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An Assessment and Geostatistics of Land-Use and Selected Physico-Chemical Properties of Soils in the Mount Cameroon Area

Nchia Peter Ghong[1*], Ngwa Martin Ngwabie[1], Godswill Azinwie Asongwe[2], Arnold Chi Kedia[3], Cheo Emmanuel Suh[4,5]

[1]Department of Agriculture and Environmental Engineering, College of Technology, University of Bamenda, Bambili, North West Region, Cameroon
[2]Department of Environmental Science, University of Buea, Buea, South West Region, Cameroon
[3]School of Geographical Sciences and Urban Planning, Arizona State University, Tempe, AZ, USA
[4]Department of Geology, Faculty of Science, University of Bamenda, Bambili, North West Region, Cameroon
[5]Economic Geology Unit, Department of Geology, University of Buea, Buea, South West Region, Cameroon
Email: *nchiaghong@gmail.com

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Abstract

This work investigated the land-use/land-cover and some physico-chemical properties of the soils of Mt Cameroon and presented same in maps. ArcGIS Pro mapping software, Landsat images, Global Positioning Systems (GPS) coordinates collected from the field combined with updated shape files from competent services were used to produce the location and land-use/land-cover maps. Sixteen topsoil samples (0 - 20 cm) were collected, 4 from each land use/cover category: farmland, forest, plantation and settlement, and analysed for soil pH, cation exchange capacity (CEC), bulk density, moisture content and soil texture, in the laboratory using standard analytical procedures. This data was used to produce spatial distribution maps using ordinary kriging, in ArcGIS Pro. The main terrestrial land use/cover categories comprised of the forest (mangrove, lowland, montane and sub-montane), agroforestry, plantations, grassland, settlement, cropland, shrubby savannah, and bare lava. Bulk density showed the highest values in settlement areas and least values under forest land-use categories. Soil moisture content exhibited a reverse trend compared to that of soil bulk density. Forest soils were the sandiest while soils in plantation agricultural land were the most clayey. The soils were slightly acidic to neutral with soils from agricultural land being more acidic ($pH_{(water)}$ = 5.43). It is discernible from the results that the conversion from forest to other land use/cover classes enhances soil degradation and that soil physico-chemical properties adequately serve as indicators of soil quality in the Mt Cameroon area.

Keywords

Geographic Information Systems, Geostatistics, Land-Use, Mt Cameroon, Soil Quality, Thematic Maps

1. Introduction

The presentation of scientific findings in forms that facilitate comprehension by non-specialists is central for the sustainable management of environmental resources and by extension, the accruing benefits to mankind. The combined use of GIS tools and related technology for the visualization of data has proven to be a reliable approach for the utilization, management, and monitoring of environmental resources [1] [2] [3].

Human interactions with the environment impact on the dynamics and functioning of ecosystems [4]. The management or exploitation of soil resources, for instance, may affect soil physical, chemical and biological properties and could result in a change of the land-use/land-cover (LULC) class [5]. LULC change, on the other hand, could lead to the alteration of soil properties [6] [7]. The sustainable use of soils and other natural resources, to maximize the benefits of their ecological services to man, remains a major challenge [8]. Monitoring and sporadic assessment of resource characteristics are primordial for sustainability [9] [10].

A change in soil properties affects processes that take place in the soils and could compromise the productivity of the land. Soil physical properties play a decisive role in the capture, retention and transmission of water; aeration and gaseous exchange; effective rooting depth; soil heat capacity and the temperature regime [11]. A disruption in soil chemistry is a big threat to soil quality, productivity, as well as environmental protection; plant, animal and human health [12] [13]. Management practices that preserve or enhance soil physical and chemical properties are, therefore, essential for the sustenance of environmental quality, safeguarding of biodiversity and promoting human wellbeing [14]. In view of these functions and challenges, land managers need information that allows them to make rational decisions.

Another challenge related to research in soil science is that data is often available on representative samples (points or lines) especially for difficult terrains and extensive study areas, but decisions are expected to be made regarding the entire land mass. Rational and far-reaching management decisions expected to enhance sustainability, require spatially continuous data. To generate such information from point or linear data calls for the use of methods that can make predictions on information at unsampled locations, using the available data. Several studies have projected geostatistics as a possible bridge between hard intermittent data obtained in the field and the continuous data required to ease scientific interpretations and the making of decisions by managers and policy makers [15] [16]. Burrough [1] demonstrated that GIS, statistics and geostatistics were essential and complimentary partners in the capturing, storage, retrieval, digitization, analysis, and display of spatial data. The interpolation results can be rendered even much easier for visual interpretation and re-evaluation by environmental managers, by importing them on to the digital elevation model (DEM) of the study area [17] [18].

The investigation of land-use and soil physicochemical properties has been the subject of numerous research projects, elsewhere. Studies on LULC changes and their relatedness to soil quality characteristics have been carried out at different scales in space and time [9] [19] [20] [21] [22] [23]. Soil physicochemical characteristics have also been extensively investigated. Fetene and Amera [24], for instance, found that sand and clay particle fractions, bulk density and soil porosity were significantly affected by land-use; while Moges, Dagnachew [10] reported that all soil textural fractions exhibited significant variations for different land-use classes; and Shaver, Peterson [25] and Agbede, Ojeniyi [26] reported significant improvement of soil physical properties following the addition of crop residues and poultry manure respectively. Barzegar, Yousefi [27] reported a negative correlation between bulk density and the rate of application of organic matter to soil; and a positive correlation between the amounts of organic matter added to the soil and soil water content.

The veracity and dependence of results of studies on the interactions between LULC and soil parameters have been established elsewhere but such studies are rare for the study area. Mount Cameroon is a biodiversity hotspot harbouring a protected area, the Mount Cameroon National Park, with a host of other features of importance and activities on its foot slopes. It is commonly described as Cameroon in miniature, comprising of land-use/land cover classes characteristic of the different ecological zones of Cameroon. The fertile lands attract huge agricultural activities; both (industrialized) plantation and peasant agriculture, as well as a rapidly growing population that leads to the expansion of settlement area. The Mountain is an active volcano where materials are constantly added to the surface, thereby modifying the soils. The type of human activities in the area and their trends points to imminent land degradation if the situation is not adequately managed. It is within the context of the fact that the availability of scientific information in easily exploitable formats is a necessary condition for rational, sound and well-informed decision making, that this study sets out to investigate the land-use, soil physical properties, acidity, the cation exchange capacity in the area and to present same geospatially, in the form of maps which can easily be exploited by policy makers.

2. Materials and Methods

2.1. Description of Study Area

Mount Cameroon, a stratovolcano, is part of the Cameroon Volcanic Line (CVL) (**Figure 1**). The peak of the mountain (~4100 m) is approximately 25 km inland from the coastline. The base of the massif, approximately elliptical in shape,

