.89 | 22.06 | 485.40 | 1.63 | 0.72 | 0.52 | 0.02 | 0.19 | 30.72 |
| | 10-20 | 1.88 | 5.6 | 1.25 | 16.71 | 360.30 | 0.82 | 0.68 | 0.36 | 0.02 | 0.17 | 29.20 |
| | 20-30 | 1.70 | 5.3 | 1.10 | 13.63 | 360.30 | 0.54 | 0.65 | 0.24 | 0.02 | 0.08 | 28.80 |
| | 30-40 | 1.20 | 5.0 | 0.91 | 13.42 | 317.41 | 1.36 | 0.60 | 0.20 | 0.01 | 0.08 | 27.20 |
| | 40-50 | 0.59 | 5.4 | 0.85 | 11.60 | 288.81 | 1.36 | 0.40 | 0.18 | 0.01 | 0.08 | 26.80 |
| | 50-60 | 0.53 | 5.9 | 0.74 | 10.93 | 285.24 | 1.22 | 0.40 | 0.04 | 0.01 | 0.08 | 25.36 |
| Plain | 0-10 | 3.38 | 4.4 | 2.42 | 34.86 | 399.62 | 1.36 | 0.68 | 0.32 | 0.05 | 0.20 | 31.20 |
| | 10-20 | 3.18 | 4.8 | 1.54 | 18.00 | 360.30 | 1.36 | 0.64 | 0.32 | 0.04 | 0.14 | 30.80 |
| | 20-30 | 2.38 | 5.1 | 1.23 | 14.80 | 349.58 | 1.22 | 0.64 | 0.12 | 0.02 | 0.14 | 30.00 |
| | 30-40 | 1.82 | 5.2 | 1.00 | 14.56 | 346.00 | 1.22 | 0.48 | 0.12 | 0.01 | 0.14 | 27.92 |
| | 40-50 | 1.76 | 5.4 | 1.09 | 10.99 | 342.43 | 1.09 | 0.44 | 0.04 | 0.01 | 0.08 | 26.80 |
| | 50-60 | 1.33 | 5.7 | 1.26 | 10.99 | 324.56 | 1.36 | 0.36 | 0.04 | 0.01 | 0.08 | 25.28 |
| Ridge top | 0-10 | 2.01 | 5.3 | 0.86 | 22.00 | 403.19 | 1.63 | 0.74 | 0.28 | 0.04 | 0.14 | 29.60 |
| | 10-20 | 1.95 | 4.3 | 1.55 | 8.47 | 338.85 | 1.50 | 0.72 | 0.24 | 0.02 | 0.14 | 26.40 |
| | 20-30 | 1.95 | 4.5 | 1.40 | 8.47 | 331.70 | 0.95 | 0.68 | 0.24 | 0.01 | 0.08 | 21.76 |
| | 30-40 | 1.82 | 4.7 | 1.19 | 8.22 | 320.98 | 1.09 | 0.56 | 0.18 | 0.01 | 0.08 | 20.80 |
| | 40-50 | 1.76 | 4.7 | 1.07 | 6.01 | 306.68 | 1.50 | 0.58 | 0.04 | 0.01 | 0.08 | 20.00 |
| | 50-60 | 0.46 | 4.7 | 0.93 | 5.82 | 274.51 | 1.50 | 0.48 | 0.04 | 0.01 | 0.08 | 19.20 |
| Swamp | 0-10 | 1.88 | 5.6 | 1.56 | 29.63 | 431.79 | 2.04 | 0.72 | 0.26 | 0.04 | 0.14 | 30.80 |
| | 10-20 | 1.88 | 6.00 | 1.35 | 28.40 | 360.30 | 1.22 | 0.68 | 0.26 | 0.01 | 0.14 | 29.20 |
| | 20-30 | 1.82 | 5.2 | 1.28 | 26.74 | 360.30 | 1.50 | 0.58 | 0.23 | 0.02 | 0.14 | 26.40 |
| | 30-40 | 1.82 | 5.3 | 1.12 | 21.26 | 356.73 | 1.63 | 0.48 | 0.18 | 0.04 | 0.08 | 21.76 |
| | 40-50 | 1.51 | 5.4 | 1.05 | 20.55 | 342.43 | 0.54 | 0.36 | 0.12 | 0.01 | 0.08 | 19.20 |
| | 50-60 | 1.27 | 5.3 | 0.95 | 17.94 | 324.56 | 0.52 | 0.28 | 0.08 | 0.01 | 0.06 | 17.60 |
| ValleyBottoms | 0-10 | 1.33 | 4.1 | 2.37 | 17.88 | 771.36 | 2.18 | 0.72 | 0.42 | 0.01 | 0.14 | 25.36 |
| | 10-20 | 1.33 | 4.6 | 1.55 | 20.28 | 753.48 | 1.77 | 0.68 | 0.22 | 0.01 | 0.14 | 28.80 |
| | 20-30 | 1.20 | 4.7 | 1.54 | 18.56 | 753.48 | 0.82 | 0.68 | 0.20 | 0.02 | 0.08 | 27.60 |
| | 30-40 | 0.90 | 5.0 | 1.14 | 17.51 | 735.61 | 1.36 | 0.56 | 0.20 | 0.01 | 0.08 | 26.80 |
| | 40-50 | 0.59 | 5.1 | 1.07 | 15.60 | 674.85 | 0.82 | 0.38 | 0.12 | 0.01 | 0.14 | 25.20 |
| | 50-60 | 0.52 | 5.0 | 1.05 | 15.42 | 413.92 | 0.68 | 0.36 | 0.08 | 0.01 | 0.14 | 25.36 |
| | Mean | 1.56 | 5.00 | 1.28 | 16.55 | 416.42 | 1.31 | 0.56 | 0.21 | 0.02 | 0.11 | 26.57 |
| | LSD | NS | NS | 0.05 | 0.05 | 0.05 | 0.04 | 0.05 | 0.05 | 0.03 | 0.05 | 0.05 |

