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Evaluation of Soil Fertility Status Based on CEC and Variation across Disturbed and Intact Tropical Coastal Forests Sites in Tanzania

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Authors' contributions

This work was carried out in collaboration between all authors. Author EJL designed the study, performed the statistical analysis and wrote the first draft of the manuscript. Authors CC and CW managed the analyses of the study. Author CW managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Although an understanding of different levels of soil calcium, magnesium, potassium, sodium, cation exchange capacity, and percentage base saturation, is important in the management of forest ecosystems; however, there is limited documentation on the status of these elements in forest subjected to crop-agriculture and livestock grazing disturbances in the tropical coastal forests. This study aimed to evaluate soil fertility based on exchangeable bases' status and variation across closed forest (control), agriculture and livestock disturbed sites in the coastal zone of Tanzania to add knowledge on the management of tropical coastal forests.

Methodology: Systematic sampling and stratification approaches were used to get representative samples of forested blocks and disturbed sites. Forty-seven (50 m x 50 m) sampling plots on each of the forest sites were established in the study area from which 141 soil samples were drawn. Ammonium acetate solution was used to extract exchangeable calcium, potassium, magnesium,

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and sodium from which cation exchange capacity and base saturation were calculated.

Results: The mean, correlation and t-values were used to compare nutrients across land uses. The mean values were 3.75, 3.11 and 0.63 for Ca^{2+}; 0.80, 5.87 and 6.67 for Mg^{2+}; 0.03, 0.55, and 0.52 for K^{+}; 0.01, 0.31 and 0.31 for Na^{+}; 2.61, 13.74 and 16.36 (cmol(+)/kg) for cation exchange capacity and 10.29, 5.86 and 4.42 (V%) for base saturation in three areas: closed forest, agriculture and livestock disturbed sites.

Conclusions: The variations show that crop-agriculture and livestock grazing disturb soil chemical properties in tropical coastal forests. Therefore, it is essential to protect closed forest sites while putting more efforts to restore the disturbed sites for sustainable forest management along the coastal areas.

Keywords: Base elements; cation exchange capacity; base saturation; forest ecosystems; land use change.

1. INTRODUCTION

An understanding of different levels of soil calcium, magnesium, potassium, and sodium, is essential in the management of forest ecosystems [1,2,3] because cation exchange capacity highly influences vegetation growth in forest ecosystems [4]. Despite the importance of these elements, little is understood about their patterns and variability in tropical forests particularly on crop-agriculture and livestock grazed land uses [5]. There is limited documentation on the status and variations of cation exchange capacity and percentage base saturation in the closed forest, forest land sites subjected to crop-agriculture and livestock disturbances mainly in the tropical coastal forests like in many other tropical forest ecosystems [5]. This study was carried out in the coastal forest of Tanzania, the zone which represents some of the remaining tropical forests after human activities and climatic change impacts [6,7]. Because of long-term above-ground conversion of coastal forests, the below ground (soil) ecosystem is affected too [8]. As a result, many of the tropical forests are characterized by limited soluble bases and sodium [9]. The variation of nutrients exists between different ecosystems because of processes such as pedogenesis variability of parent rock materials and land uses [2,3,10]. While cutting down of native vegetation to convert forest land into farms is counted as one of the processes which add soil nutrients, yet this addition is considered a temporal return of nutrients in soil stock [11]. Thus, any conversion of natural vegetation into crop or grazing lands contributes to alter some soil nutrients [11]. The depletion of nutrients is severe especially when fertilizers are not used as one of the corrective measures [11]. Unfortunately, crop-agriculture in the coastal forest reserves is practiced without additional of fertilizers, while the literature on the differences in nutrients status between and across intact forests, agriculture, and livestock disturbed sites is limited.

It is known that forest disturbances brought by human activities or natural processes affect the above ground biomass (tree species), which in turn influence nutrients biogeochemistry through variation in the quantity and chemistry of plant litter [12]. Forest disturbances affect litter accumulation, thus lowering the capacity of forest ecosystems to slow soil erosion and mineral leaching (the most factors for nutrients loss in the tropics) [8,10]. Activities which cause land cover change, for example, those associated with deforestation cause soluble bases depletion and extinction of some plant species in the tropics hence limiting the development of forest ecosystems [13,14]. Because of the roles played by soluble bases in controlling soil acidity and plant community welfare, an understanding about soluble elements quantities and variation is crucial in forest management [15].