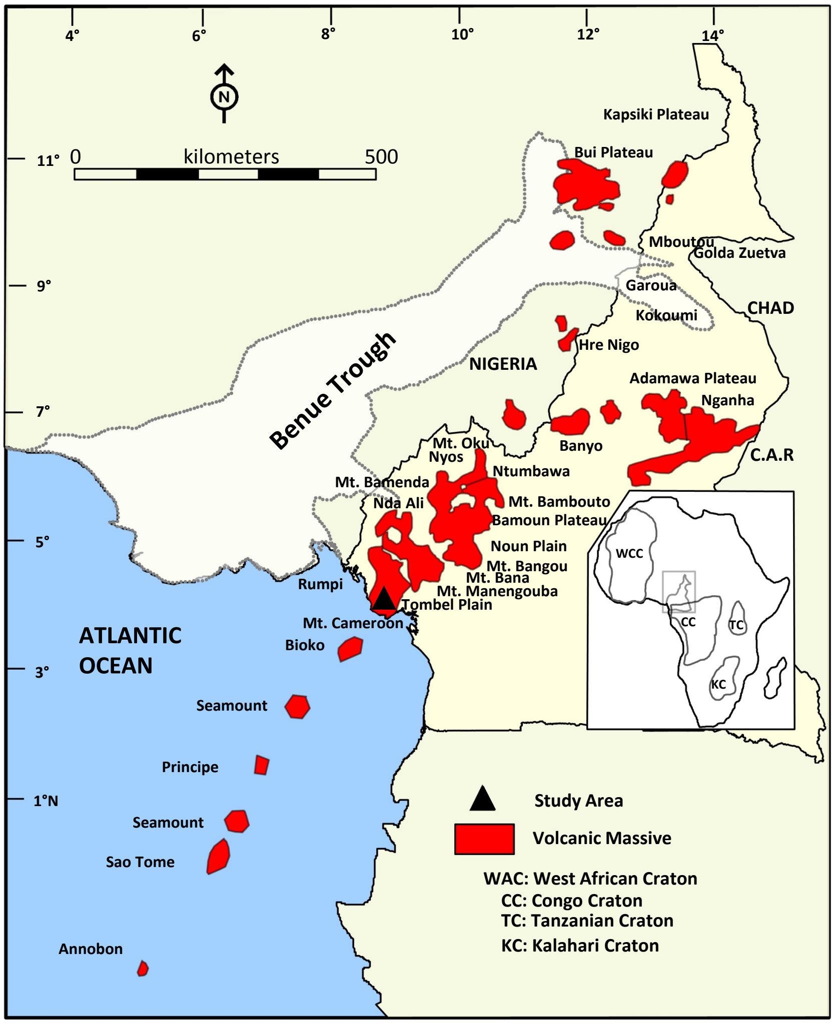


Figure 1. Volcanoes of the Cameroon Volcanic Line (Modified after: [33]).

is estimated to extend between 4˚00' - 4˚28'N and 9˚00' - 9˚30'E. It is an active volcano, with a record of eight eruptions in the 20th Century [28] [29]. The study was carried out on the southern slopes of Mt Cameroon (**Figure 2**).

The combined effect of the height of the mountain, its proximity to the Atlantic Ocean, and positions of the various spots relative to the South-westerly and Northeasterly winds, during different periods of the year instil slight changes in the microclimate of the area. For instance, West Coast, in the south west area of the Mountain has abundance of rainfall with a mean annual of c. 9000 mm at Debundscha but Buea has much less, c. 5000 mm, annual mean rainfall. To minimize the disparity in climatic conditions, the study was limited to the southern part and lower flanks of the mountain. The variations of climatic patterns around the Mountain notwithstanding, the Mt Cameroon area, generally speaking, has a tropical seasonal climate with a short dry season (December to February) and a longer rainy season (March to November). The mean annual temperature at sea level is 27˚C and about 0˚C at the summit while the relative humidity, however, remains relatively high c. 75% - 80% (at sea level) [30] [31] [32].

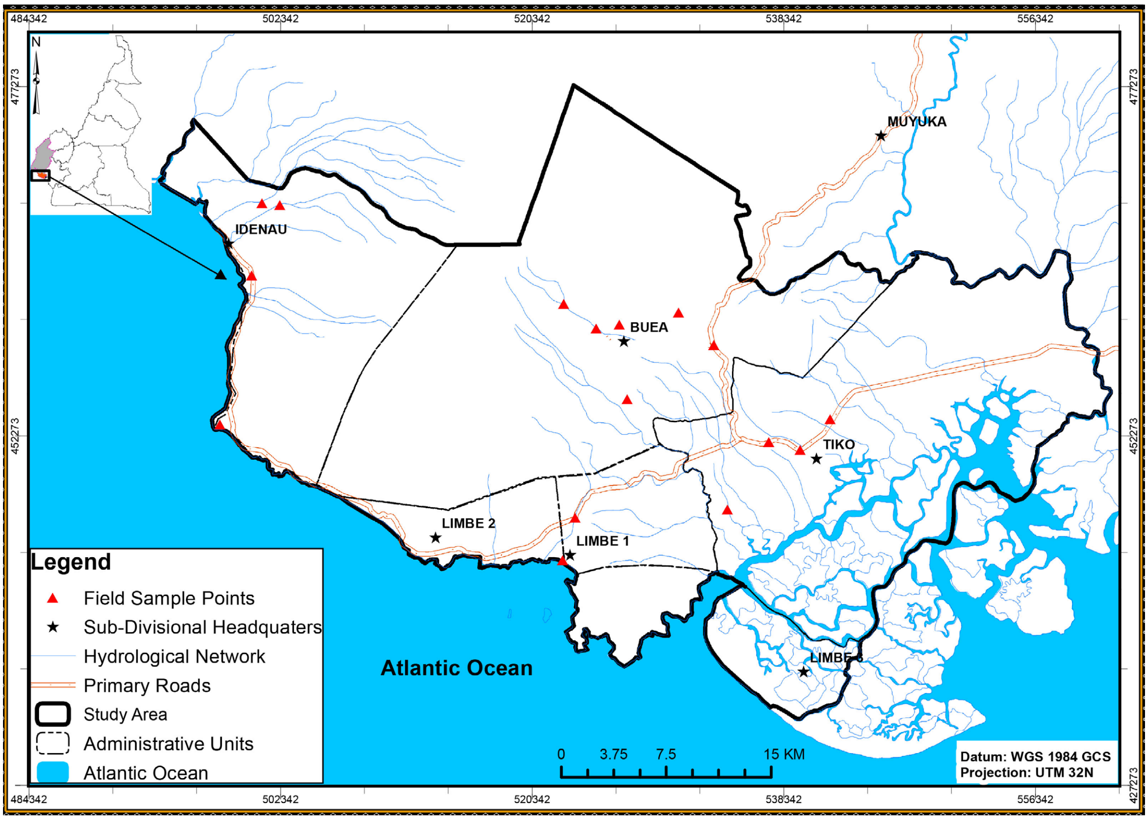


Figure 2. Location map of study area (southern slope of Mt Cameroon).

2.2. Parent Material and Soils of the Study Area

The rocks of Mt Cameroon have been variously described as products of different volcanic events but geochemically similar; comprising of basalts, basanites and hawaiites; and are reportedly covered in some areas by subsidiary fall-out tephra deposits [28] [34] [35]. Like the soil parent material, the soils of the area are of varying ages, accounting for the contrasting weathering degrees. The soils in the upper slopes of the mountain, formed from lava flows, deposits of pyroclastics and volcanic ash have been described to be well drained. Soil profiles range from being very shallow and stony on basaltic ridge crests, with parent material at times exposed on the surface, to deep and sometimes stone-free soil on more gently sloping depressions. At the lower parts of the mountain, the soils are an admixture of relict primary material, secondary minerals from heavily weathered lava and scoriaceous material, and alluvium. The soil thickness on the plains at the foot of Mt Cameroon runs up to c. 10 m in some places [31] [36].

Payton [37] describes the soils around Mount Cameroon as being varieties of Andosols, derived from alkaline basaltic material. Hasselo [36] identified volcanic and alluvial as the two sources of the parent material of the soils. The volcanic soils are said to be either products of the weathering of basement rocks (lava flows), the direct deposition of aeolian volcanic ash, the deposition of mudflows (comprising of volcanic ash and other loose material in valleys and low-lying plains) washed down from the slopes, or a combination of these. Patches of alluvial soils considered to be of marine origin and believed to have been deposited at high sea levels are also reported in the low lying land below the 100 m contour line [36]. The soil colour reflects the age, degree of laterization and organic matter content. For the mineral soils on the upper slopes of the area, the younger soils are generally darker and get more reddish with age and degree of weathering [37].

2.3. Collection of Soil Samples, Processing, Data Analysis and Map Production

Desk work before sample collection comprised of using Landsat and Google Earth images to have an overview of the LULC pattern and the pre-selection of areas to be sampled. A provisional LULC map was produced and used in the extensive field work that followed. Land-use categories were identified, and GPS coordinates recorded for "ground truthing". This information, combined with updated shape files from the Cameroonian Ministry of Scientific Research and Innovation and the Ministry of Forestry and Wild Life, respectively were used in the production of the location map and the current LULC map of the study area. In May 2021, during the on-set of the rainy season, four composite soil samples were collected from each of the 4 major LULC classes—farmland, forest, plantation agriculture and settlement. Following, are the characteristics of the LULC categories.

- Farmland: characterized by the cultivation at small holder scale and mix cropping with the major crops being cassava, cocoyam, plantain, maize, egusi and vegetables.
- Forest: the equatorial rainforest and montane forests, of more than 0.5 hectares, with a tree canopy cover of more than 10 percent, which are not primarily under agricultural or urban land uses [38].
- Plantation: mono-cropping at industrial scales (of either banana, tea, oil palm or rubber).
- Settlement: the built-up area with a high intensity of engineering activities, sometimes characterized by the removal or transported top soil.