**Table 5. Some micronutrients concentrations in different disturbed habitat types and soil depths in the Takamanda Rainforest**

| Habitat types | Soil depths(cm) | Mn (mg kg$^{-1}$) | Fe (mg kg$^{-1}$) | Zn (mg kg$^{-1}$) | Cu (mg kg$^{-1}$) | Ni (mg kg$^{-1}$) |
|---|---|---|---|---|---|---|
| Hilly slope | 0-10 | 10.88 | 0.42 | 52.29 | 0.26 | 0.07 |
| | 10-20 | 18.53 | 2.50 | 57.92 | 0.31 | 0.10 |
| | 20-30 | 28.68 | 3.12 | 64.58 | 0.40 | 0.48 |
| | 30-40 | 35.59 | 3.75 | 65.42 | 0.47 | 1.07 |
| | 40-50 | 40.44 | 6.87 | 67.50 | 2.48 | 5.95 |
| | 50-60 | 45.29 | 11.25 | 74.38 | 2.90 | 6.55 |
| Plain (low land) | 0-10 | 45.59 | 11.46 | 86.25 | 6.07 | 5.95 |
| | 10-20 | 47.50 | 12.29 | 82.29 | 7.43 | 5.24 |
| | 20-30 | 47.94 | 15.00 | 81.67 | 8.81 | 6.55 |
| | 30-40 | 50.29 | 15.21 | 84.58 | 9.67 | 8.81 |
| | 40-50 | 50.29 | 16.67 | 83.96 | 10.31 | 8.69 |
| | 50-60 | 52.06 | 19.17 | 81.04 | 10.60 | 9.88 |
| Ridge top | 0-10 | 58.38 | 23.54 | 67.50 | 16.33 | 27.14 |
| | 10-20 | 58.53 | 23.96 | 74.38 | 17.10 | 29.64 |
| | 20-30 | 60.00 | 23.75 | 91.25 | 16.21 | 31.79 |
| | 30-40 | 60.74 | 23.75 | 95.21 | 16.26 | 32.14 |
| | 40-50 | 64.56 | 24.79 | 97.71 | 16.64 | 32.14 |
| | 50-60 | 66.62 | 25.21 | 101.25 | 16.57 | 32.26 |
| Swamp | 0-10 | 49.85 | 16.04 | 89.79 | 12.86 | 12.26 |
| | 10-20 | 50.00 | 18.54 | 90.42 | 13.57 | 12.98 |
| | 20-30 | 51.03 | 18.96 | 92.92 | 13.83 | 13.21 |
| | 30-40 | 51.76 | 18.96 | 93.54 | 14.43 | 17.26 |
| | 40-50 | 52.35 | 19.37 | 96.88 | 14.76 | 20.12 |
| | 50-60 | 52.50 | 22.50 | 98.33 | 15.07 | 23.45 |
| Valley bottoms | 0-10 | 51.03 | 18.54 | 93.75 | 15.19 | 21.31 |
| | 10-20 | 51.91 | 20.00 | 92.29 | 15.38 | 22.50 |
| | 20-30 | 53.09 | 20.63 | 97.29 | 15.45 | 23.93 |
| | 30-40 | 53.24 | 20.62 | 87.92 | 15.55 | 24.76 |
| | 40-50 | 53.68 | 21.87 | 84.17 | 15.62 | 25.36 |
| | 50-60 | 57.65 | 22.29 | 86.04 | 16.02 | 26.90 |
| | Mean | 49.00 | 16.71 | 83.75 | 11.22 | 16.28 |
| | LSD (0.05) | 0.05 | NS | NS | NS | 0.05 |

*NS= Not significant*