The existing studies have documented the impacts of land cover change and carbon storage [13,16,17]. Studies on soil organic carbon have been conducted by [18] Nitrous Oxide and Methane by [19], and plant diversity in [7] and [20]. Although a study by [4] investigated soil fertility on different land uses, documentation on the comparative differences of soluble bases and sodium across forest sites subjected to different land uses along the tropical coastal forests including those found in Tanzania is lacking. This lack of information is a challenge on the management of coastal forests in the tropics. Inadequate information about soil status puts forests management in risk because the knowledge about the existence of above ground forest resources is not enough to address the entire reciprocal function of soil properties and the interplays between above and below-ground forest ecosystems [10,14]. A study of soluble bases status and variation is essential in the tropical coastal forests because these forests face pressure from human activities mainly crop-agriculture and livestock grazing [21].

This study was conducted to discover and generate information about the differences of exchangeable bases and sodium pools in the disturbed tropical coastal forests. This information is crucial in contributing to the effective management and protection of tropical coastal forest ecosystems [15]. This work evaluated, analyzed and compared the variation of topsoil (30cm in depth) nutrient concentrations across land uses. Specifically, the study addressed the following objectives: (i) The study identified the relative differences of soil chemical quantities across closed forest, agriculture and livestock disturbed sites at different elevations; (ii) the study discussed the reasons for soluble bases variation across land uses and provided suggestions on the proper land use management of tropical coastal forests. This work was carried out to test the following two hypotheses: (i) there is no significant difference in calcium, magnesium, potassium, and sodium amount in crop-agriculture and livestock disturbed sites from closed forest sites at 5% level of significance. (ii) There is no significant difference in cation exchange capacity and base saturation across land uses at 5% level of significance. The following questions guided this study. (i) How do forest land uses subjected to crop-agriculture and livestock grazing differ in soluble base contents from closed forest sites)? (ii) How cation exchange capacity and base saturation differ across forest sites subjected to different land uses and management practices?

2. MATERIALS AND METHODS

2.1 Site Descriptions

This study was conducted in a coastal representative forest known as Uzigua forest reserve (UFR) located in Bagamoyo and Chalinze Districts, Pwani Region in the coast of Tanzania (Fig. 1). The forest has a coverage area of 24,730ha located between 300 to 600m elevations [22]. This forest is within 100 km from the Indian Ocean. It is because of this geographical location, the UFR is placed among the remaining coastal forests ecosystems in Tanzania [23]. This forest is connected to villages named Mbwewe, Mpaji, Kwaruhombo, Kwang'andu, Kwamduma and Changalikwa in Mbwewe ward. Because of its location and proximity with these surrounding villages, the reserve has been encroached for human activities such as fuel-wood collection, fodder, livestock grazing and agriculture since 1960s. This reserve was purposely selected for this study because of its importance since the forest is among a few of the remaining coastal forests of Tanzania characterized by intact sites, agriculture and livestock disturbed sites [7,24].

2.2 Sampling Design

A systematic sampling design was used in this study. To cover a representative sample of forested blocks and disturbed sites in Uzigua forest reserve, the stratification approach was adopted from [22] and [25]. A comparison between impacts of disturbances was studied under each forest site. For the purpose of comparing the impacts of disturbances on soils' calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na), forty-seven random plots were established in each of the three major lands uses i.e., closed forest sites (CFS), crop-agriculture disturbed sites (ADS) and livestock grazed sites (LDS).

2.3 Data Collection

A reconnaissance survey was conducted to get geographical coordinates, which were used to produce different stratified land uses. Satellite images interpretation were used to identify areas for on-site data collection [26]. Land-cover and land-use (LCLU) change were first analyzed in this study. The spatial distribution of LCLU were obtained via classification of satellite images [27]. The normalized difference vegetation index (NDVI) was used to assess the location and extent of LCLU in the study area [28,29]. The NDVI was used together with the support vector machine image classification technique to process LCLU classes. Indeed, the identification of agriculture and livestock disturbed sites was supported by local peoples' experiences because human activities (mainly crop and livestock grazing) contribute to disturb forest ecosystems at large [30]. Land uses were classified into: (i) Closed (ii) Open forest (iii) Shrub (iv) Grasslands (v) Agriculture (vi) Grazing land (vii) Settlements and (viii) Bare land. Sites selection were carried out based on patterns of human activities (crop-agriculture and grazing) as supported by the maps and local people's experience. Conspicuous land-cover changes because of

