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Pedogenic and Contemporary Issues of Fluvisol Characterization and Utilisation in the Wetlands of Bamenda Municipality, Cameroon

Godswill Azinwie Asongwe[1,2*], Bernard P. K. Yerima[3], Aaron Suh Tening[4] and Irene Bongsiysi Bame[5]

[1]Department of Environmental Sciences, Faculty of Science, University of Buea, P.O.Box 63, Buea, Cameroon.
[2]Department of Development Studies, Pan African Institute for Development – West Africa (PAID-WA) Buea, P.O. Box 133, Buea, Cameroon.
[3]Department of Soil Science, University of Dschang, P.O Box 222, Dschang, Cameroon.
[4]Department of Agronomic and Applied Molecular Sciences, Faculty of Agriculture and Veterinary Medicine, University of Buea, P.O. Box 63, Buea, Cameroon.
[5]Institute of Agricultural Research for Development (IRAD), Bambui, Cameroon.

Authors' contributions

This work was carried out in collaboration among all authors. Author GAA designed and carried out the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors BPKY and AST validated the study. Author IBB managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Fluvisols in urban wetlands in Bamenda Municipality Cameroon play a vital role in vegetable production but they are under immense pressure. Seven representative soil profiles and 21 surface soil samples were morphologically and/or physico-chemically characterized to classify the soils, evaluate their agro-utilization constraints, and to provide adequate data for planning sustainable land management. The soil samples were analyzed using standard procedures. Critical levels

*Corresponding author: E-mail: asongwe2003@gmail.com;

established for tropical crops and vegetables were used to declare deficiency of soil nutrients. The coefficient of variation were used as an index of soil variability, while sources of soil variation and subsequent grouping into management units were identified using principal component analysis. The soils, classified as Humi-umbric fluvisols are developed from young alluvio-colluvial material of granitic origin. Like other physico-chemical properties, organic matter varied irregularly down the profile. Except of pH which was slightly (CV<15%) variable, most soil properties were moderately (CV=15-35%) to highly (CV>35%) variable. Some correlation coefficients between the soil parameters were highly significant (p<0.01) ranging - 0.95 to 0.99, but most of them have correlation values less than 0.5. Six principal components (PCs) grouping soils in management units explained 96.2% of the variations observed in the soil properties. The PCs were: base status, organic matter, weathering and moisture retention, acidity, dispersal and N-mineralization, and mineral neo-synthesis factors. We recommend that a detailed mapping of soil properties be carried out for the establishment of a soil fertility map; and individual soil management practices defined for identified units instead of a common management for all units in the municipality.

Keywords: Fluvisols; soil classification; soil characteristics; soil utilization; soil management.

1. INTRODUCTION

The World Reference Base for Soil Resources (WRB) has 32 soil groups [1], some of which occur in West and Central Africa. Deckers [2], and Bationo et al. [3] outlined the typical distribution in terms of agroecology. Fluvisols, an important soil group, and found in wetlands covers an estimated area of over 350 million hectares worldwide [1]. In Cameroon, they occupy 2.6% of the total land area [4]. Found on all continents under all kinds of climatic conditions they occur mainly on flood plains, fans and deltas of rivers [5]. In the upper part of the drainage basin, they are normally confined to narrow strips along the river. The fluvisols of floodplain wetlands are characterized by seasonal hydrological dynamics, which strongly influence vegetation stand [6]. The later equally noted that in the last century, a hydrological system of seasonal flooding of flood plains had been influenced intensively by man in the form of riversides regulation, and utilisation of parts of the floodplain wetlands for agricultural purposes thus drying up wetland areas and soils. Most importantly, these soils perform an ecological function of accumulating and fixing airborne and fluvially transported nutrients and contaminants. Since soils are good contamination indicators of floodplain ecosystems, they have been the object of research on the soil characteristics and dynamics. The mobilization of organic and inorganic contaminants, results in considerable damages of sensitive soil edaphic factors and the vegetation as well as migration of contaminants into the water saturated zone [6]. Increases in the soil acidity will fasten these migration processes.

In fluvisols, soil forming processes, other than the formation of a surface horizon through accumulation of organic matter, have not left their marks [7,1]. These juvenile soils show few or no evidence of weathering and soil formation below 25 cm depth except possible gleying. Permanent or seasonal saturation with water, because of permanent or recurrent anaerobic conditions and low biological activity, tends to preserve the original stratified nature of the original deposits. But with time, when the effects of pedogenetic agents such as soil animals, roots, repeated wetting and drying proceed downward in the profile, a cambic horizon may be formed. This implies the transformation of the Fluvisol into a Cambisol or Gleysol, depending on the drainage conditions. Flooding of some parts of the wetlands with fresh water will change the geochemistry of the soils as the basis for flora and fauna.

To date, the nutrients contents of the flooded and non-flooded areas differ considerably. Many types of plants are grown on Fluvisols today or are under grassland utilization. They are usually fertile but may need flood control. Many Fluvisols in the humid tropics, Cameroon inclusive, are under vegetable production, especially during a dry period where microbial activity is stimulated which promotes mineralization of organic matter and hence release of plant nutrients. Other factors that influence the potential productivity of wetland soils are their micro-topography, minimal soil erosion, natural fertility, and location in climatic regions of adequate rainfall for most crops.

Fertility levels have a direct bearing on the potential for development of wetland soils, especially in urban areas [8]. A vast majority of wetland benefits accrue to the local population which makes it important to conserve these valuable natural resources. Nowadays, their exploitation particularly for economical purpose is alarming [9,10]. The urban wetlands of Bamenda Municipality, which is part of the Western Highlands of Cameroon and the focus of this study, are coming under increased pressure for the production of food to meet the needs of the increasing population.

The municipality and the wetlands are characterized by a heavy demographic, technogenic and municipal load. The problem with the wastewaters and solid wastes acquires increasing importance. Here, these wetlands ecological niches have been drained for vegetable cultivation. These valuable areas are not only exploited for market gardening involved in the cultivation of vegetables, carrots, tomatoes, green beans, Irish potatoes but also for the planting of eucalyptus which help to drain the water in these wetlands [9,10]. The result is that at the present rate of exploitation the survival of this resource is at stake. Enhanced understanding of the morphological and physico-chemical properties of the fluvisols would avail pertinent information for assessing the potentials and constraints of the soils for different uses and management options. Generally, studies related to environmental concerns (soils, air and water) and society is key to develop efficient land management plans [11,12]. It is on this backdrop that the objectives of this study were to a) characterize the soils based on the morphological field description and physico-chemical properties; and to classify the soils using the World Reference Base (WRB) for Soil Resources, b) Identify the current utilization constraints and, c) to provide data for use by stakeholders in planning sustainable land management in the Bamenda urban Municipality.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The area covered by this study includes urban and peri-urban wetlands in the Bamenda City Council of the North West Region of Cameroon (Fig. 1). It is part of the Bamenda escarpment and located between latitudes 5°55'' N and 6°30'' N and longitudes 10°25'' E and 10°67'' E. The town shows an altitudinal range of 1200 - 1700 m, and is divided into two parts by escarpments; a low lying gently undulating part with altitudes ranging from 1200 to 1400 m, with many flat areas that are usually inundated for most parts of the year, and an elevated part at 1400 to 1700 m altitude that forms the crest from which creeks and streams supplying the low lying parts take their rise. This area has two seasons; a long rainy season, which runs from mid-March to mid-October and a dry season that spans from mid-October to mid-March. The area lies within the thermic and hyperthemic temperature regimes. Mean annual temperatures stand at 19.9°C. January and February are the hottest months with mean monthly temperatures of 29.1°C and 29.7°C, respectively. Yerima and Van Ranst [7] reported that the area is dominated by the Ustic and Udic moisture regimes with the Udic extending to the south. Annual rainfall ranges from 1300-3000 mm [13]. The area has a rich hydrographical network with intense human activities and a dense population along with different water courses in the watershed. The main human activity in and around this area is agriculture, which according to GP-DERUDEP [14] involves over 70% of the population and make use of rudimentary tools. The area equally harbors the commercial center that has factories ranging from soap production, and garages to metallurgy, which may be potential sources of pollutants. An important vegetation type in this area is the raffia palm bush, which is largely limited to the wetlands (Valleys and depressions). The raffia palm (*Raffia farinifera)* provides raffia wine, a vital economic resource to the indigenes who are fighting against the cultivation of these wetlands by vegetable farmers.