Specifically, the samples for the commercial agricultural plantations were collected one each from tea, oil palm, rubber, and banana plantations; and those for the settlement land-use class were collected from around major road junctions in built-up areas. For each sample site, 2 sets of samples were collected. One set was used for the determination of bulk density and moisture content and the other set was used for the determination of soil separates, soil pH and CEC. The latter set of samples was collected using a randomized complete block research design. For each preselected sample site, representative plots of 10 m × 10 m were mapped out. After clearing the debris, top soil (0 - 20 cm) samples were collected from the four corners of the plot and the centre and bulked together to form a composite sample which was later air-dried and sieved to obtain the ≤2 mm faction. The set of samples for the determination of bulk density and moisture content were collected using a metal cylinder (6 cm diameter and 6 cm height) within the plot. After clearing the debris, the metallic cylinder was carefully driven into the ground as to fill the entire cylinder without compressing the soil in it. The soil around the cylinder was excavated and the cylinder with the core in place was carefully removed by sliding a trowel under it. The mass of the core (wet soil) was determined in the field and parcelled in plastic papers, for oven drying in the laboratory.

In the laboratory, samples for the determination of bulk density and moisture content were oven dried at 105˚C to constant weight and weighed. Bulk density was determined as per Hao, Ball [39] and moisture content determined using the procedure described by Clarke Topp, Parkin [40]. With the other set of samples, particle size analysis was carried out using the hydrometer method as outlined by Kroetsch and Wang [41]. Soil textural classes were determined using the designation of the United State Department of Agriculture (USDA). The soil samples were also analyzed for pH and CEC. Soil pH was determined in both water ($pH_{(water)}$) and KCl ($pH_{(KCl)}$) [42] using a glass electrode Thermo-Russel pH meter and CEC was determined using the 1N ammonium acetate (NH_4OAc), pH 7.0 method extraction [43].

The digital elevation model (DEM) was obtained from the website of the United States Geological Survey (USGS, https://earthexplorer.usgs.gov/). The DEM, complemented by data from the fieldwork of the researchers was used in the production of maps. These data and images were processed using ArcGIS Pro 2.7.2 and WGS 84/UTM Zone 32N was used to harmonize the data. The spatial distribution maps of the selected soil physico-chemical properties were produced using ordinary kriging interpolation [1] [3].

3. Results and Discussions

3.1. Land-Use/Land-Cover Distribution

The spatial patterns and magnitudes of the LULC classes of the study area are shown in **Figure 3** and **Figure 4**, respectively. Thirteen LULC classes were identified and classified. These included: agroforestry mosaic (24.27%), mangrove (13.41%), lowland forest (<900 m) (10.31%), sub-mountain forest (>900 - <1.500 m) (9.69%), orchard or plantation forest (8.60), palm plantation (7.63%), grassland (7.07%), mountain forest (>1.500 m) (5.57%), settlement (4.56%), water (2.96%), elephant bush (1.77%), shrubby savanna (1.68%), bare lava fields (1.37%) and cropland/bare soil (1.03%). Working on the entire Mount Cameroon area, Maschler [19] identified and classified similar LULC classes, namely: montane forest, sub-montane forest, shrubby savannah, agroforestry mosaic, open agroforestry mosaic, palm plantation, tree plantation, banana plantation, tea plantation, grassland/bare soil, grassland savannah/lava and settlement. The LULC classes of the study are, therefore, reminiscent of those of the entire Mt Cameroon area. The differences in the identified and classified categories in the two studies might have arisen from subjectivity in interpretation, inexplicit definition of thematic classes, inaccuracies in reference samples, the edge pixels effect and geolocation errors [44].

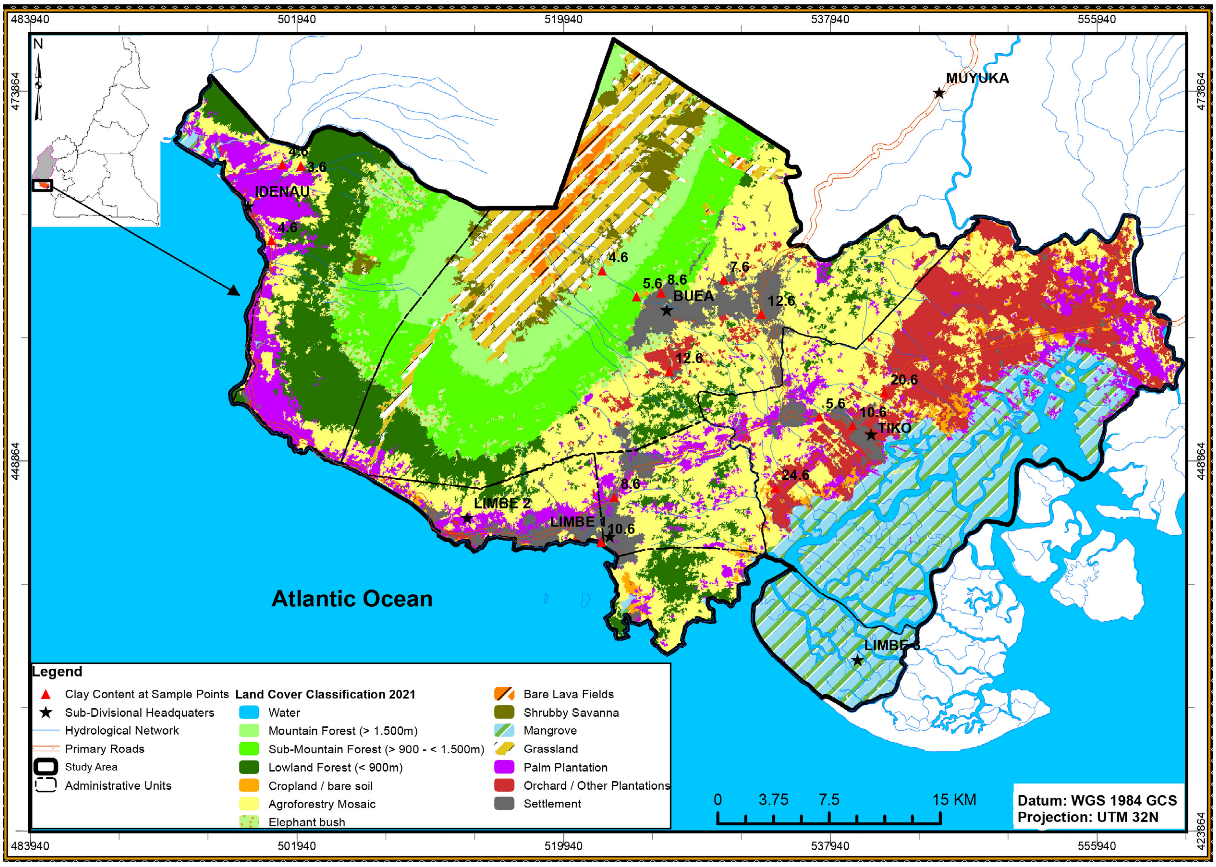


Figure 3. Land-use/land cover map of the southern slopes of the Mt Cameroon area with field sample points.

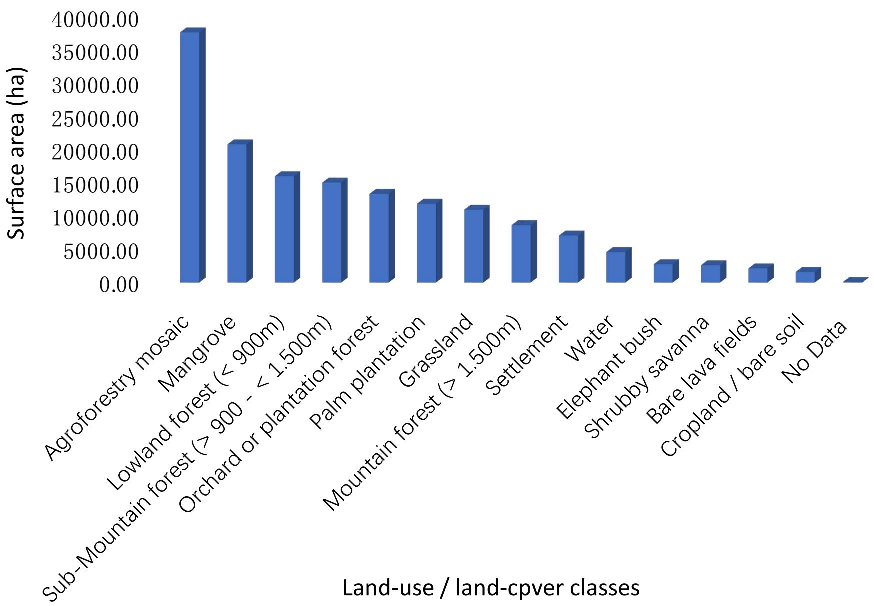


Figure 4. The distribution of the identified land-use/land-cover categories of the southern slopes of Mt Cameroon per surface area.