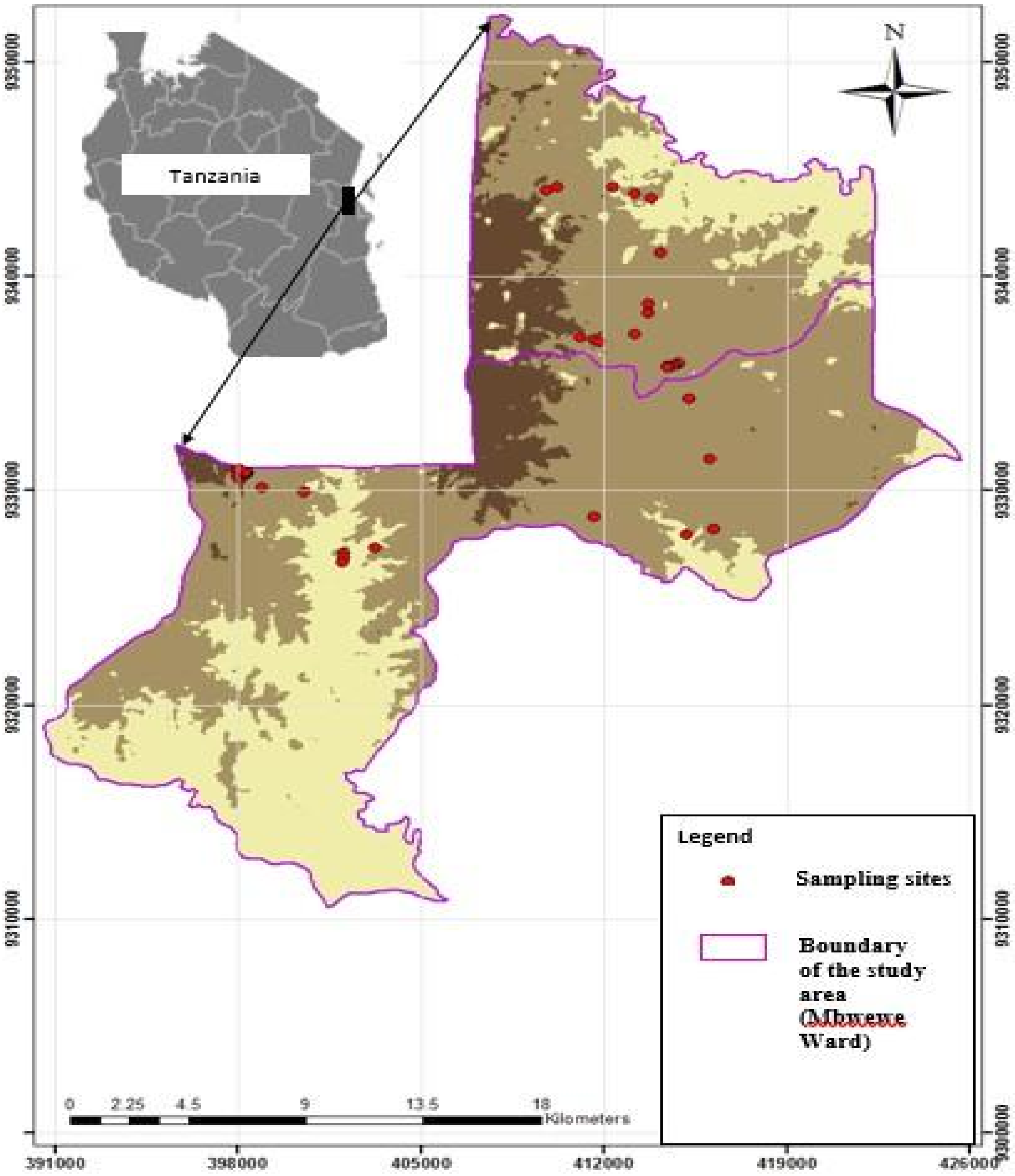

Fig. 1. The map of the study area

agriculture and grazing were purposely considered as the main sites for data collection.