2.2 Sampling Strategy

In the study (Fig. 1), seven representative soil profiles (from three wetlands) were described. These profiles represented different variability (close to the main water course and further away) in landscapes and were pedologically and morphologically described in the field as outlined by the Soil Survey Staff (2003). The depth of soil profiles and thickness of horizons were determined with the help of a measuring tape. Soil colours were selected with the help of a Munsell color chart [15]. The soils of the study area are composed of poorly drained fluvisols derived from aluvi-colluvial parent materials, on a less than 1% slope. Samples were collected by genetic horizons from pits excavated to a maximum of 1.5 m deep depending on the water table. Twenty bulk samples were collected from the various horizons. Similarly, 21 top soil samples (0 - 25 cm) were randomly collected with the use of a hand trowel into black plastic bags in the wetlands. The soil samples were air-dried, ground using a ceramic mortar. The fine earth fractions were screened through a 2-mm sieve. They were then parceled in black plastic bags and transferred to the Environmental and Analytical Chemistry Laboratory of the University of Dschang Cameroon where they were analyzed for routine parameters. Particle size distribution, cation exchange capacity (CEC), exchangeable bases, EC, and pH were determined on the fine earth fraction by standard procedures [16]. pH was measured both in water and KCl (1:2.5 soil/water mixture) using a glass electrode pH meter. Part of the fine soil was ball-milled for organic carbon (OC) and Kjeldahl-N analysis [16]. Available P was determined by method of Bray II, exchangeable cations were determined by extracting with 1N ammonium acetate at pH 7, potassium and Na in the extract were determined using flame photometer and Mg and Ca determined by complex metric titration. Exchangeable acidity was extracted with 1M KCl followed by quantification of Al and H by titration [16]. Effective cation exchange capacity (ECEC) was determined as sum of bases and exchanged acidity. Apparent CEC (CEC7) was determined directly as outlined by Pauwels et al. [16]. Based on critical values of nutrients established for vegetables, nutrients were declared sufficient or deficient.

2.3 Analytical Approach

Data obtained were subjected to statistical analyses (univariate statistics: mean, range, maximum and minimums and multivariate statistics, correlation and principal component analyses: Factorial analyses) using Microsoft Excel 2007 (Microsoft, USA) and SPSS (IBM, USA) statistical package 20.0. Soil properties were assessed from their variability using coefficient of variation (CV %) and compared with variability classes (Tables 1 and 2, respectively).

Table 1. Grouping coefficient of variation into variability classes

CV %	Variability grouping (class)
< 15 %	Slightly variable
15-35 %	Moderately variable
➢ 35 %	Highly variable

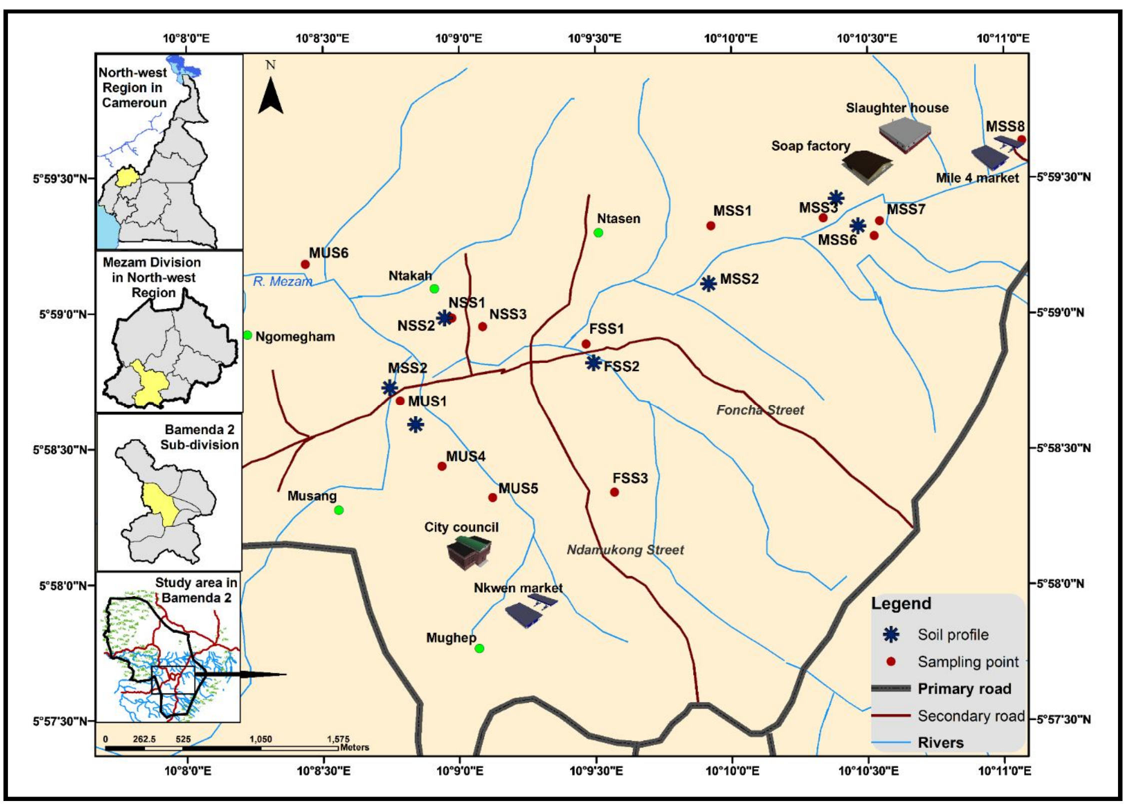

Fig. 1. Map of Bamenda Municipality showing fluvisols sampling areas

Table 2. Critical values of nutrients and soil properties

Properties	Critical values				
	Very low	Low	Medium	High	Very high
OM %	<1	1-2	2-4.2	4.2-6	>6
Total N g/Kg	< 0.5	0.5-1.25	1.25-2.25	2.25-3.0	>3.0
C/N	<10 = good, 10-14 = medium and >14 = poor				
Ca cmol/kg	<2	2-5	5-10	10-20	>20
Mg cmol/kg	<0.5	0.5-1.5	1.5-3	3-8	>8
K cmol/kg	<0.1	0.1-0.3	0.3-0.6	0.6-1.2	>1.2
Na cmol/kg	<0.1	0.1-0.3	0.3-0.7	0.7-2.0	>2
Bray 2–P mg/kg	<7	< 7-16	16-46	>46	
pH	5.3= 6.0 moderately acid, 6.0-7.0 = slightly acid, 7.0-8.5 moderately alkaline				
ESP %		<2	2-8	8-15	15-27
CEC_7 cmol/kg	0-20	21-40	41-60	61-80	81-100

Adapted from Beernaert and Bitondo [18]

Table 3. Test statistics (KMO and Bartlett's Test) for data impaction prior to principal component analysis

KMO and Bartlett's Test		Value
Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO)		0.703
Bartlett's Test of spericity	APPro. Chi-square	178.431
	Df	20
	Sig	0.000!

To identify the factors causing variation in the soil properties, principal component analysis (PCA) was performed. Varimax rotation was applied to do away with the problem of autocorrelation and to reduce the contributing soil factors to orthogonal principal components [17]. The coefficients of the principal components are the eigen values. Analysis of correlation and coefficient of variations also assisted to identifying soil factors that correlate significantly and differ, respectively.

$$\%CV = \frac{Sd\ X100}{X}$$

Where:

Sd = standard deviation
X = arithmetic mean of soil properties

To identify the factors causing variation in the soil properties, the data of the 22 variables reported in this study were subjected to R-mode factorial analysis using the six-factor model. Before this was done the data were subjected to two test statistics for inspection (Table 3) ie, the Bartlett test of sphericity and the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (usually called the MSA). The Bartlett Test of Sphericity compares the correlation matrix with a matrix of zero correlations (technically called the identity matrix, which consists of all zeros except the 1's along the diagonal). From this test we are looking for a small P value indicating that it is highly unlikely for us to have obtained the observed correlation matrix from a population with zero correlation. However, there are many problems with the test – a small p value indicates that you should not continue but a large p value does not guarantee that all is well.

The MSA does not produce a P value but we are aiming for a value greater than 0.8 and below 0.5 is considered to be unacceptable.

Good values for all variables for the MSA were obtained but the overall value was a bit low (0.703). However, Bartlett's Test of Sphericity had an associated P value of <0.001 as by default SPSS reports p values of less than 0.001 as 0.000!. So from the results, a valid factor analysis can be performed.