The water LULC category comprised of the Atlantic Ocean plus the rivers and streams in the area. Mangroves were found along the shore mostly at estuaries.

The lowland comprised mostly of the following LULC categories: lowland forest (<900 m asl), plantations and orchards (<900 m above sea level (asl)) and settlement (<1200 m asl). The other categories were predominantly within the following corresponding ranges of attitude: sub-montane forest (>900 - <1500 m asl), cropland and agroforestry (<1500 m asl), montane forest (~1500 - 1900 m asl), elephant bush (intersperse within lowland, sub-montane forests and montane forest), shrubby savanna (~900 - 2700 m asl), savanna (~2000 - 3500 m asl) and bare lava fields (at around the summit and along lava outcrops of previous eruption events, down to about 100 m asl at Bakingili).

These results revealed that the Mt Cameroon region is Cameroon in miniature; having LULC categories that are typical of the agro-ecological zones of the country. These range from the mono-modal rainforest zone, through the bimodal rainforest zone, highland zone, guinea savanna to the sudano-sahelian zone [45] [46] [47]. The LULC distribution pattern approximately followed an attitudinal gradation. This is consistent with findings by Proctor, Edwards [31] and Hall [48] who reported that there exists a reduction in tree species richness with attitude and vegetation zonation, on Mt Cameroon, respectively. The variety in the LULC classes is the combined effect of the relief of the mountain (~4100 m asl) that orchestrates temperature variation with attitude and influences the effect of the Southwesterly and Northeasterly winds on different positions of the mountain in conjunction with its proximity to the Atlantic Ocean.

The fertile soils and abundance of rainfall in the study area have endowed it with varied forms of life. It has been variedly described as one of the richest biodiversity hot spots, having rare, endangered and endermic species [30] [48] [49]. These characteristics have encouraged agricultural activities for both subsistence and industrial purposes and has attracted high immigration into the area [22] [50] with a corresponding negative impact on the forest cover. Fonge, Bechem [51] reported the yearly clearing of large expands of forest in favour of agricultural expansion, illegal logging, and the collection of fuel wood.

The distribution and expanse of LULC categories of an area have far-reaching implications, to different extends, on food security, the economy and ecology at local, regional, and global levels. They determine the type and quality of ecosystem services offered. Subsistence agriculture goes a long way to improve food security and the livelihood of rural communities and industrial agriculture increases employment and foreign exchange [22]. Vegetation, especially forest cover, serves as a carbon sink thereby attenuating the propensity of climate change and provide several other ecosystem services [4] [52]. These benefits notwithstanding, certain LULC changes could jeopardize sustainable development through biodiversity loss, land degradation, change in micro-climate, decrease in crop yield, soil erosion and rural exodus [53] [54]. To promote the conservation and judicious use of natural resources on Mt Cameroon, the government of Cameroon created a protected area, the Mt Cameroon National Park in 2009 [55].

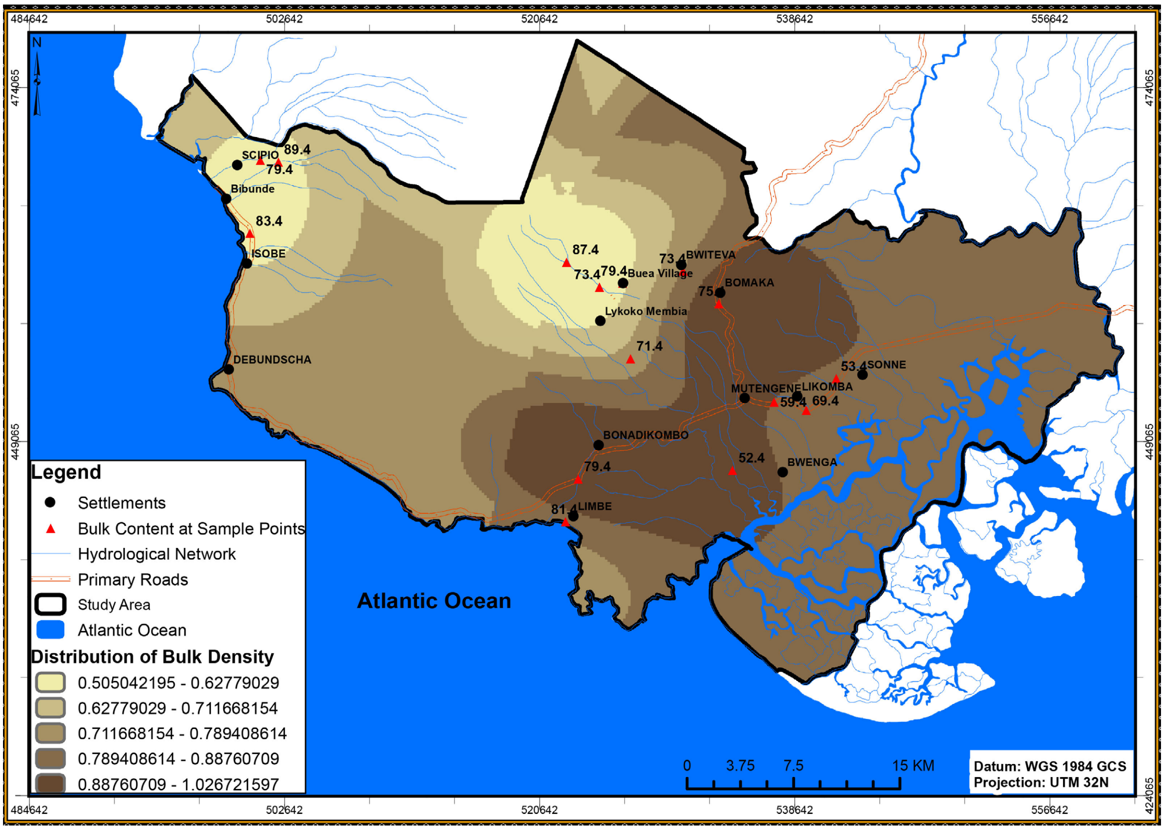
3.2. Soil Physical Properties

The results of variation of the selected soil physical properties of the study area are summarized in **Table 1** and depicted in **Figure 5**. Soil bulk density ranged between 0.33 - 1.24 g/cm^3 with the highest densities registered in settlements with high human habitation followed by areas in plantations, farmland and least in forest areas. This is consistent with the findings of earlier similar studies. For instance, Fetene and Amera [24] reported higher bulk densities for grazing land, followed by cultivated land than for adjacent forest land. Chandel, Hadda [56] reported the following relationship for bulk density: bare > horticulture > grasses > forest > cultivated land. While Bizuhoraho, Kayiranga [57] and Moges, Dagnachew [10] did not find a significant difference in bulk density for the different land-use types they, however, reported a similar sequence in the variation of bulk density: cultivated > farmland > forest, and open grassland > grazing land > forest > farmland, respectively.

Many studies have attributed the variation of soil bulk density with land-use type to differences in soil organic matter content, vegetal cover and the soil management history. Fetene and Amera [24] reported a negative significant correlation ($r = -0.82$, $p < 0.01$) between bulk density and soil organic matter content. The authors equally reported higher values of soil organic matter in soils under forests than for cultivated land. Though soil organic matter was not investigated

Table 1. Summary of selected physical properties of soils of the southern slopes of Mt Cameroon.