2.4 Soil Sampling

Soil survey and sampling were carried out from May to August 2016. The study sites were CFS, ADS and LDS. From each of the three strata, soil samples were collected by using an Edelman auger at 1-30 cm (topsoil) as adopted from [31-33]. A total of 141 soil samples were collected (47 soil samples at each LU) drawn at 50 m × 50 m sampling plots. The soil samples in each sampling plot were then mixed together to make one composite sample to eliminate variability. Representative samples were put into tightened double plastic bags, labeled and stored at 4ºC to reduce further microbial degradation. Fresh air-dried and oven dried weights were determined before subjecting soil samples to further laboratory analysis.

2.5 Soil Sample Analysis

A combined glass–calomel electrode was used to determine the pH of aqueous suspensions (1:2.5 soils: solution ratio to aid on deciding on the proper techniques for further analysis of samples. Ammonium Acetate (1M NH4OAc) (pH 7.0) was used to extract exchangeable Ca, K Mg and Na. Potassium content was determined by flame photometer [11]. Ethylene-diaminetetraacetic acid (EDTA) titration was done to measure Ca and Mg from the soil solution. Cation exchange capacity (CEC) in (cmol (+)/kg and percentage base saturation BS (V%) were calculated following the methods of [31] and [32] as shown in equation (i) and (ii)

$$\text{CEC} = \sum(Ca,\ Mg,\ K \text{ and } Na)\ (\text{cmol}\ (+)/\text{kg}) \qquad (1)$$

Where, Ca, Mg, K and Na exchangeable are in (cmol (+)/kg

Base saturation (BS) (V %) =

$$\frac{\sum(Ca,\ Mg,\ K, Na)}{CEC} \times 100 \qquad (2)$$

Where, Ca, Mg, K and Na exchangeable are in (cmol (+)/kg, CEC is also in (cmol (+)/kg).

Laboratory results were further subjected into Statistic Package for Social Science (SPSS) software and MS. Excel computer programs for computation of means, standard deviation and t-values at 5% significance interval. These outputs were compared across the land uses and elevations to gauge the differences and similarities of soluble bases.

3. RESULTS

In comparing variation across CFS, ADS and LDS, the following consistence has been maintained in the presentation of results. Means and t-values are kept constant in the order of Ca (CFS vs. ADS), Ca (CFS vs. LDS), and Ca (ADS vs. LDS); Mg (CFS vs. ADS), Mg (CFS vs. LDS) and Mg (ADS vs. LDS); K (CFS vs. ADS), K (CFS vs. LDS), and K (ADS vs. LDS); Na (CFS vs. ADS), Na (CFS vs. LDS), and Na (ADS vs. LDS); CEC (CFS vs. ADS), CEC (CFS vs. LDS), and CEC (ADS vs. LDS) and BS (CFS vs. ADS), BS (CFS vs. LDS), and BS (ADS vs. LDS). In this work, all exchangeable bases are expressed in cmol (+)/kg/ha, CEC in cmol (+)/kg/ha while BS values are expressed in percentage volume/ha.

3.1 Calcium Variation across CFS, ADS and LDS

Calcium variation between CFS and ADS was: t = 3.78, p <.001. Due to the mean (mean ± standard error mean (SE)) values of Ca between CFS and ADS and the direction of the t-value, it was concluded that there was a significant difference of Ca between these two land uses from 14.12 ± 1.07 to 10.37 ± 0.47 with a variation of 3.75 ± 0.99. The variation of Ca on CFS vs. LDS was: t = 2.91, p <.001, with the mean difference from 14.12 ± 1.07 to 11.00 ± 0.22, a difference of 3.11 ± 1.07, the variation in Ca between ADS and LDS was: t =1.10, p = .280, with a mean difference from 10.37 ± 0.47 to 11.00 ± 0.22, and a difference of 0.63 ± 1.10 (Table 1).