To take care of multiple multicollinearity the determinant was checked to see if it is greater than 0.00001. In the study, it was 0.0687.

3. RESULTS AND DISCUSSIONS

3.1 Soil Profile Characterization and Classification

Pedological and Morphological characterization of the soils showed that they were fluvisols with parent materials of alluvi-colluvial deposits, of granitic origins. The soils also indicated a varying degree of oxidation and reduction as indicated by red and blue colours of (ferric and ferrous of Fe) mottles. Munsell color values of the various horizons of the soils did not show a definite pattern throughout the profiles and generally ranged around 2.5 to 10. These marked differences observed could be ascribed to variation in drainage, topographic and/or anthropogenic influences. Similar variations in hydric soils have been noticed in many parts of the world [19,20,21]. Numerous mottles predominantly of reddish coloration of varying percentages were noticed within the various horizons in the different profiles. According to Wilding and Rehage [22], major pedogenetic processes in hydric soils apart from the mobilization and immobilization of iron and manganese concretions, includes mottling (FAO/UNESCO, 1999). The texture of soils under investigation was dominated by sandy loams, with a few sandy clay loams, based on particle size distribution. On the surface horizon, soil structure was predominantly granular, separated from weak angular block shapes. Lower horizons showed varied structures with numerous relics of man-used materials (cloths, plastics, pieces of metals, charcoal, etc.,) within most of the profiles (Fig. 2). Consistence, when moist, generally varied from friable through slightly sticky to sticky and was plastic when wet. Few to many fine roots dominated the surface horizons. Clear smooth and gradual boundaries were some prominent morphological properties. Soil moisture regime was ustic, while the temperature was isothermic.

The water table was very close to the surface with a maximum depth of 120 cm obtained at the profile Fuwambi – Ntahsen. Profiles at lower river courses were less stony indicating the river had lost a greater part of it energy and could thus transport and deposits only fine particles.

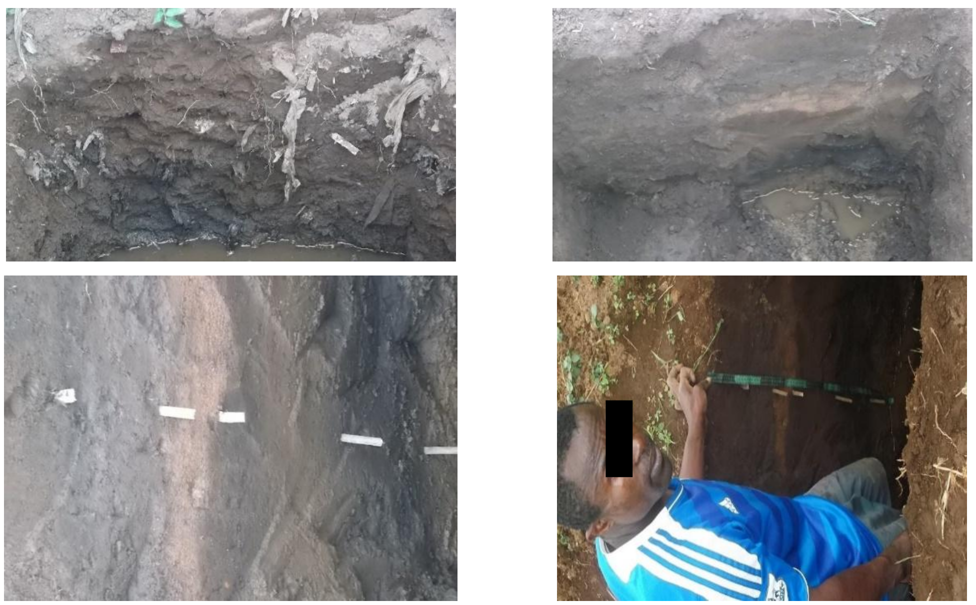

Fig. 2. (a) Soil profiles some with artifacts

Fig. 2. (b) adjacent river banks of the wetland of Bamenda Municipality Cameroon with artifacts

Table 4. Physico-chemical properties of soil profiles within wetland gardens of Bamenda Municipality

Horizon	Depth	Sand	Silt	Clay	Sand/Silt	pH (1:2.5)		EC	OC	OM	Tot. N	C/N	Av. P	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Σ Bases	Acidity	Al^{3+}	H^{+}	CECsoil	CECclay	ECEC	B.S. CEC	B.S EC
	cm	%				H_2O	KCl	uS/cm	%				mg/kg	cmol/kg					meq/100g			cmol/kg			%	
Profile 1: Fuwambi -Ntahsen Quarter																										
Ap1	0 - 15	68	17	15	4.0	4.5	4.2	233	9.49	16.37	0.6	15.82	17	0.49	0.15	0.10	0.13	0.87	0.045	0	0.04	39.76	46.80	39.81	2.19	2.19
Apg	15 - 27	68	17	15	4.0	6.3	4.5	248	8.53	14.71	0.4	21.33	17	0.84	3.10	0.40	0.12	4.46	0.010	-	-	30.00	3.87	30.01	14.87	14.86
Cag	27 - 34	66	16	18	4.1	6.8	4.5	273	9.70	16.72	0.5	19.40	14	0.30	0.35	0.04	0.12	0.81	0.010	-	-	36.80	18.62	36.81	2.19	2.19
2CAg	34 -59	69	15	16	4.6	6.4	4.4	244	10.25	17.67	0.5	20.50	19	0.34	0.17	0.05	0.10	0.66	0.010	-	-	41.20	36.63	41.21	1.60	1.60
2CAg2	59 - 83	70	16	14	4.4	6	4.3	262	7.89	13.61	0.5	15.78	60	0.43	0.20	0.05	0.10	0.78	0.010	-	-	50.16	164.57	50.17	1.56	1.55
Cg	83 - 120	72	8	20	9.0	5.6	4.2	219	7.44	12.82	0.2	37.18	7	0.44	0.36	0.03	0.14	0.97	0.070	-	-	33.93	41.43	34.00	2.85	2.85
Profile 6: Below Cow Slaughter																										
Apg	0 - 12	70	16	14	4.4	5.5	4.7	147	9.57	16.49	0.6	15.94	8	0.42	0.24	0.04	0.12	0.83	0.090	-	-	33.72	5.30	33.81	2.45	2.44
Cg	12 - 44	68	18	14	3.8	6.3	4.8	158	9.24	15.93	0.6	15.40	9	0.37	0.26	0.04	0.12	0.79	0.010	-	-	34.03	15.46	34.04	2.32	2.32
Profile 7: Below Slap																										
Apg	0 - 20	67	17	16	3.9	5.5	4.3	243	9.35	16.12	0.8	11.69	12	0.42	0.16	0.04	0.12	0.75	0.090	-	-	33.52	8.01	33.61	2.23	2.22
Cg	20 - 41	70	16	14	4.4	6.3	5.5	246	9.13	15.75	1.2	7.61	15	0.20	0.16	0.04	0.12	0.52	0.010	-	-	35.67	29.82	35.68	1.45	1.45
Profile 2: Ntenefor (Below Foncha)																										
Apg	0 - 20	80	10	10	8.0	6	4.9	134	9.00	15.51	0.6	15.00	14	0.54	0.26	0.04	0.12	0.96	0.010	-	-	34.67	36.36	34.68	2.77	2.77
ACg	20 - 30	82	8	10	10.3	6	4.9	137	8.73	15.05	0.4	21.83	13	0.20	0.35	0.04	0.12	0.71	0.010	-	-	33.72	36.22	33.73	2.10	2.10
Cg	30 - 38	81	9	10	9.0	5.7	4.6	132	8.00	13.80	0.3	26.68	8	5.13	1.12	0.04	0.12	6.41	0.090	-	-	35.57	79.74	35.66	18.02	17.97
Profile 3: Mulang –Ntahkah																										
Apg	0 - 41	63	18	19	3.5	5.7	4.5	59	9.13	15.75	0.6	15.22	13	0.54	0.26	0.04	0.09	0.93	0.060	-	-	34.13	13.89	34.19	2.71	2.71
Cg	41 - 70	62	20	18	3.1	6.2	4.6	68	9.54	16.44	0.5	19.08	10	0.20	0.16	0.04	0.11	0.51	0.010	-	-	35.77	16.02	35.78	1.41	1.41
Profile 4: Mulang Council junction																										
Ap	0 - 27	70	16	14	4.4	6.1	5.1	289	9.60	16.56	0.6	16.00	10	0.24	1.46	0.05	0.10	1.85	0.010	-	-	41.20	57.71	41.21	4.49	4.49
Cg1	27-38	62	28	10	2.2	5.9	5.0	256	8.00	13.79	0.6	13.33	27	1.34	3.80	0.05	0.10	5.29	0.090	-	-	36.96	93.80	37.05	14.31	14.28
Cg2	38 - 59	63	21	16	3.0	5.7	4.7	227	10.99	18.97	0.7	15.70	12	0.56	1.90	0.20	0.13	2.79	0.060	-	-	66.48	178.38	66.54	4.20	4.19
Profile 5: Mulang towards Army rescue																										
Ap	0 - 27	62	28	10	2.2	6.3	5.5	248	8.81	15.19	0.4	22.03	24	0.42	0.12	0.04	0.12	0.71	0.010	-	-	34.13	37.53	34.14	2.07	2.07
ACg1	27 - 37	64	26	10	2.5	6.2	4.4	214	8.92	15.38	0.5	17.84	11	0.77	0.26	0.04	0.12	1.19	0.010	-	-	35.57	48.16	35.58	3.35	3.35
ACg2	37 - 46	82	8	10	10.3	6	5.2	233	8.22	14.17	0.8	10.27	13	0.51	0.16	0.04	0.12	0.83	0.010	-	-	35.44	71.08	35.45	2.35	2.35

