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Pedological Characterization and Soil Classification of Selected Soil Units of Morogoro District, Tanzania

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Authors' contributions

This work was carried out in collaboration between both authors. Author SML designed the study, performed the statistical analysis, wrote the protocol, managed the literature searches and wrote the first draft of the manuscript. Author BMM managed the site selection of the study, edited the data, reviewed and edited the protocol and manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

The study aimed at provision of research information by pedological characterization of soil units of Morogoro District, Tanzania. Three soil units were selected coupled with field reconnaissance survey. Soil pedons were characterized at Kiziwa (KZW-P1), Mkambarani (MKA-P1) and Fulwe (FUL-P1). Pedons were observed to be formed from in-situ weathering of granitic rocks under ustic moisture and iso-hyperthermic temperature regimes. Thirteen soil samples were described and analyzed for physica-chemical and mineralogical properties. KZW-P1 and FUL-P1 had red dark brown sandy clay and gravely clay (MKA-P1) top soils overlaying mainly clayey subsoil. Both pedons indicate clay eluviation-illuviation as a dominant pedogenic process with slightly acidic condition and P<7 except FUL-P1 with 23.8 mg/kg P in top soils. Organic carbon is low in both pedons while total N is low to very low. CEC values for both pedons are 33.8, 26.4 and 27 cmol(+)/kg respectively. CIA values indicates intermediate to strong level of weathering. In USDA Soil Taxonomy and the FAO-UNESCO soil classification system, Soils were classified as: Kiziwa

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Ultisols (Alisols), and Inceptisols (Cambisols) for Fulwe and Mkambarani, reflecting their differences in potentials and constraints and hence use and management. The results reflects variations in soil characteristics both vertically and laterally so as to account for spatial linkages within the landscape.

Keywords: Soil units; soil characterization, soil morphology; physical characteristics; soil classification; Morogoro District Tanzania.

1. INTRODUCTION

Soil information obtained through systematic identification, grouping and delineation of various soils present in the locality are important for particular use for effective planning of different land uses, as they provides information related to potentials and constraints of the land. In addition, environmental characteristics (e.g. climate) and socio-economic factors are also important elements in pedological characterization to provides data and knowledge on soil properties related to the site characteristics (slope, soil color, vegetation). According to [1], parent material, biota, relief and time are soil forming factors that influence the morphological, physical, chemical and biological characteristics of soil. Understanding of soil genesis, morphology and other key soil properties is a pre-requisite to sustainable use of soil resources.

At present, soil survey conducted in Morogoro region are normally at large scale, exploratory and and/or reconnaissance scales. For instance, a work by [1] at a scale of 1:1 000 000 describes Morogoro region in three physiographic units, the Urugulu mountains, the piedmonts and mountain and ridges which covers very extensive areas classified as Fluvisols, Vertisols and Gleysols. The larger scale of this nature provides limited information at village level in forecasting constraints and limitation of the land. Soil characterization result obtained by researchers in Tanzania [2] give generalization which cannot put into practice at farm level. According to [3], soils vary both in their physical and chemical properties and agricultural production is governed by major soil types and precipitation patterns. Due to the limitation pointed out above, it becomes unavoidable to carry out site specific soil characterization in order to identify the existing heterogeneity of the soil pattern in order to generate required information for purposes of determining the potential of the soils and appropriate soil management practices. Furthermore agronomic technologies developed on such well characterized soils can easily be extrapolated to other areas with similar ecological conditions [2]. A report by other workers [4] is of the same location has pointed out the necessity to carry out site specific soil characterization taking into account as crop production is a function of soil properties. Further to this, site soil resource information is required by agricultural extension staff and farmers as a tool for soil fertility management. Thus, knowledge of site characterized soil physical and chemical properties with other ecological conditions will aid in determining the correct type and amounts of fertilizer to be applied for optimum crop production and nourishment of improved soil fertility.

The current study aimed at on site identification, description and characterization of three soil units of Morogoro District in terms of morphological characteristics, Physico-chemical and mineralogical properties and classification according to the United States Department of Agriculture (USDA) Soil Taxonomy [5] and the FAO-World Reference Base [6].