LULC	Quantity	Bulk density (g/cm^3)	Moisture content (%)	Clay (%)	Silt (%)	Sand (%)
Farmland	min	0.52	18.53	4.60	12.00	59.40
	max	0.88	39.86	7.60	35.00	83.40
	Mean	0.64	30.91	5.85	21.75	72.40
	SD	0.17	9.32	1.26	9.64	9.87
Forest	min	0.33	25.56	3.60	7.00	81.40
	max	0.67	50.47	10.60	8.00	89.40
	Mean	0.50	35.62	5.60	7.50	86.90
	SD	0.17	11.70	3.37	0.58	3.79
Plantation	min	0.51	22.23	4.60	16.00	52.40
	max	1.05	38.71	24.60	26.00	79.40
	Mean	0.79	27.11	15.60	20.25	64.15
	SD	0.25	7.82	8.87	5.06	13.40
Settlement	min	0.73	18.26	8.60	12.00	69.40
	max	1.24	27.20	12.60	20.00	79.40
	Mean	0.98	22.08	10.10	14.00	75.90
	SD	0.28	4.10	1.91	4.00	4.73


Legend
Settlements
Bulk Content at Sample Points
Hydrological Network
Primary Roads
Study Area
Atlantic Ocean
Distribution of Bulk Density
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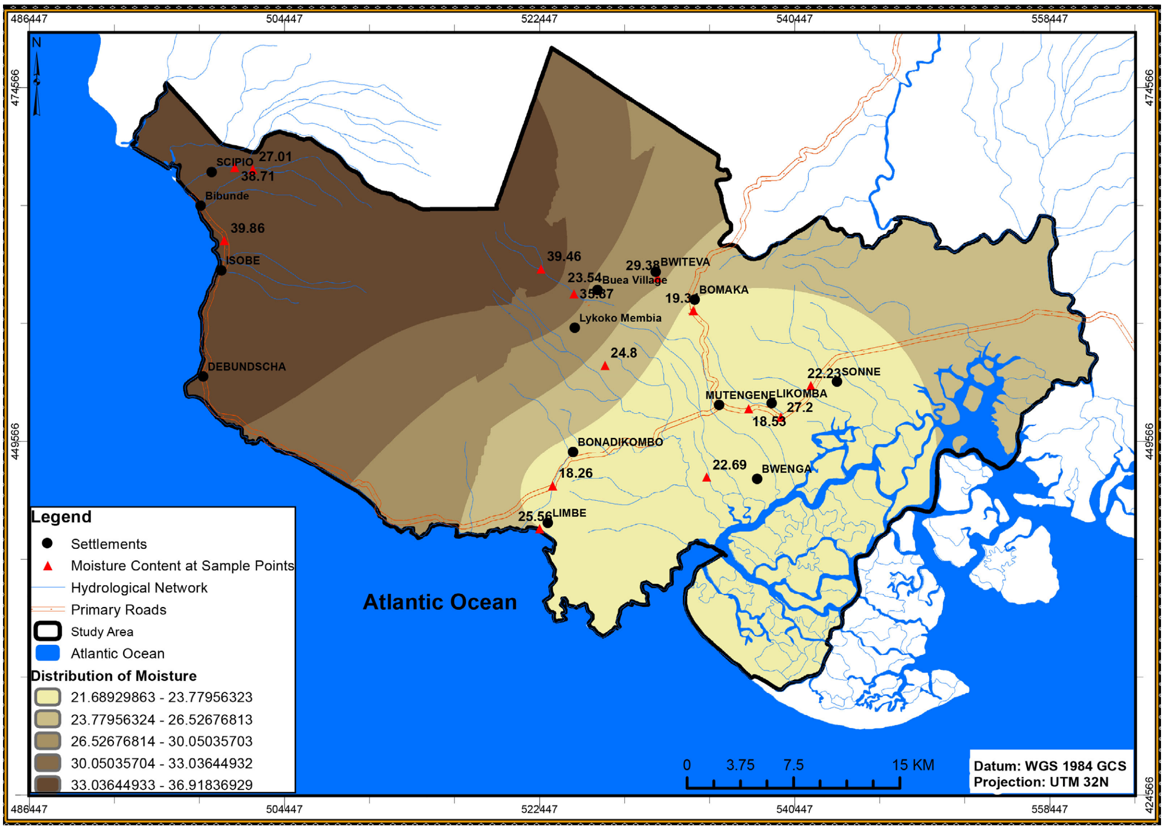
0.62779029 - 0.711668154
0.711668154 - 0.789408614
0.789408614 - 0.88760709
0.88760709 - 1.026721597
Atlantic Ocean
SCIPIO
Bibunde
ISOBE
DEBUNDSCHA
BWITEVA
Buea Village
BOMAKA
Lykoko Membia
SONNE
MUTENGENE
LIKOMBA
BONADIKOMBO
BWENGA
LIMBE
Datum: WGS 1984 GCS
Projection: UTM 32N
0 3.75 7.5 15 KM

(a)


Legend
Settlements
Moisture Content at Sample Points
Hydrological Network
Primary Roads
Study Area
Atlantic Ocean
Distribution of Moisture
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26.52676814 - 30.05035703
30.05035704 - 33.03644932
33.03644933 - 36.91836929
Atlantic Ocean
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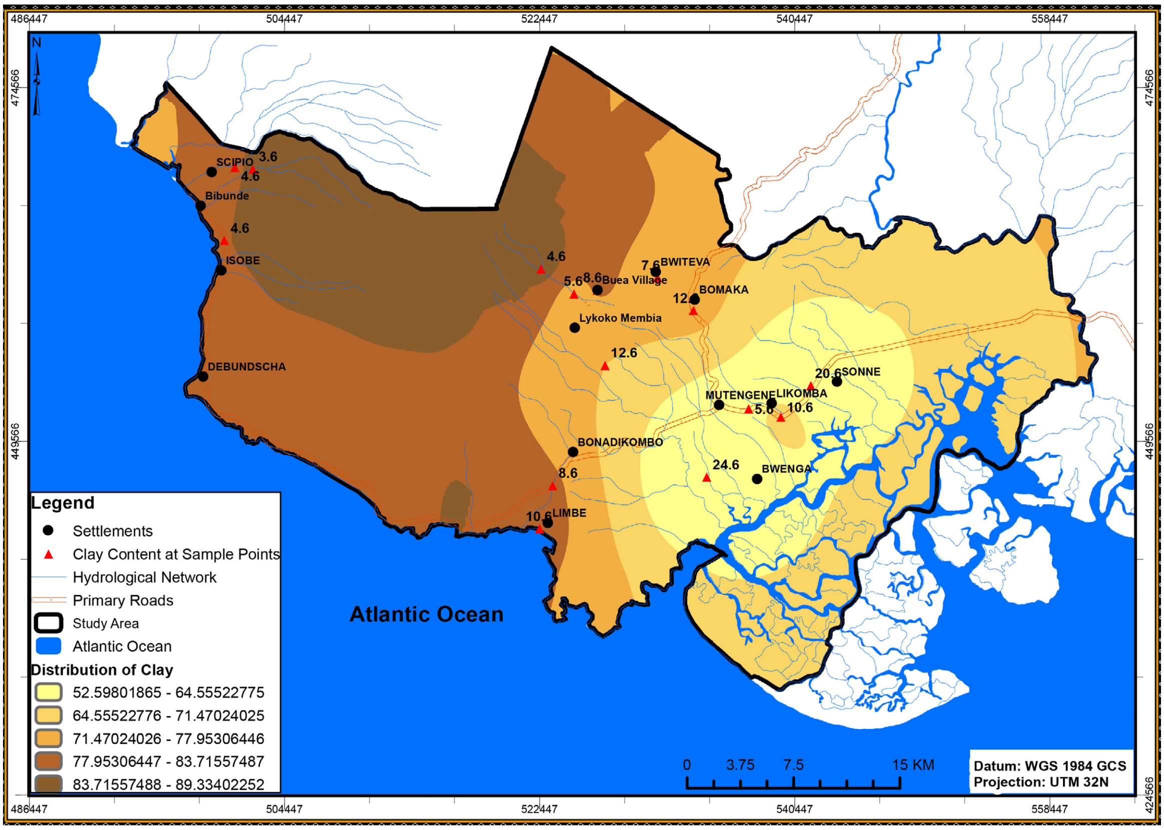
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LIMBE
Atlantic Ocean
Legend
Settlements
Clay Content at Sample Points
Hydrological Network
Primary Roads
Study Area
Atlantic Ocean
Distribution of Clay
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64.55522776 - 71.47024025
71.47024026 - 77.95306446
77.95306447 - 83.71557487
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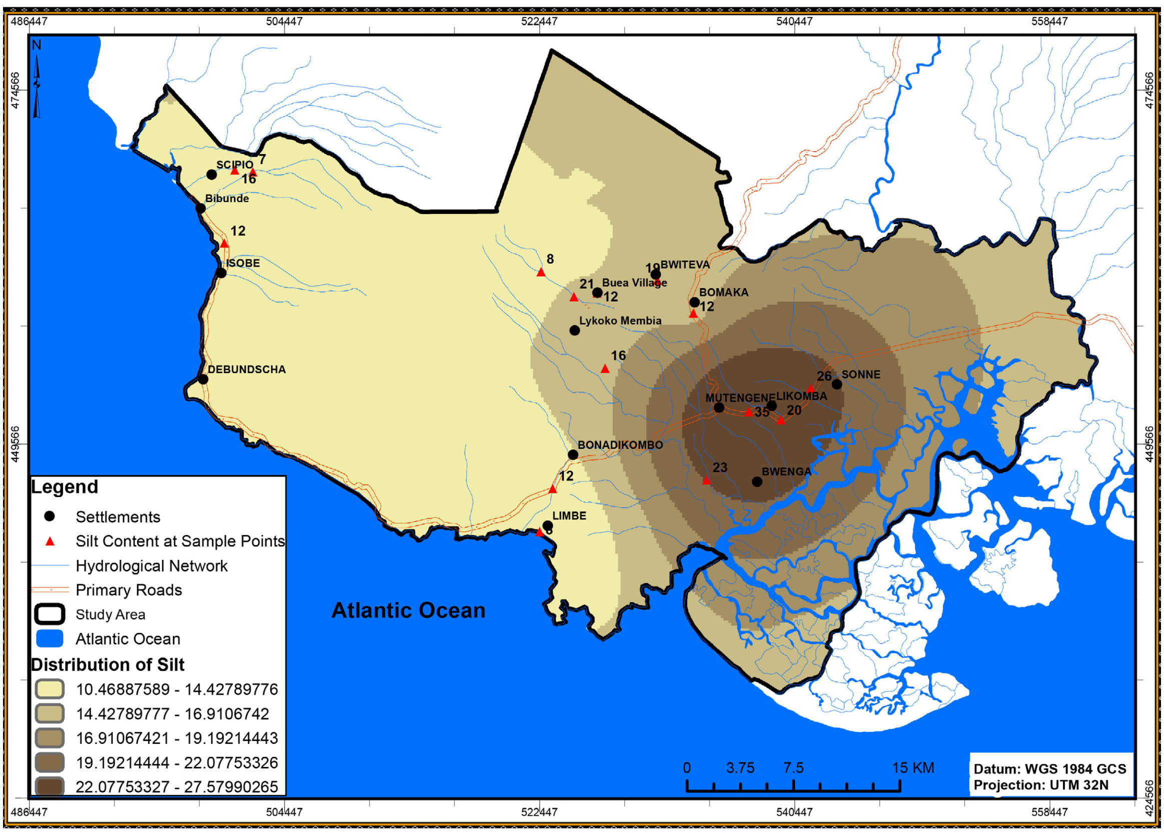
Datum: WGS 1984 GCS
Projection: UTM 32N