3.2 Classification

Based on the USDA soil Taxonomy and with an approximate correlation of WRB 14 soil legend [23], the near absence of diagnostic horizons qualified the soils for classification in the Entisol order of soil Taxonomy. The ustic moisture regime of the profiles coupled with gleyzation processes qualified the soils to be fitted into the suborder Fluvent, Great group Ustivluvet and subgroup Typic Ustifluvent. FAO/ISRIC/ISSS [24] allocated these alluvial soils to the group of azonal soils. Other correlations made include: alluvial soils, Regosols.

The FAO/UNESCO equivalent is Humi-umbric Fluvisol.

3.3 Physical and Chemical Properties of Soil Profiles

Studies of the seven soil profiles revealed that the physico-chemical properties varied considerably within and between the profiles (Table 4). Similar variations in hydric soils have been noticed in many parts of the world [19,20,21]. The sand fractions were the dominant soil separates and irregularly distributed within the profiles with mean values of 69.5%. Silt contents were moderately distributed. Moderate values of silt could be allied to constant fluviatile deposits and sedimentation processes. Clay contents of the soils were generally low and ranged from 10% in the profiles at Ntenefor (Below Foncha) and that at Mulang toward Army rescue to 20% in the Cg horizon of the Fuwambi – Ntahsen profile. The low clay content could be attributed to some extent to the processes of selective destruction of clay in the surface soil horizons and ferrolysis. The irregular distribution of and stratification of sand in these profile horizons suggest different periods of deposition of sediments rather than the deep weathered nature of parent materials. Similar findings in wetlands have been reported by Ojannuga (1991). In most of the profiles, the A horizons were dark in colors attributed to higher organic matter contents (Table 4). The organic matter content did not show regular decreases with depth often witnessed in most undisturbed soil profiles around the world [25,26]. This inexistence of definite trends of organic matter in the profiles could be ascribed to the continuous excavation activities and/or seasonal deposition of run-off sediments and urban wastes as evident in the profiles and river banks (Fig. 2), respectively). These results are in concordance with reports by FAO-ISRIC-ISSS [24] and Yerima and Van Ranst [25] who noted that fluvisol profiles have irregular distribution of organic matter. Total nitrogen showed similar pattern as organic matter. The pH (1:2.5 soil: water) of these soils ranged from very acidic (4.5) in the Ap horizon of the profile at Fuwambi – Ntahsen to moderately acidic (6.8) in the CAg horizon of the same profile. However, the profiles showed slight decreases of pH with depths which were not significant. Such variation is uncommon in stable ferritic soils where pH decreases are always significant with depth increases [25,26]. Lower pH values observed in some surface horizons might be as a result of deposition of acidic substances through routine farm management practices such as the application of fertilizers, a common phenomenon of the area and/or from municipal swept offs and this was also reported by Asongwe et al. [10]. The very acidic nature of some of the samples might result in Al and Mn toxicity. This would affect the availability of available P. Beernaert and Bitondo [18] reported that in soils with such acidic nature, Ca, Mg and Mb may also be deficient. To address the situation of acidity, ammonium sulphate and triple superphosphate fertilizers should be avoided. The EC values were high and ranged from 59 to 289 uS/cm with an average value of 203.3 uS/cm. The concentrations of Ca and Mg which dominated the exchange complex of the soils ranged from 0.20 to 5.13 and 0.12 to 3.80 cmol/kg, respectively. A potential local source of calcium might be relatively unweathered gneissic rocks rich in oligoclase (soda-lime plagioclase feldspar), hornblende (an amphibole containing calcium, magnesium, sodium, iron and aluminium) or augite (a pyroxene containing calcium, magnesium, iron and aluminium). Of particular importance, crushed or ground animal bones (bone meal) can be used as a slow-acting source of both calcium and phosphorus [27]. All vegetable and bone waste can be re-used in various ways as fertilizers and, using processes that have proved successful in other African countries [27], this could be extended to include human faeces and urine. They respectively showed highly significant ($P < 0.01$) positive correlation coefficients of 0.776 and 0.780 with base saturation and CEC (Table 6).

The sand/silt ratios were fairly constant but evidenced stratigraphic breaks in some profiles. According to Yerima and Van Ranst [25], in environments characterized by slowly flowing or stagnant water, stratification of deposits may be difficult to detect, and as such successive deposits will seem to be homogenous. This would have been the case of the fluvisols of the wetland gardens in Bamenda Municipality. Sombroek and Zonneveld [28] reported that silt/clay ratios also predict ages of parent materials, young or old ones. Where the ratio is more than 0.15, the parent material is a young one and vice versa. In this case, the ratios exceeded 0.15, an indication that the parent materials of the Fluvisols in urban wetland gardens are young. The CEC of the soils ranged from low to high with an average value of 37.73 cmol/kg. The ECEC showed a week positive relationship (r = 0.044) with exchange acidity at the 5% probability level. Though CEC clay was not determined directly but calculated from CEC soil, the values ranged from 3.87 in the Apg horizon of the Fuwambi – Ntahsen profile to 178.38 cmol/Kg in the Cg2 horizon of the profile at Mulang council junction. This predicts suiting mineralogy of the soils to be dominated by 1:1 minerals such as Kaolinites and sesquioxides with some limited interstratification with 2:1 minerals. The clay fraction of soil showed an insignificant ($p > 0.05$) positive correlation (r = 0.302) with organic matter at the 95% Confidence level (Table 6). The insignificant positive relationship is an indication that the distribution of organic matter does not depend on the clay content but on external factors, possibly varying degrees of sedimentation.

3.4 Physico-chemical Properties of Surface Soil Samples Collected from the Wetland Gardens of Bamenda Municipality

Descriptions of adequacy of nutrient levels were done using critical values for nutrients and soil properties (Table 2).

The results of the physico-chemical properties (Table 7) of soils in the Urban and Peri-urban wetlands of the Bamenda Municipality under smallholder agricultural farms vary considerably. Ninety percent of the soils in the wetlands have a sandy loam texture while 10% are of the sandy clay-loam textural class. The clay contents of the soils ranged from 10% to 21% with an average of 16.7% (Table 8). According to Mengel and Kirkby [29], sites with high percentage of clay and silt are recommended for agricultural practices as they are capable of providing good aeration and retention and therefore supply of nutrients and water. However, these soils were poor in such parameters, predicting agronomic lapses. The soils of the area vary from acidic, through moderately acidic to slightly acidic. Average soil pH (H_2O) was 5.3 and 4.6 for pH (KCl). Generally, pH KCl range from 4.0 to 5.4 and are lower than those of pH water which ranged from 4.3 to 6.3. The variation of ΔpH ($pH_{KCl} - pH_{H2O}$) was negative throughout. This indicates that the net charge on the exchange complex is negative, and thus exhibit cation exchange capacity. However, according to Yerima and Van Ranst [7], some tropical soils due to intensive rainfalls and weathering are dominated by positive charges with anion exchange capacity predominantly. Percent organic carbon ranged from 3.21% (Mile 4 market area) to 13.63% (Mulang 4 near houses) with an average value of 8.19 % in the entire area. The organic matter according to critical values by Beernaert and Bitondo [18] (Table 2), varying from high to very high values, with a range from 5.67% to 23.50%. It had a weak positive correlation with the clay fraction of soil (r = 0.218) at the 5% probability level. This is an indication that the distribution of organic matter in the soil is not influenced by clay. This variation might be attributed to the constant addition of organic matter from varying anthropogenic activities (application of poultry manure, municipal wastes (Table 7) and varying levels of stratification due to seasonal flooding. In the tropics, soil organic carbon is central to sustaining soil fertility on smallholder farms [30,31]. In low-input agricultural systems in the tropics, it helps retain mineral nutrients (N, S, micronutrients) in the soil and make them available to plants in small amounts over many years as it is mineralized. In addition, soil organic carbon increases soil flora and fauna (associated with soil aggregation, improved infiltration of water and reduced soil erosion), complexes toxic Al and manganese (Mn) ions (leading to better rooting), increases the buffering capacity on low-activity clay soils, and increases water- holding capacity [31]. Continuous cropping, with its associated tillage practices, provokes an initial rapid decline in soil organic matter, which then stabilizes at a low level [31].