2. MATERIALS AND METHODS

2.1 Description of the Study Site

The study was carried out in Morogoro District, Tanzania. Three sites representing three soil units in Morogoro district were identified based on the landforms and physiographic attributes, soil profiles were excavated and described. Soil profiles were located at Kiziwa 06° 46' 49.6" E/ 037°51' 21.6" S), Fulwe (06°46' 06.9" E037°52' 31" S) and Mkambarani (06°46' 12.5" E 037°49' 27.8" S) at elevation of 417 m, 492 m and 414 m above sea level respectively. Both pedons are developed from granitic rocks of pre-cambrian age. In terms of physiography, the soils are formed on peneplains with gradients ranging between 2 and 5%. Surface characteristics depicted slight interill/sheet erosion with no deposition in the identified sites.

The climatic condition of the area is characterized by long bimodal rainfall which gets its peak on April-May, while the short rains have its peak during December. The maximum temperatures vary between 26.1℃ to 29.6℃ and minimum temperature range between 24.5℃.

2.2 Field Methods

A reconnaissance survey was carried out using transect walks, auger observations, and description in the field to identify major landforms and soils. At each observation site, data on landform, elevation, slope, soil morphological characteristics, parent material, vegetation and land use were collected. Three observation land units were selected, In each identified land unit, soil observation was made to a maximum of 1.8 m or limiting layer. The gathered data were filled to the soil description forms adopted from the FAO guideline for soil description [6]. Three soil profiles were excavated from each soil unit to present the major soil type. Soil profile pits opened were studied, described and sampled according to the FAO guideline [6]. Sites were Geo-referenced by international coordinates using Global Positioning System (GPS) using Global Positioning System (GPS) (model OREGON 400t).

Soil colors were determined by Munsell soil color charts [7]. In each profile pit, undisturbed (core) soil samples at depths of 0-10/13 cm, 10/13-40/50 cm, and 90-95/132 cm FUL-P1, 0-20/32 cm, 32-65/75 cm and 75-100/117 cm for MKA-P1 and 0-49/69 cm, 49/69-99 and 99-132 cm for KZW-P1 were sampled, while disturbed samples were taken from all designated natural horizons for laboratory physical and chemical analysis.

2.3 Laboratory Method

Undisturbed (core ring) samples were used for determination of bulk density, porosity and moisture retention characteristics. Bulk density was determined by the core method [8]. Disturbed soil samples were air-dried, ground and passed through a 2-mm sieve for physical and chemical soil properties. Particle size distribution was determined by hydrometer method [9] after dispersing soil with sodium hexametaphosphate and textural classes determined using the USDA textural triangle [10]. Soil pH in water was measured potentiometrically using a soil water ratio of 1:2.5 weights to volume basis [11]. Potentiometric method was used to determine electrical conductivity while available phosphorus was extracted using Bray-1 extraction method [12] and determined by spectroscopy at 884 nm following colour development by the Molybdenum blue method [13]. Organic carbon was determined by Walkey-Black wet oxidation method [14] and total nitrogen was determined by micro-Kjeldahl digestion method [15].

Cation exchange capacity of the soil (CEC_{soil}) and exchangeable bases were determined by saturating soil with neutral 1M NH4OAc (ammonium acetate) and the adsorbed NH4+ were displaced by using 1M KCl and then determined by Kjeldahl distillation method for estimation of CEC of the soil [14]. The exchangeable bases ($Ca^{2+,}$ Mg^{2+}, Na^+ and K^+) were determined by atomic absorption spectrophotometer [15]. The total exchangeable bases (TEB) were calculated arithmetically as a sum of the four exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) for a given soil sample. Other parameters which were calculated include C/N ratio, and base saturation percentage (BS %). Chemical index of alteration was calculated as a ratio of $Al_20_3/(AL_20_3+CaO\ +Na_2O+K_2O)$ as described by [16].

2.4 Soil Classification

Soil morphological, physical and chemical properties define the diagnostic horizons and other features that assist to classify the soils up to the family level of the Soil Taxonomy [4] and up to Tier-2 category of the FAO World Reference Base [6].