**Table 6. Some micronutrient concentrations in different undisturbed habitat types and soil depths in the Takamanda Rainforest**

| Parameters | Soil depths (cm) | Mn (mg $kg^{-1}$) | Fe (mg $kg^{-1}$) | Zn (mg $kg^{-1}$) | Cu (mg $kg^{-1}$) | Ni (mg $kg^{-1}$) |
|---|---|---|---|---|---|---|
| Hilly slope | 0-10 | 75.15 | 21.33 | 116.67 | 20.76 | 38.57 |
| | 10-20 | 75.44 | 22.08 | 119.08 | 20.19 | 38.93 |
| | 20-30 | 75.44 | 23.12 | 120.50 | 20.60 | 37.38 |
| | 30-40 | 75.49 | 23.67 | 122.92 | 21.52 | 38.45 |
| | 40-50 | 77.94 | 24.58 | 125.21 | 21.64 | 38.93 |
| | 50-60 | 77.96 | 25.83 | 129.79 | 21.72 | 42.74 |
| Plain | 0-10 | 66.76 | 23.96 | 134.58 | 22.64 | 34.76 |
| | 10-20 | 69.71 | 23.98 | 136.75 | 22.59 | 37.14 |
| | 20-30 | 71.03 | 24.12 | 137.71 | 22.67 | 38.81 |
| | 30-40 | 71.29 | 24.87 | 138.13 | 22.98 | 38.86 |
| | 40-50 | 72.06 | 24.90 | 141.25 | 23.38 | 40.24 |
| | 50-60 | 72.18 | 24.97 | 142.83 | 23.48 | 40.93 |
| Ridge top | 0-10 | 77.03 | 19.37 | 168.75 | 23.48 | 45.24 |
| | 10-20 | 78.51 | 20.62 | 165.83 | 25.74 | 46.19 |
| | 20-30 | 78.53 | 23.96 | 169.38 | 24.07 | 47.62 |
| | 30-40 | 79.56 | 24.17 | 181.25 | 24.57 | 47.98 |
| | 40-50 | 79.98 | 25.21 | 188.54 | 26.12 | 48.21 |
| | 50-60 | 81.03 | 26.87 | 191.88 | 26.14 | 49.05 |
| Swamp | 0-10 | 78.82 | 22.29 | 135.63 | 21.67 | 41.07 |
| | 10-20 | 78.82 | 22.50 | 141.67 | 22.17 | 43.10 |
| | 20-30 | 78.97 | 24.17 | 141.67 | 22.86 | 43.10 |
| | 30-40 | 79.56 | 24.79 | 143.33 | 23.02 | 44.05 |
| | 40-50 | 80.44 | 25.21 | 148.33 | 24.17 | 45.00 |
| | 50-60 | 80.59 | 27.29 | 151.46 | 24.69 | 46.31 |
| Valley bottoms | 0-10 | 76.82 | 20.38 | 114.17 | 21.07 | 42.14 |
| | 10-20 | 77.03 | 20.42 | 116.46 | 21.36 | 42.86 |
| | 20-30 | 77.59 | 24.37 | 121.67 | 21.57 | 43.36 |
| | 30-40 | 78.09 | 24.46 | 128.33 | 21.86 | 43.43 |
| | 40-50 | 80.15 | 24.67 | 132.50 | 22.43 | 43.74 |
| | 50-60 | 80.44 | 26.92 | 145.21 | 23.71 | 45.07 |
| | Mean | 76.71 | 23.48 | 138.88 | 22.52 | 42.12 |
| | LSD (0.05) | NS | NS | NS | NS | NS |