Total N ranged from 0.3 to 0.8% (Table 8). Landon [32] reported that for tropical soils, total nitrogen content of 0.13% is sufficient. Nitrogen is highly mobile and easily lost and vegetables need high quantities. This necessitates the high application of nitrogen fertilizers to maintain the production of vegetables on the wetland which is already vulnerable given that the sand fraction dominates them. The organic carbon was perfectly correlated to organic matter (r = 1.00)

(Table 9). The C/N ratio varying from 5.58 to 36.03 indicated that, the soils range from good to poor. Despite of the fact that the soil are rich in organic carbon, the very high C/N ratio witnessed in some areas predicts difficulties in mineralization which could be ascribed to water stagnation. Likewise, farm specific practices might have also influenced the inconsistent pattern in mineralisation. Areas characterized by rapid mineralization would result to high nitrogen losses which necessitate high nitrogen fertilization, a constraint to peasant farmers caused by poverty. Generally, a majority of the soils had C/N ratios that were less than 25. According to Mengel and Kirkby [29], soils with such C/N ratios (less than 25) are ameliorating and the litter are of the mull type.

Available P is associated with organic carbon. It ranged from 8 mg/Kg to 76 mg/Kg. Available P concentrations lower than 16 mg/Kg in soils are considered low to ensure adequate phosphate supply to most plants [32]. The low P in some of the soils could be related to the rapid lost due to fast mineralization rate of organic matter given by low values of C/N values. The availability of phosphorus might also be limited due to the nature of parent material that is generally basaltic in this area, and probably high sorption due to surface mineralogy [33].

Ca and Mg dominates the exchange complex but their concentrations were low ranging from 0.20 to 0.54 cmol/Kg for Ca (with a variance of 0.015) and 0.37 to 0.68 cmol/Kg for Mg (with a variance of 0.011). According to Landon [32] deficiencies of Ca are normal in soils with pH ≤ 5.5 which have been a witness in some sites of this study. Continues cultivation without returning residues to soil depletes these nutrients and thus low future yields. Major sources of magnesium in soils include amphiboles, olivine, pyroxene, dolomites and clay minerals [34]. According to the later, dolomites have a high concentration of magnesium while clay minerals have low concentration. Ca and Mg showed a highly significant positive correlation ($r = 0.869$ and $r = 0.780$) with exchangeable bases at the 1% probability level (Table 9).The Al concentration ranged from 0.02 to 0.05 meq/100g. Within the exchanged acidity, its concentrations were significantly ($r = 0.710$) lower than that of H, at the 5% probability level. This is an indication that the sources of charges on the exchange colloids displaced by neutral salts are pH dependent.

Table 5. Descriptive statistics for some physico-chemical properties of soil profiles in Bamenda Municipality

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Sand	21	20.00	62.00	82.00	69.4762	6.60014	43.562
Silt	21	20.00	8.00	28.00	16.5714	5.96298	35.557
Clay	21	10.00	10.00	20.00	13.9524	3.30872	10.948
Sand /silt	21	8.10	2.20	10.30	5.0048	2.60796	6.801
pH water	21	2.30	4.50	6.80	5.9524	0.46864	0.220
pH KCl	21	1.30	4.20	5.50	4.7048	0.38791	0.150
EC	21	230.00	59.00	289.00	203.3333	66.63207	4439.833
OC	21	3.55	7.44	10.99	9.0252	0.83786	0.702
OM	21	6.15	12.82	18.97	15.5619	1.44691	2.094
N	21	1.00	0.20	1.20	0.5667	0.20575	0.042
CN	21	29.57	7.61	37.18	17.7919	6.20378	38.487
Av.P	21	53.00	7.00	60.00	15.8571	11.30171	127.729
Ca	21	4.93	0.20	5.13	0.7000	1.04752	1.097
Mg	21	3.68	0.12	3.80	0.7143	1.03059	1.062
K	21	.37	0.03	0.40	0.0690	0.08414	0.007
Na	21	.05	0.09	0.14	0.1162	0.01203	0.000
SBases	21	5.90	0.51	6.41	1.6010	1.68893	2.852
Acidity	21	0.08	0.01	0.09	0.0345	0.03376	0.001
Al	1	0.00	0.00	0.00	0.0040	.	.
H	1	0.00	0.04	0.04	0.0410	.	.
CECsoil	21	36.48	30.00	66.48	37.7348	7.76672	60.322
CECclay	21	174.51	3.87	178.38	49.4952	47.24357	2231.955
ECEC	21	36.53	30.01	66.54	37.7695	7.76819	60.345
BSCEC	21	16.61	1.41	18.02	4.3567	4.86537	23.672
BSECEC	21	16.56	1.41	17.97	4.3505	4.85492	23.570

Table 6. Pearson correlation coefficients for some physico-chemical parameters of soil profiles in wetlands of Bamenda Municipality

	Sand	**Silt**	**Clay**	**Sand/silt**	**pH H_2O**	**pH KCl**	**EC**	**OC**	**OM**	**N**	**C/N**	**Av. .P**	**Ca**	**Mg**	**K**	**Na**	**ΣBases**	**Acidity**	**CECsoil**	**CECclay**	**ECEC**	**BSCEC**	**BSECEC**
Sand	1																						
Silt	-0.866**	1																					
Clay	-0.434*	-0.075	1																				
Sand/silt	0.937**	-0.903**	-0.242	1																			
pH H_2O	-0.083	0.134	-0.076	-0.107	1																		
pH KCl	0.138	0.144	-.0534*	0.045	0.370	1																	
EC	-0.148	0.205	-0.075	-0.207	0.147	0.101	1																
OC	-0.373	0.245	0.302	-0.444*	0.044	-0.011	-0.008	1															
OM	-0.373	0.245	0.302	-0.445*	0.043	-0.010	-0.007	1.000**	1														
N	-0.069	0.102	-0.047	-0.204	-0.007	.0441*	0.175	0.345	0.346	1													
CN	0.124	-0.267	0.234	0.332	-0.011	-0.382	-0.114	-0.352	-0.352	-0.869**	1												
Av. .P	-0.132	0.222	-0.135	-0.218	0.080	-0.067	0.359	-0.297	-0.296	-0.024	-0.172	1											
Ca	0.323	-0.169	-0.341	0.275	-0.152	-0.079	-0.194	-0.352	-0.351	-0.315	0.300	-0.108	1										
Mg	-0.212	0.318	-0.152	-0.226	0.047	0.088	0.278	-0.128	-0.127	-0.108	0.004	0.080	0.271	1									
K	-0.158	0.106	0.124	-0.188	0.009	-0.153	0.213	0.125	0.127	-0.097	0.055	0.025	0.008	0.603**	1								
Na	0.238	-0.261	-0.005	0.322	-0.273	-0.082	0.111	-0.042	-0.042	-0.094	0.350	-0.409	0.040	-0.150	0.174	1							
ΣBases	0.065	0.093	-0.298	0.025	-0.068	-0.003	0.061	-0.291	-0.289	-0.267	0.194	-0.020	0.786**	0.807**	0.424	-0.050	1						
Acidity	-0.085	0.023	0.130	-0.007	-0.613**	-0.290	-0.153	-0.123	-0.123	-0.071	0.138	-0.197	0.456*	0.277	-0.082	0.112	0.449*	1					
CECsoil	-0.213	0.160	**0.137**	-0.219	-0.126	-0.103	0.261	.0461*	**0.463***	0.141	-0.146	0.323	-0.065	0.152	0.165	-0.007	0.060	0.039	1				
CECclay	0.012	0.095	-0.195	-0.001	-0.137	-0.010	0.300	-0.038	-0.035	0.009	-0.069	0.542*	0.200	0.282	0.071	-0.052	0.298	0.100	0.060	1			
ECEC	-0.213	0.160	0.137	-0.219	-0.129	-0.105	0.260	0.460*	0.463*	0.140	-0.145	0.322	-0.063	0.153	0.165	-0.006	0.062	0.044	1.000**	0.849**	1		
BSCEC	0.103	0.053	-0.302	0.058	-0.029	-0.015	0.035	-0.382	-0.381	-0.305	0.226	-0.035	0.776**	0.780**	0.451*	-0.056	0.979**	0.399	-0.123	0.141	-0.121	1	
BSECEC	0.103	0.054	-0.302	0.058	-0.028	-0.015	0.035	-0.382	-0.381	-0.305	0.226	-0.036	0.776**	0.780**	0.451*	-0.056	0.979**	0.398	-0.123	0.140	-0.121	1.000**	1