3.2 Magnesium Variation in CFS, ADS and LDS

Magnesium variation between CFS and ADS was: t = 4.71, p <.001. Due to the mean values of Mg between CFS and ADS and the direction of the t-value, it was concluded that there was a significant difference of this element between these two land uses from 2.96 ± 0.06 to 2.16 ± 0.17 with a variation of 0.80 ± 0.17. The variation of Mg in CFS vs. LDS was: t = 13.85, p <.001, with the mean difference from 2.96 ± 0.17 to 8.84 ± 0 .44, a difference of 5.87 ± 1.07, and the variation in Mg between ADS and LDS was: t = 17.11, p <.001, with a mean difference from 2.16 ± 0.17 to 8.84 ± 0.44, and a difference of 6.67 ± 0.39 (Table 1).

3.3 Potassium Variation between CFS, ADS and LDS

Potassium variation between CFS vs. ADS was: t = 0.41, p =.860. Due to the mean values of K between CFS and ADS and the direction of the t-value, it was concluded that there was a significant difference of K between these two land uses from 0.70 ± 0.05 to 0.72 ± 0.05 with a variation of 0.03 ± 0.06. The variation of K between CFS and LDS was: t = 5.88, p <.001, with the mean difference from 0.70 ± 0.05 to 1.24 ± 0.08, a difference of 0.55 ± 0.09, and the variation in K between ADS and LDS was: t = 5.88, p <.001, with a mean difference from 0.72 ± 0.05 to 1.24 ± 0.08, and a difference of 0.52 ± 0.09 (Table 1).

3.4 Sodium Variation in CFS, ADS and LDS

Sodium variation between CFS and ADS was: t = 0.19, p = .240. Due to the mean values of Na between CFS and ADS and the direction of the t-value, it was concluded that there was a significant difference of Na between these two land uses from 0.13 ± 0.01 to 0.14 ± 0.01 with a variation of 0.01 ± 0.01. The variation of Na between CFS and LDS was: t = 7.96, p < .001, with the mean difference from 0.13 ± 0.01 to 0.44 ± 0.04, a difference of 0.31 ± 0.01, and the variation in Na between ADS and LDS was: t = 7.37, p < .001, with a mean difference from 0.14 ± 0.01 to 0.44 ± 0.04, and a difference of 0.31 ± 0.04 (Table 1).

3.5 The CEC Variation in CFS, ADS and LDS

Cation exchange capacity variation between CFS and ADS was: t = 10.65, p = .001. Due to the mean values of CEC between CFS and ADS and the direction of the t-value, it was concluded that there was a significant difference of CEC between these two land uses from 20.74 ± 0.46 to 13.39 ± 0.49 with a variation of 4.35 ± 0.69. The variation of CEC between CFS and LDS was: t = 1.98, p <.053, with the mean difference from 20.74 ± 0.45 to 18.46 ± 1.09, a difference of 2.28 ± 1.15, and the variation in CEC between ADS and LDS was: t = 7.48, p <.001, with a mean difference from 13.39 ± 0.49 to 18.46 ± 1.09, and a difference of 5.07 ± 1.11 (Table 2).

3.6 Base Saturation Variation in CFS, ADS and LDS

Base saturation variation between CFS and ADS was: t = 2.38, p <.021. Due to the mean values of BS between CFS and ADS and the direction of the t-value, it was concluded that there was a significant difference of BS between these two land uses from 63.83 ± 3.29 to 55.43 ± 2.11 with a variation of 8.40 ± 3.53. The variation of BS between CFS and LDS was: t = 0.65, p = .522, with the mean difference from 63.83 ± 3.29 to 60.24 ± 4.41, a difference of 3.58 ± 5.55, and variation in BS between ADS and LDS was: t = 0.84, p = .400, with a mean difference from 55.43 ± 2.11 to 60.24 ± 4.41, and a difference of 4.81 ± 5.31 (Table 2).

Table 1. Soluble bases variation across land uses

	Ca		Mg		K		Na	
Land uses	**mean**	***p*-value**	**mean**	***p*-value**	**mean**	***p*-value**	**mean**	***p*-value**
CFS vs. ADS	3.75±0.99	<.001	0.80 ± 0.17	<.001	0.03 ± 0.06	<.680	0.01±0.01	<.240
CFS vs. LDS	3.11±1.07	<.001	5.87 ± 0.42	<.001	0.55 ± 0.09	<.001	0.31±0.04	<.001
ADS vs. LDS	0.63±0.58	<.280	6.67 ± 0.39	<.001	0.52 ± 0.09	<.001	0.31±0.04	<.001