3. RESULTS AND DISCUSSION

3.1 Morphological Characteristics

Key morphological characteristics of studied soil units are presented on Table 1. Soil horizons were, easily demarcated, ranging from clear to abrupt with either wavy or smooth horizon topography. MKA-P1 and KZW-P1 was very deep, well drained pedons with red dark brown sandy clay top soils overlying dark reddish brown to red clayey sub soils. Abundant distinct clay cutans were observed in the subsoil indicating eluviation-illuviation as dominant pedogenic process. FUL-P1 pedon was deep, well drained with brown sandy loam overlying a sandy loam sub soil. A and B horizons of KZW-P1, FUL-P1 and MKA-P1, had well developed soil structures breaking into moderate to coarse sub-angular blocks. The subsoil of profile FUL-P1 was massive and crumby.

Table 1. Morphological characteristics of studied soil profiles

Profile no.	Horizon	Depth (cm)	Texture	Dry color	Moist color	Consistence	Structure	Horizon boundary
KIZ-P1	Ap #	0 - 49/60	SC	drb (5YR3/2)	rb(7.5YR3/2)	SHA,fr, sm & p	m,f-c sbk, m,m,cr	c/w
	Bt1	49/60-99	C	drb (2.5YR3/4)	db(7.5YR(3/2)	SHA,HA, fr,sp	w-m,f+m, sbk	ds
	Bt2	99- 132	C	dr(10YR3/6)	rb (7.5YR2.5/2)	SHA,fr, st & p	w-m, f+m, sbk	Ds
	Bt3	132 - 184	C	r (10R4/6)	dr(7.5YR2.5/2)	SHA, fr, st & p	m,m+f, sbk	g-d/s
FUL-P1	Ap	0 - 10/13	SC	b (7.5YR4/4)	db(7.5YR3/3)	SHA,fm, , sm & p	m,m, sbk, m,m, cr	c/s
	Ah	13 - 40/50	SL	lbg (10Y6/2)	db (7.5YR3/2)	SHA,fr,sm&p	co, m-c wsb	c/d
	Bwt1	50 - 95/102	SCL	lbg (10YR6/2)	rb(7.5YR2.5/2)	VHA,ns & np	co, m-c wsb	Gw
	Bwt2	102 -129/134	SCL	dg (10YR5/2)	dg(10YR4/1)	VHA,ns & np	co, m-c wsb	Gw
	CB	134 - 160	SL	dg (10YR4/1)	dg (10YR4/1)	VHA,ns & np	co, m-c wsb	Gw
MKAP1	Ap	0-20/32	gC	b(10YR4/2)	dr(10YR3/1)	HA,fi, ss & sp	w-m,f+m, cr	Gw
	Bwt1	32-65/75	C	Rb(5YR5/2)	db (7.5YR(3/2)	Ha,ss & sp	m,m+f, sbk	Cw
	Bwt2	65/75 -100/117	gC	rb (10YR4/4)	lb(10YR6/2)	vfr, ss & sp	Massive,w-m, sbk	c/s

Key: c = clay, drb = dark red brown, r = red, ha = hard, fr = friable, s = stiky, p = plastic, sbk = subangularblocks, c/w = clear weavy, db = dark brown, rb = red brown, sha = slightly hard, ha=hard, ss = slightly sticky, sp = slightly plastic, f=friable, fr = friable; st = sticky; ss = slightly sticky; sp = slightly plastic; p = plastic; ha =hard, sha = slightly hard, sha - ha = slightlyhard to hard, and vha = very hard when dry
m, f-c sbk = moderate to coarse subangular blocky; m, m,cr = moderate medium crumby; w-m,f+m, sbk = weak to moderate fine and medium subangular blocky; m,m, sbk & ab = moderate, medium subangular & angular blocky; w-m, sbk = massive breaking to weak medium subangular blocky;co, m-c wsb = compact medium to coarse wedge-shaped blocks a = abrupt; c = clear; g = gradual; sm = smooth; w = wavy; gw = gradual wavy; ds = diffuse smooth; aw = abrupt wavy; cw = clear wavy; dw = diffuse wavyp is always italicized and capitalized