*NS= Not significant*

### 3.4.8 Soil cation exchange capacity in the undisturbed forest

The cation exchange capacity (CEC) varied significantly ($P< 0.001$) across soil depths and habitat types in the undisturbed forest (Table 4). The trend of CEC decreases with soil depths except the valley bottom that showed no trend. The highest CEC concentration was observed at plain (31.20 cmol/kg) at soil depth 0-10 cm while the least CEC concentration was observed at the swamp (17.60 cmol/kg) at soil depth 50-60cm.

## 3.5 Soil Micronutrients Concentrations

### 3.5.1 Some soil micronutrients concentration across habitat types and soil depths in the disturbed Takamanda rainforest

The soil micronutrients concentrations across habitat types and soil depths in the disturbed forest are shown in Table 5. Generally, micronutrients (Mn, Fe, Zn, Cu and Ni) concentration increases with soil depths and varied across habitat types in the disturbed forest. The highest concentration of Mn was observed on ridge top (66.62 mg $kg^{-1}$) at soil depth 50-60 cm while the least concentration was noted on hilly slope (10.88 mg $kg^{-1}$) at soil depth 0-10 cm and it was significantly different at $P<0.05$) (Table 5). The concentration of Fe increases with soil depths. The highest Fe concentration was noted on ridge top (25.21 mg $kg^{-1}$) at soil depth 50-60 cm while the least Fe concentration was reported on hilly slope(0.42 mg $kg^{-1}$) at soil depth 0-10 cm (Table 5). It was noticed that there was no trend in Zn concentration across depths and habitat types (Table 5). The highest Zn concentration was noted on ridge top(101.25 mg $kg^{-1}$) at soil depth 50-60 cm while the least concentration of Zn was recorded on hilly slope(52.29 mg $kg^{-1}$) at soil depth 0-10 cm (Table 5).The concentration of Cu varied significantly ($P< 0.001$) across the habitat types. There was an increase in Cu concentration with soil depths (Table 5). The highest Cu concentration was on ridge top (17.10 mg $kg^{-1}$) at soil depth 10-20 cm while the least concentration of Cu (0.26 mg $kg^{-1}$) was recorded on hilly slope at soil depth 0-10 cm (Table 5).

The Ni concentration increases with soil depths (Table 5). The highest Ni concentration was observed on ridge top (32.26 mg $kg^{-1}$) at soil depth 50-60 cm while the least Ni concentration was obtained on hilly slope (0.07 mg $kg^{-1}$) at soil depth 0-10 cm in the disturbed forest. There were significant differences at $P<0.05$.