Table 2. The variation of CEC and BS across CFS, ADS and LDS

Land use	CEC		BS	
	mean	**p-value**	**mean**	**p-value**
CFS vs. ADS	7.35 ± 0.69	< .001	8.40 ± 3.52	< .021
CFS vs. LDS	2.28 ± 1.15	< .053	3.58 ± 5.55	< .052
ADS vs. LDS	5.07 ± 1.11	< .001	4.82 ± 5.31	< .368

Table 3. Paired soluble bases correlation across land uses

Land uses	Ca		Mg		K		Na	
	r	***p*-value**	**r**	***p*-value**	**r**	***p*-value**	**r**	***p*-value**
CFS vs. ADS	0.373	<.010	0.135	<.365	0.247	<.094	0.042	<.780
CFS vs. LDS	0.074	<.623	0.320	<.028	0.074	<.622	0.421	<.003
ADS vs. LDS	0.288	<.050	0.463	<.001	0.051	<.734	0.075	<.616

Table 4. Paired sample correlation of CEC and BS across land uses

Land uses	CEC		BS	
	r	*p*-value	r	*p*-value
CFS vs. ADS	0.279	<.058	0.538	<.000
CFS vs. LDS	0.079	<.596	0.082	<.584
ADS vs. LDS	0.613	<.000	0.263	<.001

Table 5. Correlation of Ca, Mg, K, Na, CEC and BS with elevation

LU and Elevation	Ca		Mg		K		Na		CEC		BS	
	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*
Elevation and CFS	1	0.250	0.04	0.794	0.09	0.539	0.14	0.365	0.08	0.615	0.05	0.750
Elevation and ADS	0.18	0.222	0.25	0.095	0.02	0.987	0.08	0.589	0.15	0.329	0.01	0.972
Elevation and LDS	0.04	0.775	0.03	0.863	0.02	0.890	0.03	0.851	0.05	0.727	0.12	0.418

3.7 Correlations of Ca, Mg, K, Na, CEC and BS between LU

There was a statically positive correlation between; Ca in CFS and ADS (r = 0.139); Mg in CFS and LDS (r = 0.153); Mg in ADS and LDS (r = 0.168); K in CFS and ADS (0.062); Na in CFS and LDS (r = 0.004); Na in LDS and CFS (r = 0.179); CEC in CFS and ADS (r = 0.290); BS in CFS and ADS (r = 0.007). There was statistically weak positive correlation between Ca in CFS and LDS (r = 0.005); Mg in CFS and ADS (r = 0.018); K in ADS and LDS (r = 0.004); Na in ADS and LDS (r = 0.078). There was a negative correlation between Ca in ADS and LDS (r = 0.083); K in CFS and LDS (r = 0.006); Na in CFS and ADS (r = 0.005); CEC in ADS and LDS (r = 0.375). There was strong negative correlation between CEC in CFS and LDS (r = 0.006); BS in ADS and LDS (r = 0.054). Table 3 shows a correlation summary of soluble bases and table 4 indicates the correlation of CEC and BS between land uses.

3.8 Correlation of Ca, Mg, K, Na, CEC and BS with Elevation

The correlation was positive between base elements and elevation (E) as follows: Ca vs. E in CFS, Mg vs. E in CFS, Na vs. E in CFS, CEC vs. E in LDS and BS vs, E in CFS. The correlation was negative in the following patterns: Ca vs. E in ADS, Ca vs. E in LDS, Mg vs. E in ADS, Mg vs. E in LDS, K vs. E in CFS K vs. E in ADS, Na vs. E in ADS, Na vs. E in LDS, CEC vs. E in CFS, CEC vs. E in ADS, BS vs. E in ADS and BS vs. E in LDS (Table 5).