**Correlation significant at 5%*
***Correlation significant at 1*

Table 7. Physico-chemical properties of surface soil samples, poultry manure and Municipal waste within the wetlands of the Bamenda Municipality

No	Site	Sand	Silt	Clay	pH (1:2.5)		EC	OC	OM	Tot. N	C/N	Av. P	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	ΣBases	Exch. Acid.	$Al3^{+}$	H^{+}	CECsoil	CECclay	ECEC	B.S. CEC	B.S. ECEC
		%			H2O	KCl	uS/cm	%				mg/Kg	cmol/Kg					meq/100g			cmol/Kg			%	
1	Fuwambi Near Ntasen	56	24	20	4.6	4.3	235	5.88	10.13	0.8	7.34	18	0.31	0.56	0.03	0.12	1.02	0.45	0.04	0.41	32.30	60.21	32.75	3.16	3.11
2	Fuwambi near GTTC	58	24	18	5.6	4.7	212	7.52	12.96	0.6	12.53	8	0.20	0.37	0.04	0.13	0.73	0.09	-	-	33.93	44.44	34.02	2.16	2.15
3	Slap 1	58	21	21	4.5	4.3	230	10.58	18.23	0.6	17.63	14	0.31	0.46	0.05	0.12	0.94	0.4	-	-	37.62	5.49	38.02	2.51	2.48
4	Slap 2	57	22	21	6.3	5.2	197	9.40	16.21	0.7	13.43	12	0.20	0.56	0.04	0.13	0.92	0.01	-	-	35.98	16.98	35.99	2.57	2.56
5	Slap 3	58	20	20	5.3	4.0	237	10.81	18.64	0.3	36.03	22	0.20	0.52	0.04	0.13	0.88	0.4	-	-	38.04	3.81	38.44	2.32	2.30
6	Slap 4	55	26	19	4.5	4.1	247	9.4	16.21	0.6	15.67	33	0.31	0.37	0.06	0.15	0.89	0.47	0.05	0.42	34.34	10.14	34.81	2.59	2.56
7	Slap 5	56	24	20	4.3	4.0	248	7.52	12.96	0.3	25.07	17	0.54	0.6	0.04	0.14	1.32	0.49	0.05	0.44	35.77	49.21	36.26	3.69	3.64
8	Mile 4 market	57	23	20	5.2	4.7	233	3.29	5.67	0.5	6.58	19	0.31	0.56	0.04	0.13	1.04	0.1	0.04	0.06	32.60	106.26	32.70	3.19	3.18
9	Foncha right of road	63	25	12	6.3	4.7	113	8.23	14.18	0.3	27.42	22	0.54	0.68	0.04	0.13	1.39	0.01	-	-	34.44	50.67	34.45	4.02	4.02
10	Foncha left of road	64	26	10	5.7	4.5	105	10.11	17.42	0.4	25.26	17	0.20	0.37	0.03	0.13	0.72	0.06	-	-	35.46	6.22	35.52	2.03	2.03
11	Ndamukong	63	26	11	6.0	4.8	167	4.70	8.10	0.7	6.71	13	0.31	0.56	0.04	0.13	1.04	0.09	-	-	33.93	161.11	34.02	3.06	3.05
12	Ntahkah inn	63	18	19	5.7	4.5	78	8.23	14.18	0.6	13.71	13	0.54	0.46	0.04	0.13	1.17	0.06	-	-	34.13	30.38	34.19	3.41	3.41
13	Ntahkah out	61	19	20	5.6	4.8	127	4.47	7.70	0.7	6.38	11	0.31	0.37	0.04	0.13	0.85	0.09	-	-	34.34	94.71	34.43	2.46	2.46
14	Ntahkah before bridge	62	18	20	5.1	4.5	130	10.58	18.23	0.3	35.25	20	0.54	0.68	0.04	0.13	1.39	0.3	0.03	0.27	37.74	6.38	38.04	3.67	3.64
15	Mulan council junction	79	10	11	5.4	5.0	458	6.58	11.34	0.4	16.45	76	0.31	0.44	0.04	0.13	0.92	0.09	0.02	0.07	34.54	107.77	34.63	2.65	2.64
16	Mulang left of road	68	17	15	5.8	5.4	279	9.40	16.21	0.6	15.67	25	0.20	0.56	0.02	0.13	0.90	0.05	-	-	34.24	12.16	34.29	2.63	2.63
17	Mulang middle	80	10	10	4.9	4.3	437	4.47	7.70	0.8	5.58	17	0.54	0.46	0.04	0.13	1.17	0.3	0.03	0.27	32.39	169.96	32.69	3.60	3.56
18	Mulang 4 near houses	62	20	18	4.6	4.1	273	13.63	23.50	0.6	22.72	16	0.31	0.66	0.04	0.13	1.14	0.4	0.04	0.36	48.99	11.05	49.39	2.32	2.30
19	Army Rescue	62	18	20	5.4	4.9	269	9.17	15.80	0.6	15.28	8	0.31	0.56	0.05	0.12	1.04	0.10	0.03	0.07	39.06	10.61	39.16	2.66	2.66
20	Ngomegham	80	10	10	6.0	5.1	140	6.82	11.75	0.5	13.63	20	0.31	0.37	0.04	0.12	0.84	0.01	-	-	47.00	116.59	47.01	1.79	1.79
21	Mbelewa	67	18	15	4.5	4.2	57	11.28	19.45	0.7	16.11	12	0.31	0.4	0.07	0.12	0.87	0.40	0.04	0.36	29.96	1.72	30.36	2.90	2.87
22	Poultry manure	-	-	-	7.4	7.1	1500	23.50	40.51	29.00	0.81	130	24960.00	8043.3	13442.00	1329.00	47774.3	0.002	-	-	50.32	-	50.32	94940.98	94937.20
23	Municipal solid waste	-	-	-	7.6	5.5	5201	47.71	82.24	17.20	2.77	112	21961.00	7698.0	13711.00	14213.00	57583.0	0.004	-	-	44.43	-	44.43	129603.87	129592.20

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Table 8. Descriptive statistics of surface soil samples from the Wetland gardens of Bamenda Municipality

	Descriptive Statistics							
	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Sand	21	25.00	55.00	80.00	63.2857	1.68345	7.71455	59.514
Silt	21	16.00	10.00	26.00	19.9524	1.11372	5.10369	26.048
Clay	21	11.00	10.00	21.00	16.6667	0.91894	4.21110	17.733
pHwater	21	2.00	4.30	6.30	5.3000	0.13680	0.62690	0.393
pHKCl	21	1.40	4.00	5.40	4.5952	0.08521	0.39048	0.152
EC	21	401.00	57.00	458.00	212.9524	22.44756	102.86762	10581.748
OC	21	10.34	3.29	13.63	8.1938	0.57950	2.65558	7.052
OM	21	17.83	5.67	23.50	14.1224	0.99936	4.57965	20.973
N	21	0.50	0.30	0.80	0.5524	0.03560	0.16315	0.027
CN	21	30.45	5.58	36.03	16.8786	1.94166	8.89779	79.171
AV.P	21	68.00	8.00	76.00	19.6667	3.09172	14.16804	200.733
Ca	21	0.34	0.20	0.54	0.3386	0.02707	0.12407	0.015
Mg	21	0.31	0.37	0.68	0.5033	0.02315	0.10608	0.011
K	21	0.05	0.02	0.07	0.0414	0.00221	0.01014	0.000
Na	21	0.03	0.12	0.15	0.1290	0.00153	0.00700	0.000
SBases	21	0.67	0.72	1.39	1.0086	0.04245	0.19453	0.038
Acidity	21	0.48	0.01	0.49	0.2081	0.03893	0.17840	0.032
Al	10	0.03	0.02	0.05	0.0370	0.00300	0.00949	0.000
H	10	0.38	0.06	0.44	0.2730	0.04844	0.15319	0.023
CECsol	21	19.03	29.96	48.99	36.0381	0.98710	4.52347	20.462
CECclay	21	168.24	1.72	169.96	51.2319	11.71137	53.66824	2880.280
ECEC	21	19.03	30.36	49.39	36.2462	0.98819	4.52846	20.507
BSCEC	21	2.23	1.79	4.02	2.8281	0.13132	0.60180	0.362
BSECEC	21	2.23	1.79	4.02	2.8114	0.12999	0.59570	0.355
Valid N (listwise)	10							