### 3.5.2 Some soil micronutrient concentrations across habitat types and soil depths in the undisturbed Takamanda rainforest

Soil micronutrients concentrations were not significantly different at $P=0.05$ across habitat types and soil depths in the undisturbed forest (Table 6). The trend in the micronutrients (Mn, Fe, Zn, Cu and Ni) concentration showed increases with soil depths across habitat types (Table 6). The highest Mn concentration was observed on ridge top (81.03 mg $kg^{-1}$) at soil depth 50-60 cm while the least Mn concentration was reported in plain (66.76 mg $kg^{-1}$) at soil depth 0-10 cm (Table 6). The highest Fe concentration was observed in swamp (27.29 mg $kg^{-1}$) at soil depth 50-60 cm while the least Fe concentration was recorded on ridge top(19.37 mg $kg^{-1}$) at soil depth 0-10cm and they were not significantly different. The highest Zn concentration was noted on ridge top (191.88 mg $kg^{-1}$) at soil depth 50-60 cm while the least concentration of Zn was on hilly slope(116.67 mg $kg^{-1}$) at soil depth 0-10cm.The highest concentration of Cu was observed on ridge top(26.14 mg $kg^{-1}$) at soil depth 50-60 cm while the least Cu concentration was observed on ridge top(20.76 mg $kg^{-1}$) at soil depth 0-10 cm. The highest concentration of Cu was recorded on ridge top (26.14 mg $kg^{-1}$) at soil depth 50-60 cm while the least Cu concentration was observed on ridge top (20.76 mg $kg^{-1}$) at soil depth 0-10 cm. The highest concentration of Ni was noted on ridge top (49.05 mg $kg^{-1}$) at soil depth 50-60 cm and the least Ni concentration was obtained in plain (34.76 mg $kg^{-1}$) at soil depth 0-10 cm in the undisturbed Takamanda rainforest (Table 6).

## 4. DISCUSSION

The bulk densities were highest in the habitats of ridge top and hilly slope in the undisturbed and disturbed forests and this might be due to lower soil organic matters and high percentage of pebbles in these habitat types. Similar result was reported by [31] on impact of altitude on soil physical and chemical properties of SraGhurgai. The higher bulk density recorded in the swampy habitat in the undisturbed forest might have been a result of higher sand particles in this habitat over silt and clay content. It was generally noticed that the disturbed forest had a higher bulk density as compared to the habitat types in the undisturbed forest. This result could be attributed to anthropogenic activities; mainly frequent logging. Also, the open canopy in the disturbed forest exposes the soils to a lot of physical and abrasive actions such as wind and direct rainfall drops on forest floor. This finding collaborates that of [32] who reported high bulk density increase under *Pinus tecunumanii* plantations without canopy closure.[33] reported a higher bulk density in the disturbed tropical forest in Cote d' Ivoire than for protected forest sites mainly due to human activities.

Soil porosity was highest in plain and valley bottoms in the undisturbed forest. Perhaps this may be linked to the accumulation fine sand particles which have been washed from the slopes. [11], reported similar findings with lower soil porosity in sole plantation with high disturbances than in secondary forest with fewer disturbances in the Nigerian rainforest.

The electrical conductivity was reported to be highest in the valley bottom in the undisturbed forest. Probably the high electrical conductivity in this habitat type could be attributed to soil erosion which carries nutrients to the valley bottoms. Furthermore, the eroded soil could have carried along plant and animal debris which decomposes to release more nutrients in the valley bottoms.

The soil textural class varied from top-soil to sub-soil in the different habitat types in the two forests. Probably the variations from loam, sandy loam, silt loam, sandy loam, loamy sand, silty clay, silty clay, sandy clay loam and clay loam could be as a result of the undulating nature of the terrain which gives rise to a wide variety of textural classes. Similar findings were reported by [34] who mentioned that site characteristics and relief nature of the area could influence textural classes.