4. DISCUSSION

4.1 Variations of Soluble Bases across Land Uses

The tested hypotheses in this study show that there is significant variation of soluble bases, cation exchanges capacity and base saturation across forests sites subjected into different management practices. This variation supports the findings by other researchers that spatial nutrients variation is contributed by land use management [33]. From these findings, we establish that that soluble bases vary because of different land uses and management supporting the findings by [31]. Across the study sites, agriculture and grazed disturbed sites have lost soluble bases, the conditions which is associated with loss of vegetation [34]. The effect of land use and management systems on soil fertility and chemical properties presented in this study is in agreement with some observations made by [4] and [33]. The evidence that intact soil sites harbor higher bases than disturbed sites has been clearly observed in Ca, Mg and CEC where by these bases and CEC were high in CFS and declined towards LDS and ADS unlike the K, Na and BS. The variation shows that disturbances affect soluble bases differently across land uses. However, information to support low differences of variation in Mg, K and Na is questionable. However, it is possible that leaching and uptake of Mg, K and Na was checked by the little vegetation in ADS and LDS. The significant differences of Ca and Mg in CFS and, LDS and ADS is a good indicator of impacts of disturbances on these two major soluble bases in the tropical coastal forests. The interpretation is that Ca and Mg highly get lost in disturbed than in the intact sites [11]. It is because of the higher quantities of these two soluble bases, the variations of cation exchange capacity and base saturation between CFS and ADS is higher, followed by ADS and LDS as well as that between CFS and LDS. These variations suggest the role of vegetation in checking the loss of soluble bases in intact and grazed forest sites than in crops agriculture land.

Low amount of Ca and Mg in ADS than in LDS shows that converting land into farms and grazing land use makes soil vulnerable to soil erosion and leaching and uptakes by crops [14,35,36]. Low amount of Ca and Mg in ADS and LDS partially shows that human activities in these land uses disturb nutrients through conversion of forests into other land uses. Low quantities of soluble bases in disturbed soils is supported by [9]. Indeed, the low quantities of soluble bases in disturbed sites indicate that cropped and grazed sites have lost nutrients contributed by vegetation loss, whereby loss of vegetation have influenced soil chemical properties by influencing the distribution and concentrations of soluble bases unlike in the intact forest sites where trees and other vegetation contribute to increase exchangeable bases in the soils [4,12].

We established that low base elements in disturbed sites is partially explained by loss of vegetation or the removal of soil elements from the soil by crop harvests or livestock grazing and leaching [36]. A combination of these three factors (i.e. clearing vegetation, crop harvests and grazing) affects the status of nutrients in the coastal forests, in turn these factors affect forests ecosystems because of the interdependence between above and below ground forests ecosystem components. For example, variations of Ca, Mg, K and Na between CFS and the disturbed sites indicate that conversion of forests in other land uses results into a release of nutrients locked in vegetation mainly in the form of woody [9]. The wooden locked nutrients are released into soils and animals where they are temporarily stored before they get lost [11]. Therefore crop-agriculture and grazing disturb vegetation and litter hence soil nutrients in the tropics agreeing the results in [33]. A higher value of soluble bases in intact sites is a good indicator that undisturbed sites maintain nutrients circulation than the disturbed sites agreeing the findings of [37].

Indeed, the variation across soluble bases in response to disturbances shows that nutrients loss is not uniform throughout all soluble bases. For example, across the study sites K and Na were low in all land uses compared to Ca and Mg. Low K and Na is the condition reported in the tropical forests because of the origin of the soils, high rainfall and high temperatures effects [38]. These environmental factors when combined with crop-agriculture and livestock grazing pressure affect more K and Na in the tropics than other soluble bases [38]. Human activities accelerate the loss of K in the tropics, in turn low K affects carbohydrate and protein formation in forests trees. In this view, human activities cause K deficiency in forest ecosystems partly threatening the productivity of these forests [32,39].

4.2 Correlation of Soluble Bases across Land Uses

Calcium had higher correlation with almost all other soluble especially in CFS. This correlation indicates that intact forest sites have the capacity to retain nutrients than disturbed sites in agreement with [11]. Soluble bases such as Ca and Mg showed a positive and strong correlation across all the land uses except in ADS. The negatively correlation of Ca and Mg in ADS is in line with [15]. The interplays of nutrients as a result of disturbances can be used to indicate that certain activities accelerated loss of some nutrients, for example, the negative correlation of Ca and Mg in ADS than in any other land uses can be used to show that there are more declines in Mg than Ca in the disturbed forests sites supporting the findings in [35]. The main reason for high loss of Mg than Ca is that, the former base is vulnerable to leaching than the latter in disturbed sites [40]. Because crop-agriculture and livestock grazing contribute to disturb forests sites by affecting vegetation and accelerating soil erosion and leaching, it is established that crop agriculture and livestock grazing contribute to loss of Mg than Ca through leaching [12,15]. The positive and negative correlation findings on soluble bases in the intact forests and disturbed sites are also reported in [41]. Therefore, there is no uniformity in nutrients trends and dynamics other than variation across forests sites when exposed to different land use.