The CEC of the soil according to the critical values of soil nutrients varied from low to medium, ranging from 29.96 to 48.99 cmol/Kg of soil with a standard deviation of 4.52347. These soils could thus have few weatherable minerals desiring nutrient application when extensively cultivated. Nkona (1998) reported that ECEC values of 4 meq/100g of soil mark the minimum limits. The soils in this regard have moderate potential to hold nutrient and avoid nutrients lost. It is thus imperative to raise the pH of the soil in areas of low pH in order to harness this potential.

Base saturation CEC for the soils were low ranging from 1.79% at Ngomegham to 4.02% at Foncha right of the road. This parameter is a good indicator of soil fertility in terms of the availability of nutrient elements. An ideal soil should have the exchange complex saturated to 76, 18, 6 by the elements Ca/Mg/K, respectively [7]. In this study, Ca, Mg, and K occupied respectively 38.33%, 56.98%, and 4.68% on the absorbed complex, necessitating amendment by Ca 1.7894 cmol/kg Mg 0 cmol/kg values for K. CEC clay was not directly determined but was calculated from CEC soil. It ranged from 3.2 to 7.5 cmol/Kg. This indicates that the mineralogy of the soil is dominated by low activity clays of the 1:1 type and sesquioxides. The Na content was fairly constant throughout the area with 1.3 value.

3.5 Variability of Surface Soil Properties in the Wetlands of Bamenda Municipality

Table 9 show the mean physico-chemical properties of surface soil properties in the three major laps assessed. The coefficient of variations (CV %) was used to evaluate the variability of the soils. Similar groupings have been used by Tabi and Ogunkunle [35]. According to Ogunkunle [36], Tabi and Ogunkunle [35], Tabi et al. [37], CV values ranging 0-15% are considered slightly variable, 15-35% moderately variable, while > 35% they are considered highly variable (Table 11). Soil pH (H_20 or KCl), percentage sand, CEC soil, and Na were consistently slightly variable.

Tabi and Ogunkunle [35] similarly reported slight variability of soil pH for Alfisols in Southern Nigeria. In a like manner for vertisols under rice cultivation in the Logone flood plain of Nothern Cameroon slight variability was also obtained [37]. Soil pH is one of the most very important parameter that influences the availability of nutrients and minor changes in pH units have significant effects on nutrient availability. The variability of Silt, clays, EC, ECEC, and $Al^{3+,}$ were slight to moderate (dominated by the moderate) class. This could be attributed to variation in levels of alluvial materials received. Also, variation in Chrono sequences of materials that have been subjected to different intensities of weathering could have a significant effect on these physical parameters. All these factors have significant implications on water and nutrient management of the wetlands of Bamenda Municipality. The exchangeable bases were moderately variable in a greater portion of the farms, probably associated with variation of soil amendment activities. The bases moderate variation implies that a single policy such as the application of organic or inorganic fertilizer will not be sufficient to properly manage the farms of the area. Organic carbon, organic matter, available P, exchange acidity, CEC clay, BSCEC, BSECEC, H^+, Tot. N, were moderately to highly variable. Most of these parameter owe a lot to organic materials. Natural denudational activities inclusive, urban swept off, farming activities such as residue management, crop species and land preparation/management practices could have influence the nature and management of soil properties of the area. The available phosphorus and base saturation which is equally slightly variable reflects pH variability.

3.6 Sources of Variation of Soil Properties

The correlation coefficients were used to group various soil properties on each side. The correlation coefficients of 21 soil properties examined are shown in Table 9. The coefficients ranged from -0.950 to 0.999. Even though some of the correlations were highly significant ($p<0.01$), most of them have correlation values less than 0.5. The highest positive correlation coefficients were observed between BSECEC and BSCEC (1.00), ECEC and CECsoil (0.999), exch. Acidity and H^+ (0.999), exch. Acidity and Al (0.739), BSCEC and exchangeable bases (0.866), Ca and BSCEC (0.833), Ca and exchangeable bases (0.869), Ca and BSCEC (0.834), Mg and exchangeable bases (0.585), OC and CN (0.687), OM and CN (0.687) all at the one percent confidence interval. The high correlation value between OC and CN, could be an indication that they mainly contributed to the soils of this area from a single source making management of this parameter easier when identified. The highest negative correlation coefficients were obtained between pH H_2O and H^+ (-0.950), pH H_2O and Al (- 0.827), and pH H_2O and acidity (-0.919) which was significant at the 1 % confident interval. Similarly, at the 1% probability level, sand equally had a negative correlation with Al content of the soils (r = -0.768). The negative correlation could be attributed to the facts that as the soil becomes sandier, very little colloids are left in place for retention of Al which is toxic to the plants. The data of 24 variables considered in this study were also subjected to R-mode analysis using the six-factor model, which accounted for 96.240% of the total data variance. The resulting varimax is summarized in Table 12. The computations were performed using SPSS computer software package version 20.0. Only variables with loadings > 0.5 were considered significant. Contributions of the various principal components (PCI) were 20.896% (PC1), 18.655% (PC2), 17.125% (PC3), 16.562% (PC4), 14.9837% (PC5), and 8.020% (PC6).

The 6 PCs identified constitute the minimum dataset required to group fluvisols for vegetable cultivation in the Wetlands of Bamenda Muncipality. The factors (PCI) extracted from Table 12 are as follows (Table 13):

Factor 1 was made up of pH H_2O, pH KCl, Exch. acidity, Al, and H. This factor is an acidity factor because of the high negative loading (- 0.949) for pH water and (- 0.949) pH KCl and high positive loading of exch. Acidity (0.945), H^+ (0.942) and Al^{3+} (0.738). Acid dependent charges highly influence the acidity of this environment as opposed to isomorphic substitution. The source of this acidity would be anthropogenic from the urban area.

Factor 2 constituted BSCEC,BSECEC, ΣBases, Ca, Mg. The principal component was named the base status factor because it had a high positive loading on base saturation CEC (0.930), base saturation ECEC (0.933), sum of bases (0.871), exchangeable Ca (0.916), and moderate loading of Mg (0.508). The same naming was given to soils of the Logone and Chari plain in the northern region of Cameroon under rice cultivation with similar constitution [37].

Table 9. Pearson correlation coefficient of surface soil samples from wetland gardens in Bamenda Municipalityon significant at the 5% probability