3.2 Soil Physical Characteristics

3.2.1 Soil particle size distribution

Textural data and textural classes of the studied pedons are presented in Table 2. The Table describes particle size distribution in relation to depth. Particle size distribution for top soils of the studied profiles varied from Sandy clay (KZW-P1), sandy loam (FUL-P1), and sandy clay for MKA-P1. This supports the fact that the three pedons have developed largely under same soil forming factors and have attained comparable degree of pedogenesis [16]. Despite Sandy clay (KZW-P1), and sandy clay for MKA-P1, the two pedons are dominantly clayey type. Silt/clay ratios particularly for subsoils of the two pedons are very low, indicating high level of weathering in this pedons.

3.2.2 Bulk density and soil moisture characteristic curves

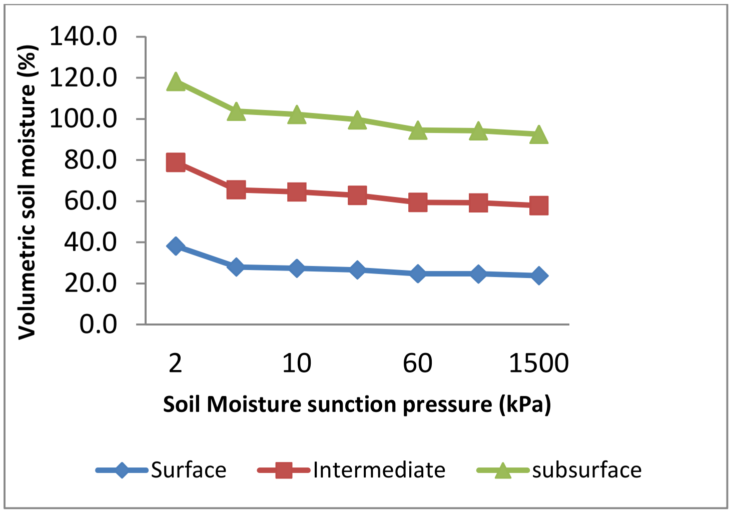
The determined bulk density for top soils were 1.3, 1.5, 1.2 g/cm^3 for KZW-P1, FUL-P1 and MKA-P1 respectively (Table 2). Critical levels of bulk densities for clay are 1.0 to 1.6 g/cm^3 and for sand is 1.2 to 1.8 g/m^3 with potential root restriction occurring at ≥ 1.4 g/ cm^3 for clay; and ≥1.6 g/cm^3 for sand [3]. Pedon FUL-P1 had relatively high bulk density (1.5 cm^3) with one unit less to the upper boundary of the critical value. Bulk density guide to rate soil compaction, porosity, root penetration and soil aeration [12] Bulk density determines the magnitude of particle-to-particle contacts and is related to total porosity and has an influence on available soil moisture [17]. The relatively high bulk density value in topsoil may likely reduce water infiltration and favor surface water run-off while an increase of the same with depth could result to poor root growth, reduced aeration and decreased water infiltration. According to [18] bulk density is influenced by the amounts of organic matter in the soil.

The soil moisture of KZW-P1 and MKA-P1 (Fig. 1) indicates a higher retention capacity with a gradual decrease as the suction potential increases. FUL-P1 profile portrays a drastic decrease in available water content as the suction potential increases. These suggests an effect of drastic dryness of field crops whenever there is a dry spell during the rainy season consequently causing plants to experience temporal wilting [18]. The trend of the curves agrees with the seemingly rapid run-off and rapid infiltration under natural drainage as observed in FUL-P1 profile during the field study. Soil moisture characteristic curve (Fig. 1) depends on soil particle size distribution and organic matter content which play an important role especially in low suctions [19].