(c)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SONNE
MUTENGENE
LIKOMBA
35
20
BONADIKOMBO
12
23
BWENGA
LIMBE
Atlantic Ocean
Legend
Settlements
Silt Content at Sample Points
Hydrological Network
Primary Roads
Study Area
Atlantic Ocean
Distribution of Silt
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14.42789777 - 16.9106742
16.91067421 - 19.19214443
19.19214444 - 22.07753326
22.07753327 - 27.57990265
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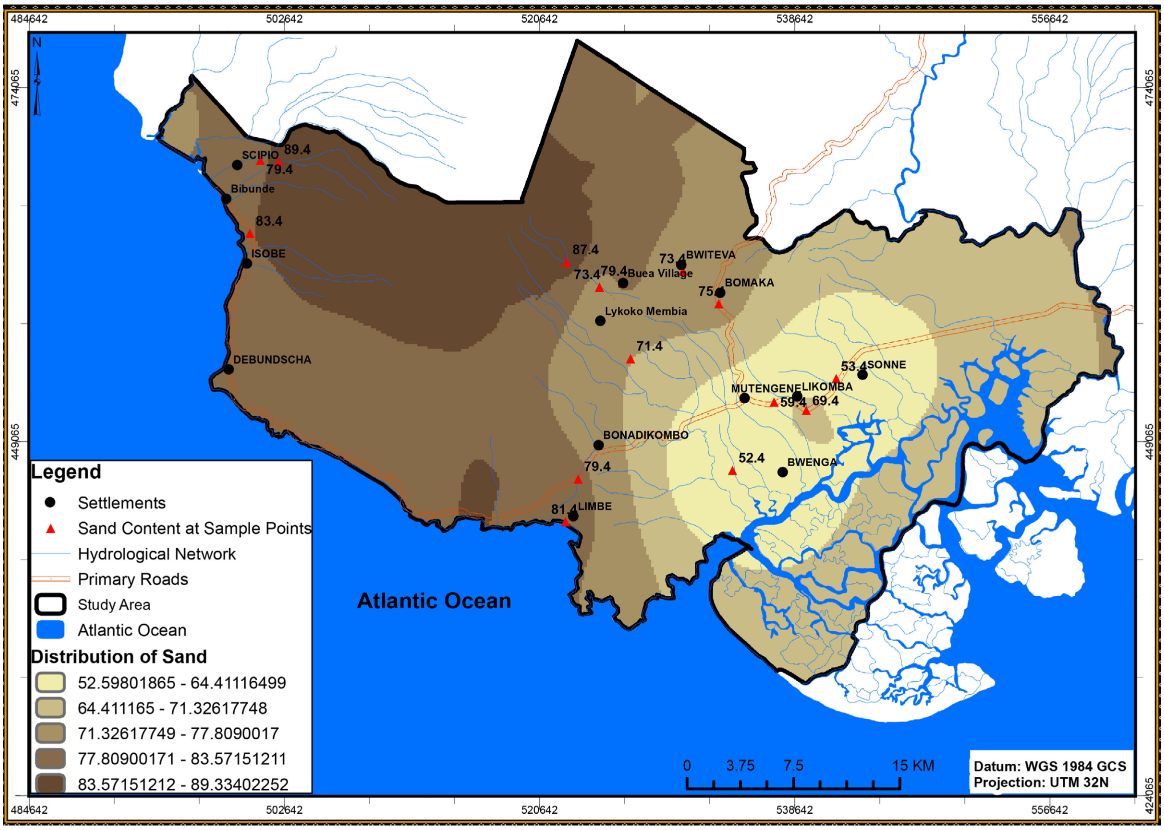
Datum: WGS 1984 GCS
Projection: UTM 32N

(d)



(e)

Figure 5. Spatial distribution of soil physical properties of the top soils of Mt Cameroon (a) bulk density, (b) Moisture content, (c) clay content, (d) silt content, (e) sand content.

in this study, results partly suggest the same trend. The effect of soil organic matter on bulk density is due to the improvement of soil structure with higher contents of organic matter, through the formation of macro aggregates which leads to an increase in the total pore space and a reduction of the potential of soil crusting [27] [58]. Soil vegetal cover and the management history of the soils affect soil bulk density through the influence of activities or processes that impact on soil surface crusting and compaction. The use of machinery; for deforestation, cultivation or urban development, for instance, could also be a contributory factor to explain the trend in bulk density variation with land-use [5].

The trend obtained in this study for bulk density variation was to be expected. Heavy machinery that tends to compact the soil is used for different engineering purposes within the urban centres and occasionally in the plantations for field preparation and harvesting. In addition, irrigation is used in the banana plantations. Farmland is cultivated yearly and the soils of natural forest experience little or no human activity. Forest soils are rich in organic matter owing to fallen litter and limited activities that can lead to the loss of organic matter. Though soil organic matter is lost in farmland facilitated by tilling activities, some organic matter is regained through the ploughing back of crop residue. The return of soil organic matter in the plantations, through falling leaves, is limited while it is mostly constantly being depleted in urban centers.