4.3 Soluble Bases, CEC and BS vs. Elevation

The findings in this study show that base elements varied with elevation. There was significant variation for Mg in ADS, Ca, in ADS, CEC in ADS, and Na in CFS and BS in LDS. These variations show that Mg and Ca were low at high elevations (350 to 600 m) across the study area meaning that the agricultural activities carried out at high elevations pose some potential risk for soluble bases depletion [15]. There were more less variations of nutrients in CFS against elevation, a trend which can be associated with less leaching on nutrients in the CFS across different elevations. The variation of nutrients in LDS against elevation compared to other land uses was not significant. This little variation is partially explained by that, grazed land contains some vegetation especially woods, which contribute to recycle soil nutrients, and partially returning theses nutrients through animal feces [9,34,42]. Although LDS had less variation of nutrients across the elevation, it is established that low nutrients availability at high elevations (350 to 600 m) contributed to limit vegetation growth, which upon grazing pressure; it results into loss of soil nutrients more than the lower bottoms. This limited supply of nutrients in-turn promotes nutrients insufficiency for wood production and thus livestock grazing continues to be among the factors affecting soluble bases in our study area like in other tropical forests [14,31].

4.4 Soluble Bases CEC, BS and UFR Sustainability

Although this study lacked baseline quantities of soluble bases, CEC and BS to make a comparison of whether the variation and quantities are sufficient or not to sustain UFR, still the current variation can be used to establish soluble bases status in the coastal forests. The available data on Ca and Mg, CEC and BS are useful in predicating sustainability of coastal forests relationships because these factors largely control forest ecosystems by affecting the distribution of plants in forests [15]. Higher amount of Ca and Mg (for example) in CFS is a good indication that the uptake and recycling of these nutrients by trees and other vegetation is not in excess than the amount lost by leaching in disturbed soils [15]. High amount of Ca and Mg in CFS is a good indicator that CFS health is promising because these two soluble bases are important in natural sustainability of forest ecosystems. In order that coastal forests maintain the forest capacity to retain nutrients, protection of forests and leaving trees regenerations must be in place. It is important to protect vegetation in intact forests sites and restore disturbed sites to rejuvenate the lost nutrients and prevent further degradation of forests ecosystems. Protection and restoration must aim in improving the soluble bases because these bases largely govern soil acidity and, consequently, plant species composition [15]. Improvement on the composition of species in turn affects forest soils nutrients [15]. These efforts will contribute into providing the function of runoff, soil and nutrient loss reduction and improve circulation of nutrients in coastal tropical forest [41]. A limitation in this study was that the interplays of nutrients variation on each were not explored. Therefore, an understanding of how and reasons for certain patterns of nutrients correlations opens another area for further research.

5. CONCLUSIONS

This study came up with a significant spatial chemical attributes variation of calcium, magnesium, potassium as well as sodium, cation exchange capacity and base saturation across closed forest, crop-agriculture and livestock grazing disturbances. These elements were significantly different across the sites. From the variation of cations exchange capacity status across the sites, it shows that disturbed forest sites have low nutrients than intact ones. These variations were also observed across different elevations. The variation indicates that soils in the disturbed sites at high elevations (350 to 600 m) should be conserved for essential nutrients circulation to promote forest vegetation growth and development along the coastal ecological gradient. Improvements in forest ecosystems should not necessarily need addition of base elements, rather than avoiding further disturbances, protecting the intact and restoring disturbed sites by taking the advantage of natural forest capacities to recycle nutrients. It is suggested for further studies to identify correlation of soil elements in the tropical coastal forests in different land uses to establish a trend of nutrients at risk because of anthropogenic activities mainly crop-agriculture and livestock grazing. Studies on forest nutrient mapping should be carried out to contribute into exploration of the above and below ground forest ecosystem nutrients pools and suggest possible remedies for sustainable coastal forests across different regions and landscapes in Tanzania.

COMPETING INTERESTS

We authors declare that no competing interests exist in production of this paper.

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