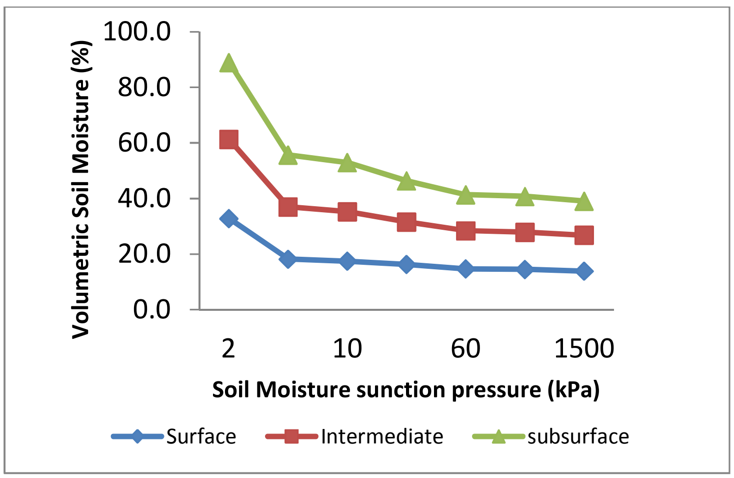
Table 2. Physical properties of soil units of agricultural soils Morogoro district

Profile no	Horizon	Depth	Particle size distribution (%)			Textural	Bulk density
		(cm)	Sand	Silt	Clay	Class*	g cm^{-3}
KZW-P1	Ap	0-49/60	43.7	7.6	48.7	C	1.3
	Bt1	49/60 - 99	45.7	7.6	46.7	SC	1.4
	Bt2	99 - 132	47.7	13.6	38.7	SC	1.6
	Bt3	117-124	37.7	7.6	54.7	C	n.d
MKA_1	Ap	0-20/32	45.7	3.6	50.7	SC	1.2
	Bwt1	32-65/75	37.7	9.6	52.7	C	1.3
	Bwt2	65/75 - 100/117	51.7	5.6	42.7	SC	1.2
FUL-P1	Ap	0 - 10/13	77.7	9.6	31.7	SL	1.5
	Ah	13- 40/50	77.7	3.6	31.7	SL	1.5
	Bwt1	50-95/102	71.7	3.6	25.7	SCL	1.5
	Bwt2	102-129/134	71.7	3.6	25.7	SCL	n.d
	CB	134-175	77.7	3.6	31.7	S L	n.d
	C	175+	83.7	5.6	37.7	S	n.d

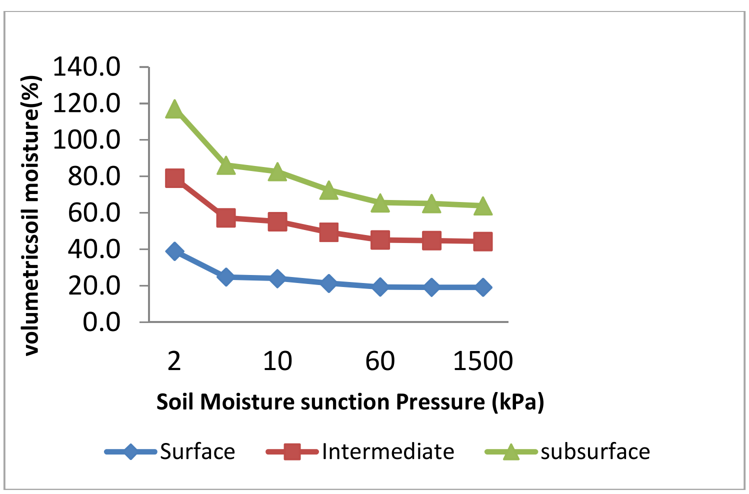
Key: C = Clay, SC = Sand Clay, SL= Sandy Loam, SCL = Sandy Clay Loam, n.d= Not Determined



Soil Characteristic Curve (KZW-P1)



Soil Characteristic Curve (FUL-P1)



Soil Characteristic Curve (MKA-P1)

Fig. 1. Soil moisture characteristic curves for the studied soils

3.3 Chemical Properties

Some selected soil characteristics are presented in the Table 3.