Moisture content, on the other hand, which ranged between 18.26% and 50.47%, with a mean value of 28.93% was highest in the forested areas, followed by areas in farmland, plantations and least in areas with high human settlement (**Table 1**). This pattern of variation was to be expected, as soil compaction or the collapse of the soil aggregate structure reduces the total pore space in the soil, and hence, it's water retention capacity. This is similar to the results obtained by Chandel, Hadda [56] who found the highest water holding capacity for forest soils, followed by those of horticulture, grasses, cultivated land, and least for bare land land-use. Anderson, Gantzer [58] suggested that soils with higher soil organic matter content have higher water retention capacities.

The proportion of clay was greatest in plantation and least in the forest land-use (plantation > settlement > farmland > forest); while that of silt was greatest in the farmland and least in the forest land-use (farmland > plantation > settlement > forest). The forest land-use class was the sandiest while the plantation LULC class was the least sandy (forest > settlement > farmland > plantation). Using the United States Department of Agriculture (USDA) soil classification scheme, the soils could be classified as sandy, loamy sand, sandy loam and loamy clay sand (**Figure 6**). Moges, Dagnachew [10] reported similar results: the highest proportion of sand in the protected forest land-use class and a relatively higher proportion of clay in the farmland LULC type. They suggested that the relatively higher clay fraction in the farmland could be accounted for by an increased weathering rate, enhanced by farming activities and a change in both the water and temperature regimes of soils in farmland. Tellen and Yerima [59] found the highest percentage of sand at mid-attitudes in an afforested area and the least in a farmland and equally attributed the lower sand content in farmland to the effects of tillage activities.

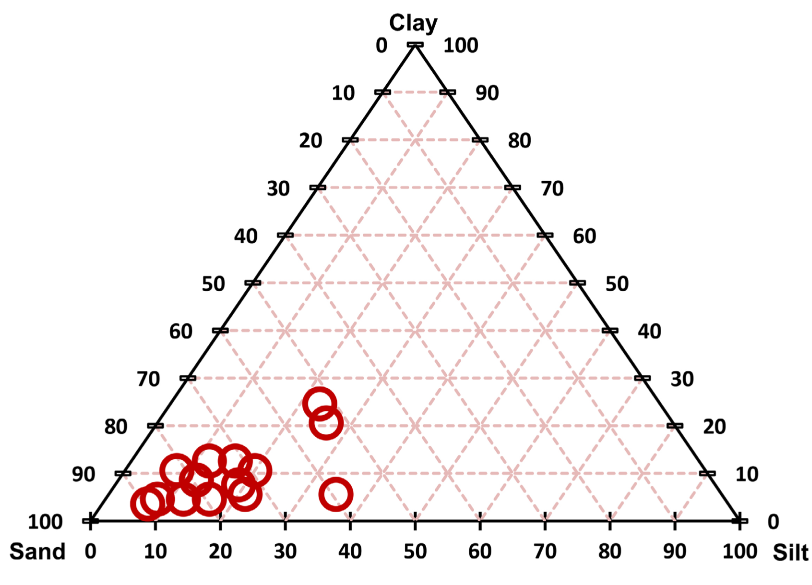


Figure 6. Ternary diagram of textural classes of the top soils of Mt Cameroon.

3.3. Soil chemical Properties

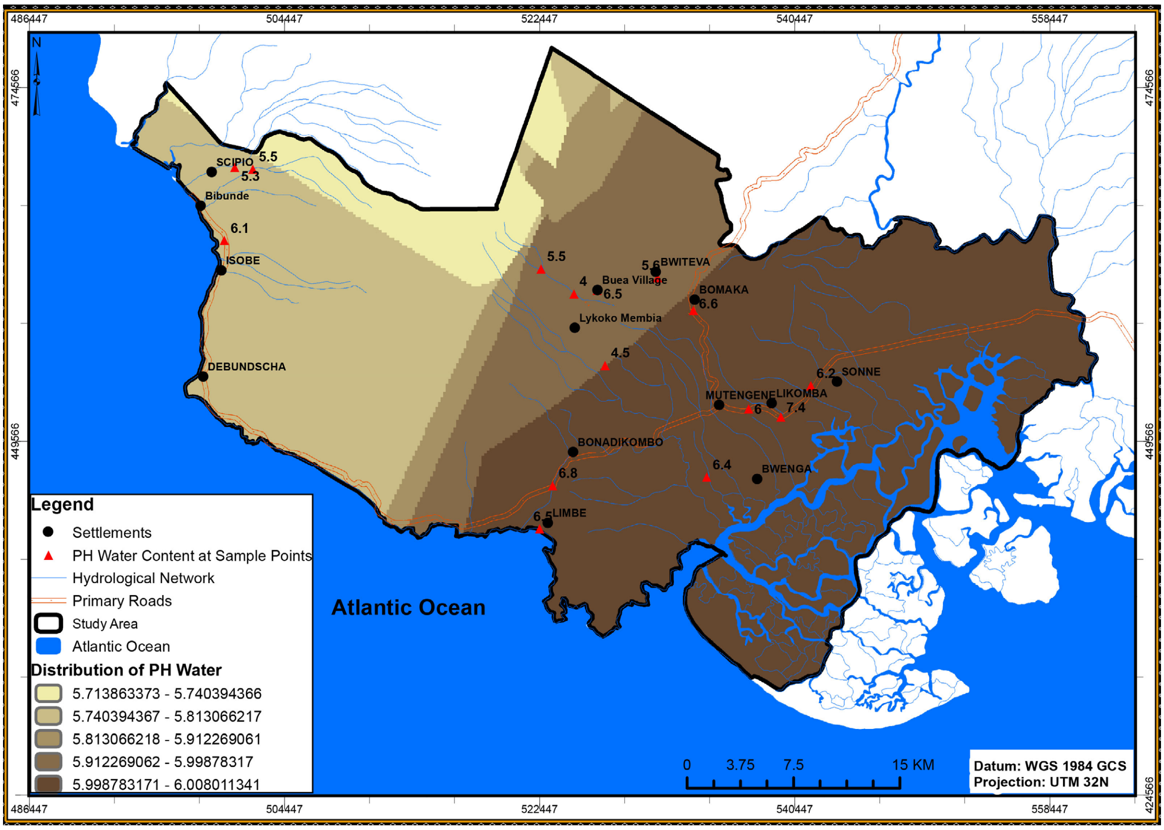
The results of the variation of soil acidity and cation exchange capacity (CEC) are summarized in **Table 2** and illustrated in **Figure 7**. Soil acidity was measured both as pH in water and pH in KCl. $pH_{(water)}$ with a mean of 5.9 and standard deviation 0.86 varied between 4.0 and 7.4 while $pH_{(KCl)}$ with a mean of 5.15 and standard deviation 0.74 ranged between 3.8 and 7.1. CEC registered a mean of 14.39, standard deviation of 2.14 and range 10.4 - 17.87.

$pH_{(water)}$ and $pH_{(KCl)}$ exhibited similar trends across the study area. The average values were highest for settlements and least for the agricultural areas. These results tie with the findings of Tellen and Yerima [59] who found the lowest pH averages for farmland and higher values for grassland and grazing land. Fetene and Amera [24] recorded the highest mean value of pH for forest, followed by grazing land and cultivated land. The results, however, contradict those of Sebhatleab [60] who reported low pH values for forest land and grassland compared to bare land. Lake [61] identified parent material, weathering and agricultural practices as the main factors that influence soil pH.