In the undisturbed forest the highest percentage soil organic carbon which was recorded in plains where erosion is limited and environmental conditions are suitable for the decomposition of organic matter. The percentage soil organic carbons in the undisturbed forest habitats were higher as compared to the disturbed forest. This might be due to deforestation which has reduced the amount of organic matter on the forest floor due rapid development as a result of temperature increases. This result is in conformity with that of [35] on spatial patterns of soil properties under tree canopy in the Nigeria rainforest.

The soils are acidic in both disturbed and undisturbed sites. The acidity of the soil in the area could have been as a result of parent rock which is made of granite, gneisse, quartzite from which the soils were formed. This finding is in accordance with the works of [19] who reported that the parent rocks in this area are made of a basement complex of granite, gneisses, schist and quartzite. These rocks are acidic in nature and therefore influence the soil pH of the area. It was noted that the undisturbed forest soils were more acidic than those in the disturbed forest. Perhaps it may be due to the high concentrations of Mn and Fe as compared to the disturbed site. These displace cations such as $H^+$, $K^+$, $Ca^{2+}$ and $Mg^{2+}$ in an exchange complex, these cations can be easily leached from the soil to greater soil depth.

Total nitrogen, available phosphorus, total phosphorus and Sulphur in both forest sites generally decreases with increase in soil depths. However, the values were higher in the undisturbed forest as compared to the disturbed forest. The higher values recorded at the upper layers in both the undisturbed and the disturbed forests sites could be as a result of high organic matter levels in the closed canopy and these decomposed to release more of these nutrients into the top soil. [36], confirmed this in their work as they observed microorganisms abundant at the top soil and this plays a major role in nutrients releasing and recycling of nutrients in dead plant and animal parts. In the swampy habitat which recorded the lowest concentrations of most of these nutrients could perhaps be attributed to the water logged condition which makes decomposition very slow for nutrients release to be recycle into the system. This is because the condition is anaerobic and most of the soil organisms need oxygen in the decomposition processes. The low concentrations of total nitrogen, available phosphorus, total phosphorus and sulphur in the disturbed site could be attributed to anthropogenic activities which might increase the rate of soil erosion and thereby influence leaching of these nutrients.

Calcium, Mg, K, Na and CEC showed generally no trends decrease with soil depths in the two forests, which might be due to leaching and the undulating nature of the terrain with different habitat types. [37] reported that the distribution of soil nutrients with soil depths in forest ecosystem decreases with soil depth due to limited organic matter for decomposition and nutrient release in the sub soils.

The soil micronutrient concentration increases with soil depths in both habitat and forest sites. Probably, these high values noticed with increase in soil depths could have been due to leaching of these minerals to the lower part of the soil. [38] reported that they are many factors that enable the availability of micronutrients to plants. The primary factors included soil pH, soil organic matter, soil moisture and temperature; variation in these soil factors can lead to leaching of nutrients to the lower soil depth. The higher values of the micronutrient concentrations in the undisturbed forest sites in all habitats as compared with the disturbed sites could be attributed to perturbations that occur in the disturbed forest. [34], confirmed that perturbations affect the storage and retention of nutrients in the forest ecosystem. The parent rock from which the soil was formed is acidic and may have contributed to high concentration of Mn and Fe.

## 5. CONCLUSION

This study revealed that the Takamanda rainforest showed variations in physicochemical properties across habitat types and soil depths in the two forests. The bulk densities varied across habitat types and soil depths in the two forests. The soil porosity was influenced by soil texture and percentage organic matter. The variations were reported to be as a result of anthropogenic activities. The soil textural classes showed variations in soil textures in the top soil and sub soil in the two forests types. The soil pH was acidic and decreases with depths across habitat types and forest sites. The macronutrients concentrations across habitat and soil depths showed no specific trends with soil depths while micronutrients concentrations increased with soil depths in the two forests sites. The soils of these areas would influence growth of the plant species and also their diversity when properly managed.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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