3.3.1 Soil reaction (pH)

According to [14,20] both pedon have slightly acidic condition. The results proves that there no limited nutrients imbalances, toxicity and nutrients unavailability because the pH is at optimal range of about 6.5 to 7.5. Low soil pH values below pH < 5.5 have potential to cause toxicity problems and deficiency of some essential plants nutrients as well as affect soil microbial activities [21]. Soil pH <5.5 could also cause dissolution of aluminum and iron minerals which precipitates with phosphorus effectively causing its fixation and further lowering the soil pH [22].

3.3.2 Available phosphorus (P)

According to [23,12,24], both pedons have very low to low P (Below <7), and further below further below the critical level of 2 mg/kg [17]. The low available P in these soils are linked with P is fixation under alkaline and acid condition to form insoluble compounds [25] and low phosphorus parent materials in which soils were developed such as granitic rocks. Phosphorus availability to plants is strongly influenced by soil pH, and maximized when pH is between 5.5 and 7.5 [26].

3.3 3 Organic carbon, nitrogen and carbon nitrogen ratio

Both pedons has low to medium organic carbon content, very low to low Nitrogen and C/N ratio of 16 to 12.9. Which are below the critical values for rating of good quantity organic matter. This indicates that organic matter are of moderate to poor quality [24,12]. A correlation between organic carbon and total nitrogen is evident and this agrees with other reports e.g. the works of [27] and [10].

3.3.4 Exchangeable calcium (Ca), magnesium (Mg), and potassium (K)

Exchangeable cations laboratory results of the studied soil is given in Table 4. Both pedons. Exchangeable cations are being rated as high to medium except exchangeable K is low at KZW-P1 pedon. Levels of Exchangeable cations has direct implications on the cation exchange capacity (CEC), soil pH and finally plant nutrient imbalances, unavailability and nutrient induced deficiencies. For example, Mg acts as a phosphorus carrier in plants and therefore, P uptake is influenced by Exchangeable Mg [28].

Table 3. Some chemical properties of agricultural soils of three soil units of Morogoro district, Tanzania

Profile	Hor	pH		EC (mS/cm)	OC (%)	N (%)	C/N ratios	OM (%)	P
		H_2O	KCl						Bray1 P (mg/kg)
KZW-P1	Ap	6.9	5.1	0.04	1.2	0.27	4.4	2	23.8
	Bt1	6.7	5.0	0.04	0.9	0.11	8.1	1.5	1.8
	Bt2	6.3	4.8	0.06	0.8	0.08	10	3.1	0.8
	Bt3	5.2	7.1	0.04	0.9	0.09	10	1.7	1.1
FUL-P1	Ap	6.9	5.6	0.03	1.17	0.16	7.3	2.0	6.9
	Ah	6.4	5.7	0.02	0.23	0.14	1.6	0.4	1.9
	Bwt1	5.8	5.4	0.03	0.51	0.16	3.1	0.9	3.4
	Bw2	6.3	4.2	0.03	0.51	0.02	25	0.9	7.1
	Bwt3	7.1	4.6	0.03	0.16	0.01	16	0.3	4.1
	CB	7.2	4.6	0.02	0.43	0.06	7.2	0.7	1.4
MKA-P1	Ap	6.5	5.3	0.03	1.4	0.01	1.4	2.4	1.9
	Ah	6.8	5.5	0.04	0.8	0.09	8.8	1.3	0.7
	Bwt1	7.1	5.2	0.04	0.3	0.05	6	0.5	0.7