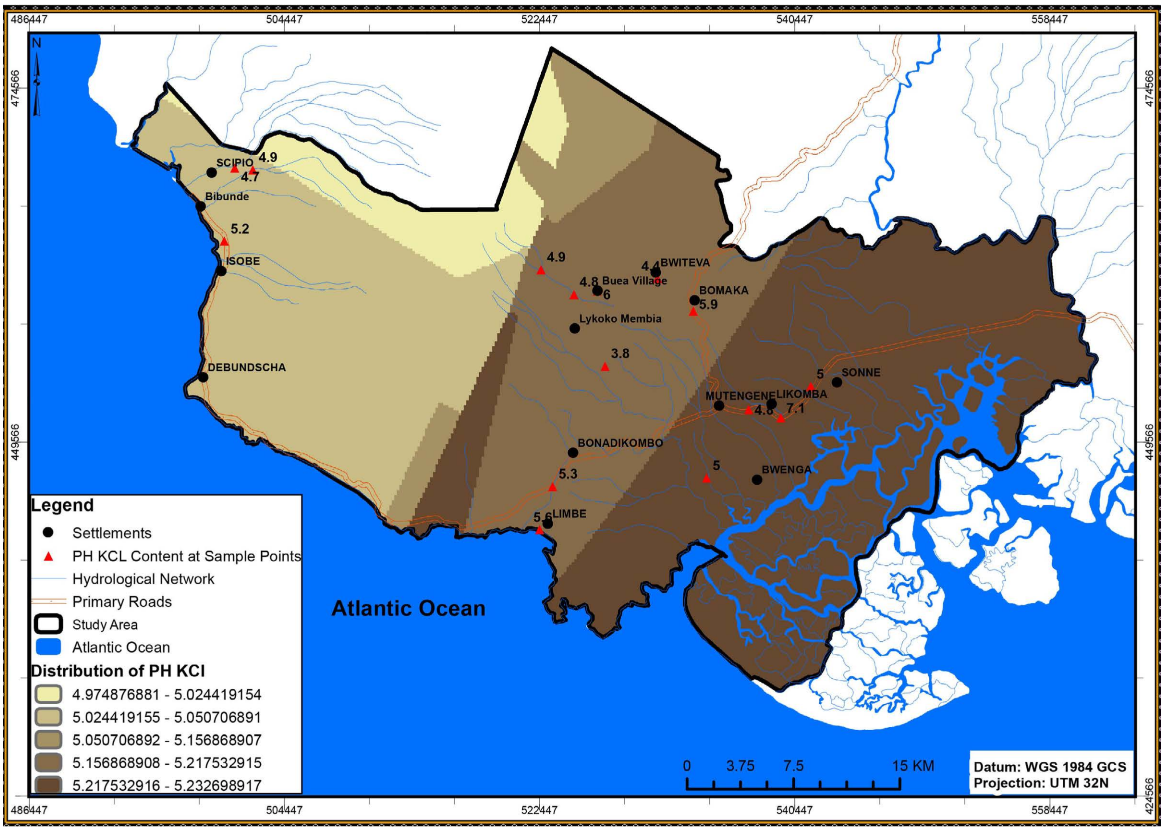
The low pH values for agricultural land-use classes could be attributed to the predominant use of agro-chemicals, especially ammonium fertilizers. The relatively low pH values for forest could be as a result of the formation of (weak) organic acids following the decomposition of SOM and nitrogen mineralization by soil microbes. The settlement LULC class generally has little organic carbon

Table 2. Summary of selected chemical properties of soils of the southern slopes of Mt Cameroon.

LULC	Quantity	$pH_{(H2O)}$	$pH_{(KCl)}$	CEC
Farmland	min	4.00	4.40	10.40
	max	6.10	5.20	17.87
	Mean	5.43	4.80	13.94
	SD	0.97	0.33	3.06
Forest	min	5.50	4.90	12.80
	max	6.50	5.60	17.60
	Mean	5.78	5.13	15.33
	SD	0.49	0.33	1.98
Plantation	min	4.50	3.80	12.00
	max	6.40	5.00	17.20
	Mean	5.60	4.63	14.03
	SD	0.88	0.57	2.52
Settlement	min	6.50	5.30	13.07
	max	7.40	7.10	15.93
	Mean	6.83	6.08	14.25
	SD	0.40	0.75	1.25


Legend
Settlements
PH Water Content at Sample Points
Hydrological Network
Primary Roads
Study Area
Atlantic Ocean
Distribution of PH Water
5.713863373 - 5.740394366
5.740394367 - 5.813066217
5.813066218 - 5.912269061
5.912269062 - 5.99878317
5.998783171 - 6.008011341
Atlantic Ocean
SCIPIO
Bibunde
ISOBE
DEBUNDSCHA
BWITEVA
Buea Village
BOMAKA
Lykoko Membia
SONNE
MUTENGENE
LIKOMBA
BONADIKOMBO
BWENGA
LIMBE
0 3.75 7.5 15 KM
Datum: WGS 1984 GCS
Projection: UTM 32N

(a)


Legend
Settlements
PH KCL Content at Sample Points
Hydrological Network
Primary Roads
Study Area
Atlantic Ocean
Distribution of PH KCl
4.974876881 - 5.024419154
5.024419155 - 5.050706891
5.050706892 - 5.156868907
5.156868908 - 5.217532915
5.217532916 - 5.232698917
Atlantic Ocean
SCIPIO
Bibunde
ISOBE
DEBUNDSCHA
BWITEVA
Buea Village
BOMAKA
Lykoko Membia
SONNE
MUTENGENE
LIKOMBA
BONADIKOMBO
BWENGA
LIMBE
0 3.75 7.5 15 KM
Datum: WGS 1984 GCS
Projection: UTM 32N

(b)

(c)

Figure 7. Spatial distribution of soil chemical properties of the top soils of Mt Cameroon (a) $pH_{(water)}$, (b) $pH_{(KCl)}$, (c) CEC.

and experience minimal use of chemicals. The acidity of soils in the settlement land-use is, consequently, dominated by the chemistry of the soil parent material which is mostly basic rocks, basalts, basanites and hawaiites [29]. This certainly accounts for the high mean pH values (low acidity) for soils of the settlement land-use areas.

The difference between the 2 pH values for each sample ($pH_{(water)}$ - $pH_{(KCl)}$) gives the net charge. The average net charge for the study area is positive, highest in areas dominated by plantations followed by those for settlement, forest, and farmland, respectively. The acidity of the soil was greater when measured in KCl most probably due to the mobilization of reserved acidity on the soil colloids whereby Al cations in the colloids are displaced by K cations from the KCl. The positive net charge of the soils is an indication of the fact that the rate of cation exchange is higher than that of anions [62].

CEC did not reveal any clear pattern of variation. The mean values of CEC for the various LULC classes, however, were in the following order: forest > settlement > plantation > farmland. According to the rating proposed by Hazelton and Murphy [63], the mean values of CEC for all LULC classes of the study area were moderate (12 - 25 cmol (+)/kg). This implies moderate resistance to changes in soil chemistry and reasonable availability of plant nutrients to the root system (fertility of the soil) [64]. There was neither a clear match in the trend of CEC means exhibited in the study and those of other studies nor was there any consistency in the trends for similar studies in the literature. Fetene and Amera [24], for instance, associated the variation of CEC in soils with the types and relative amounts of clays and soil organic matter. This may account for the inconsistencies.

4. Conclusions

The major LULC categories of the southern slopes of Mount Cameroon were forest, agroforestry, settlement, and orchards/plantation. It is discernible from the results that subsistence agriculture was a key source of livelihood, as the agroforestry LULC was the largest in surface area extent. The variation of the mean values of the selected soil properties with LULC exhibited the following trends: bulk density (settlement > plantation > farmland > forest); moisture content (forest > farmland > plantation > settlement); clay (plantation > settlement > farmland > forest); silt (farmland > plantation > settlement > forest); sand (forest > settlement > farmland > plantation); $pH_{(H2O)}$ (settlement > forest > plantation > farmland); $pH_{(KCl)}$ (settlement > forest > farmland > plantation) and CEC (forest > settlement > plantation > farmland).

The soils were moderately acidic to neutral (pH: 4.00 - 7.04) and the soil texture was sandy to loamy clay sand. From the geostatistics, land management, reflected by LULC, impacted on soil acidity, bulk density, moisture content, soil texture and CEC. Conversion from forest to other LULC categories, therefore, leads to a decrease in CEC, soil moisture content and pH, while there is an increase in bulk density and clay. Consequently, changes in these soil physico-chemical properties are a pointer to possible soil degradation. Hence, soil physico-chemical properties can be considered as indicators of soil quality and on the other hand, a change in these properties could serve as a proxy for LULC change.

The major limitation of the study included the inaccessibility of some areas due to the nature of the terrain and security threats posed by wild animals and the civil strife in the region. Future studies could consider increasing the sample density and increasing the number of soil chemical parameters.

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Conflicts of Interest

Authors have declared that no competing interests exist.

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