Soil profiles: KZW-P1 = Kiziwa, FUL - P1 = Fulwe MKA - P1 = Mkambarani

Table 4. Exchangeable bases and the related chemical properties

Site	Horizon	Exchangeable bases (cmol(+)/kg)				TEB	CEC	BS
		Ca	Mg	K	Na	cmol(+)/kg		(%)
Kiziwa	Ap	11.8	1.98	0.25	0.30	14.3	33.8	42.4
	Bt1	11.43	2.01	0.31	0.23	14.0	26.4	53.0
	Bt2	9.7	0.99	0.61	0.19	11.5	28.2	40.7
	Bt3	9.3	1.54	0.27	0.36	11.5	27.6	41.6
Fulwe	Ap	4.096	0.20	0.70	0.07	5.1	20.4	24.8
	Ah	4.94	0.80	0.41	0.09	6.2	25.2	24.7
	Bwt1	4.51	0.73	0.13	0.14	5.5	18.2	30.3
	Bw2	4.52	0.59	0.16	0.23	5.5	17.6	31.2
	Bwt3	3.93	0.67	0.10	0.01	4.7	16.4	28.7
	CB	4.096	0.25	0.08	0.07	4.5	14.6	30.8
Mkambarani	Ap	6.2	1.00	0.80	0.06	8.1	15.2	53.0
	Bwt1	5.789	1.40	0.18	0.24	7.6	15.2	50.1
	Bwt2	5.95	2.51	0.15	0.29	8.9	14.2	62.6

Key: Soil profiles: KZW-P1= Kiziwa, FUL-P1= Fulwe MKA-P1= Mkambarani: TEB =Total exchangeable bases, BS=Base saturation, CEC=Cation exchange capacity

3.3.5 Cation exchange capacity (CEC) of the soils

The CECsoil is medium in the top soil and low in the subsoil. According to [24,12], CEC values of the pedons indicate possible negative influence on the buffering capacity of the soil and reduced retention of base cations by the soils studied. CEC protects soluble cations from leaching out of the plant root zone and helps soils resist changes in pH [24,29].

3.3.6 Exchangeable sodium (Na) and exchangeable sodium percentage (ESP)

According to [27,24,30], both pedons have low sodium values ranging between 0.15 - 0.28 and low ESP values (< 6%). The low ESP implies that both soils are non-sodic.

3.4 Mineralogical Composition

Concentrations of total oxides of elements in soil units studied areas are given in Table 5. The most abundant oxide determined was SiO_2, which ranges from 17-37.4%. The high values of SiO_2 indicate the existence of amorphous silica. The Al_2O_3 (6 to 10%), Fe_2O_3 (6% -10%) are abundant oxide, probably the soils is derived from gibbsite and hematite [31]. The SiO_2/Al_2O_3 ratio ranged from 2.1 to 4.47% which is generally low according to [27] The same trends of abundance of Ti, Si, Al and Fe oxides have observed in similar study [31] in soils of Mbeya and soils of Sumar, Philippines. TiO2 was very high for soils of MKA-P1. The concentration of Fe2O3 in soils indicates the presence of iron oxides particularly goethite.

Table 5. Total elemental composition of selected samples

Profile	Depth	Al_30_2	$Si0_2$	Fe_20_3	P_20_5	CaO	K_2O	TiO_2	MnO	Total	CIA[#]
	(cm)					%					
KZW-P1	0-49/69	8.97	42.42	43.2	2.45	1.19	0.49	1.56	0.12	100.4	84.22
	99-132	8.42	43.32	36.98	4.74	2.86	0.72	1.38	0.14	98.56	70.16
	13-180	6.73	44.41	39.66	4.06	1.38	0.58	1.19	0.15	98.16	77.44
FUL-P1	0-10/13	7.29	74.35	7.78	0.00	1.81	0.99	0.44	0.001	92.66	72.24
	50-95/102	9.53	69.35	11.36	0.00	0.94	0.91	0.53	0.03	99.25	83.74
	168-180	0.00	88.64	8.34	0.00	1.07	0.81	0.37	0.02	99.25	0.00
MKA-P1	0-20/32	10.66	48.42	24.15	3.41	2.22	0.78	0.89	0.09	90.62	78.03
	75-100/116	11.21	41.33	37.93	2.98	2.12	0.34	1.15	0.12	97.18	82.00
	124-175	8.42	43.63	40.56	2.79	2.14	0.55	1.59	0.14	99.82	75.78

Table 6. Summary of the diagnostic horizons and other features, and classification of the studied soils of Morogoro district, Tanzania (USDA soil taxonomy - soil survey staff, 2006

Profile name	Diagnostic epipedon(s) and subsurface horizon(s)	Other diagnostic features	Soil taxonomy taxa				
			Order	**Suborder**	**Great group**	**Subgroup**	**Family**
KZW-P1	Umbric epipedon; argillic subsurface horizon	Very deep soil, almost flat (slope 0 - 1%), clayey particle size distribution, slighly acid, ustic SMR, isohyperthermic STR	Ultisols	Ustults	Haplustults	Typic Haplustults	*Very deep, almost flat, clayey, slighly acid, ustic, isohyprthermic Typic Haplustults*
FUL-P1	Ochric epipedon; cambic subsurface horizon	Very deep soil, almost flat (slope 0 - 1%), loamy particle size distribution, slightly acid to neutral, ustic SMR, isohyperthermic STR	Inceptisols	Ustepts	Dystrustepts	Typic Dystrustepts	*Very deep, almost flat, loamy, slightly acid to neutral, ustic, isohyperthermic Typic Dystrustepts*
MKA-P1	Mollic epipedon; cambic subsurface horizon	Deep soil, gently undulating (slope 5%), clayey particle size distribution, slightly acid to neutral, ustic SMR, isohyperthermic STR	Inceptisols	Ustepts	Dystrustepts	Humic Dystrustepts	*Deep, gently undulating, clayey, slightly acid to neutral, ustic, isohyperthermic Humic Dystrustepts*

Table 7. Diagnostic horizons, other features and FAO-WRB soil names for the studied soils of Morogoro district, Tanzania

Profile name	Diagnostic horizon	Reference soil group (RSG)	Prefix qualifiers	Suffix qualifiers	WRB soil name
KZW-P1	Umbric horizon, Argillic horizon	Alisols	Cutanic Umbric	Manganiferric Clayic Rhodic	*Umbric, Cutanic Alisols (Manganiferric Clayic, Rhodic)*
FUL-P1	Cambic horizon	Cambisols	Haplic	Ferric Eutric Clayic	*Haplic Cambisols (Ferric, Eutric, Clayic)*
MKA-P1	Mollic horizon, Cambic horizon	Cambisols	Haplic	Dystric	*Haplic Cambisols (Dystric)*

Lead and arsenic was almost not detected in all soils studied. Generally, high levels of SiO2 in the studied soils as compared to Al2O3 and Fe2O3 are probably due to amorphous silica and quartz [13].

3.4.1 Chemical index of alteration (CIA)

The overall CIA values for KZW-P1 varies from 70 to 84.22, 83.74 to 72.24 for FUL-P1 and 75.78 to 82 percent for MKA-P1 Table 5. Nevertheless, there is no strong variation of the CIA values across and within the pedons except in FUL-P1, at a depth of 168 - 180 subsoil, where a CIA value of 0 was recorded which indicates no weathering process happening. According to classification of weathering intensity by [13], Samples from these soil units constitute strong weathering while few of them fall in the intermediate stage. Results revels that there is strongest weathering in Kiziwa and Mkambarani, except one layer in Fulwe. According to [7], soils having CIA values for average shales range from 70 to 75%, and the large amount of aluminous clay minerals (such as kaolinite) formed during intensive chemical weathering is reflected in the high CIA values (80–100) of muds formed under tropical conditions. The studied soils probably contain shales and kaolinite because of high CIA values.

3.5 Soil Classification

Soil morphological, physical and chemical properties enabled definition of the diagnostic horizons and other features that assist to classify the soils. Table 6 presents a summary of the diagnostic horizons and features for classifying the soils up to the family level of the Soil Taxonomy (Soil Survey Staff, 2006) and up to Tier-2 of the FAO World Reference Base. Similarly, Table 7 presents diagnostic horizons and features for classifying soils according to [11].

4. CONCLUSION

The following conclusions can be made from the results of the study;

a. Soil physico-chemical characteristics differed from one pedon to the other under similar agro-ecological conditions.
b. Soil physical properties had an influence on the available water content, soil strength and matric potential of which have influence on nutrient uptake and root ramification.
c. Soil pH in both sites is slightly acidic with low to very low exchangeable cations that could have implications on the CEC, nutrient uptake and consequently nutrient imbalances and induced toxicities.
d. Both soils are weathered with KZW-P1 and MKA-P1 profile showing more advanced stages of weathering thus, necessitating immediate attention to revert the already depleted plant required nutrients.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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