	Sand	Silt	Clay	pH H_2O	pH KCl	EC	OC	OM	N	CN	AV.P	Ca	Mg	K	Na	ΣBases	Acidity	Al	H	CECsol	CECclay	ECEC	BSCEC	BSECEC
Sand	1																							
Silt	-0.850**	1																						
Clay	-0.785**	0.346	1																					
pH H_2O	0.227	-0.042	-0.366	1																				
pHKCl	0.361	-0.299	-0.263	0.743**	1																			
EC	0.336	-0.418	-0.114	-0.266	0.056	1																		
OC	-0.199	0.102	0.218	-0.226	-0.204	-0.207	1																	
OM	-0.200	0.102	0.219	-0.226	-0.204	-0.207	1.000**	1																
N	0.051	-0.081	0.041	-0.098	0.138	0.101	-0.259	-0.258	1															
CN	-0.170	0.125	0.108	-0.074	-0.320	-0.187	**0.687****	**0.687****	**-0.819****	1														
AV.P	0.428	-0.378	-0.330	-0.028	0.142	**0.557****	-0.083	-0.083	-0.332	0.116	1													
Ca	0.157	-0.167	-0.058	-0.185	-0.325	-0.038	-0.172	-0.173	-0.218	0.144	-0.016	1												
Mg	-0.262	0.197	0.238	0.008	0.039	0.063	0.184	0.184	-0.297	0.383	-0.083	0.375	1											
K	-0.095	0.011	0.164	-0.425	-0.427	-0.179	0.242	0.242	0.134	-0.011	-0.070	0.097	-0.279	1										
Na	-0.282	0.348	0.090	-0.125	-0.258	0.164	-0.027	-0.027	-0.260	0.162	0.254	0.165	-0.002	0.020	1									
ΣBases	-0.058	0.013	0.107	-0.139	-0.215	0.020	-0.013	-0.013	-0.308	0.301	-0.044	**0.869****	**0.780****	-0.050	0.149	1								
Acidity	-0.329	0.157	0.387	-0.919**	-0.834**	0.185	0.331	0.331	0.028	0.254	-0.026	0.169	0.108	0.388	0.195	0.192	1							
Al	-0.768**	0.866**	0.565	-0.827**	-0.789**	-0.468	0.148	0.149	0.051	0.020	-0.458	-0.024	-0.025	0.248	0.497	0.007	0.739*	1						
H	-0.038	0.488	0.204	-0.950**	-0.913**	-0.363	0.375	0.375	0.190	0.228	-0.321	0.242	-0.015	0.132	0.338	0.160	0.999**	0.710*	1					
CECsol	0.154	0-.243	0.002	0.033	0.159	0.025	0.432	0.432	-0.228	0.321	-0.054	-0.092	0.192	-0.099	-0.149	0.047	0.008	-0.019	0.030	1				
CECclay	0.518*	0-.334	-0.523*	0.213	0.208	0.338	**-0.852****	**-0.852****	0.266	**-0.606****	0.178	0.230	-0.130	-0.186	-0.030	0.080	-0.277	-0.373	-0.355	-0.142	1			
ECEC	0.141	-0.236	0.017	-0.003	0.126	0.032	0.445*	0.445*	-0.226	0.331	-0.055	-0.086	0.196	-0.084	-0.141	0.054	0.048	0.003	0.059	0.999**	-0.153	1		
BS CEC	-0.085	0.102	0.053	-0.136	-0.269	0.003	-0.262	-0.262	-0.135	0.070	-0.018	**0.834****	**0.584****	0.009	0.179	0.866**	0.161	0.042	0.154	-0.450*	0.190	-0.443*	1	
BS ECEC	-0.080	0.100	0.046	-0.114	-0.251	-0.005	-0.265	-0.266	-0.140	0.069	-0.018	0.833**	0.585**	0.003	0.177	0.866**	0.138	0.026	0.127	-0.449*	0.193	-0.443*	1.000**	1

**correlation significant at the 5% probability level, **correlation significant at the 1% probability level*

Table 10. Physico-chemical properties of surface soil properties at the Mile Four, Foncha and Mulang Laps of the Bamenda Municipality

Site	Sand	Silt	Clay	pH(1:2.5)		EC	OC	OM	Tot. N	C/N	Av. P	Ca^{2+}	Mg^{2+}	K^+	Na^+	ΣBases	Exch. Acid.	Al^{3+}	H^+	CECsoil	CECclay	ECEC	B.S. CEC	B.S. ECEC
		%		H2O	KCl	uS/cm		%			mg/Kg			cmol/Kg				meq/100g			cmol/Kg			%
Mile Four Lap	57	23	20	5.04	4.41	230	8.05	13.88	0.55	16.8	18	0.30	0.50	0.04	0.1305	0.97	0.3013	0.045	0.333	35.07	37.07	35.37	2.77	2.75
Foncha Lap	63	22	15	5.73	4.63	120	7.72	13.30	0.50	19.1	16	0.41	0.52	0.04	0.1265	1.09	0.1017	0.030	0.270	35.01	58.25	35.11	3.11	3.10
Mulang Lap	72	14	14	5.35	4.87	309	8.34	14.38	0.58	14.9	27	0.33	0.51	0.04	0.1239	1.00	0.1583	0.030	0.193	39.37	71.36	39.53	2.61	2.60

Table 11. Variability classes of soil properties for the different sites

Site	Least variable (CV< 15%)	Moderatly Variable (15 < CV≤ 35%	Highly Variable CV> 35%)
Mile Four area	Sand, silt, clay pHH_2O, pHKCl, EC, Na^+, Al^{3+}, CECsoil, ECEC	OC, OM, Tot.N, Ca^{2+}, Mg^{2+}, K^+, ΣBases, BSCEC, BSECEC.	C/N, Av. P, Exch.acodity, H^+, CECclay.
Foncha area	Sand, pHH_2O, pHKCl, K^+, Na^+, CECsoil, ECEC.	Silt, clay, EC, OC, OM, Av.P, Mg^{2+}, ΣBases, BSCEC, BSECEC.	Tot. N, C/N, Ca^{2+}, Exch. Acidity, ECECclay
Mulang	Sand, pHH2O, pHKCl, Na^+	Silt, Clay, Tot. N, Ca^{2+}, Mg^{2+}, K^+, Na^+, ΣBases, Al^{3+}, CEC sol, BSCEC	EC, OC, OM, C/N, Av.P, Exch. Acidity, H^+, CECclay, BSCEC

Table 12. Total Variance explained from Physico-chemical properties of wetland soils in the wetland gardens of Bamenda Municipality

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	7.501	31.254	31.254	7.501	31.254	31.254	5.015	20.896	20.896
2	4.933	20.553	51.807	4.933	20.553	51.807	4.477	18.655	39.550
3	4.437	18.486	70.293	4.437	18.486	70.293	4.110	17.125	56.675
4	2.536	10.567	80.860	2.536	10.567	80.860	3.975	16.562	73.237
5	1.921	8.004	88.864	1.921	8.004	88.864	3.596	14.983	88.220
6	1.770	7.377	96.240	1.770	7.377	96.240	1.925	8.020	96.240
7	0.623	2.595	98.836						
8	0.198	0.827	99.663						
9	0.081	0.337	100.000						
10	6.649E-016	2.770E-015	100.000						
11	4.939E-016	2.058E-015	100.000						
12	3.993E-016	1.664E-015	100.000						
13	3.097E-016	1.290E-015	100.000						
14	2.069E-016	8.621E-016	100.000						
15	1.530E-016	6.376E-016	100.000						
16	5.699E-017	2.375E-016	100.000						
17	4.010E-017	1.671E-016	100.000						
18	-5.979E-017	-2.491E-016	100.000						
19	-1.267E-016	-5.281E-016	100.000						
20	-1.565E-016	-6.519E-016	100.000						
21	-1.663E-016	-6.930E-016	100.000						
22	-2.446E-016	-1.019E-015	100.000						
23	-3.771E-016	-1.571E-015	100.000						
24	-6.116E-016	-2.548E-015	100.000						

Extraction Method: Principal Component Analysis

Table 13. Varimax Rotated of Factor Matrix (Six-Factor Model) of some 24hysic-chemical properties of surface soil samples in the wetland gardens of the Bamenda Municipality

	Component					
	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**	**Factor 6**
Sand	-0.263	0.031	**-0.954**	-0.080	-0.092	-0.031
Silt	0.409	**-0.116**	**0.901**	0.017	0.008	0.078
Clay	0.033	0.092	**0.950**	0.162	0.204	-0.038
pH H_2O	**-0.949**	-0.013	-0.181	-0.126	0.026	0.015
pH KCl	**-0.931**	-0.238	-0.155	-0.069	0.217	0.006
EC	-0.172	-0.129	**-0.579**	**-0.638**	0.255	0.310
OC	0.224	-0.210	-0.003	**0.862**	0.401	-0.040
OM	0.224	-0.210	-0.003	**0.862**	0.401	-0.040
Tot. N	0.329	-0.452	-0.224	-0.296	-0.150	-0.690
CN	-0.002	0.428	0.098	0.732	0.359	0.357
Av. P	-0.306	-0.258	-0.418	-0.141	-0.093	**0.690**
Ca	0.223	**0.916**	-0.232	-0.019	0.059	0.119
Mg	-0.191	**0.508**	0.367	0.073	0.718	-0.166
K	0.179	-0.390	-0.041	**0.626**	**-0.540**	-0.010
Na	0.435	0.019	0.115	-0.078	0.014	**0.818**
ΣBases	0.051	**0.871**	0.088	0.040	0.468	0.038
Exch. Acid	**0.945**	0.092	0.148	0.178	0.047	-0.012
Al	**0.738**	-0.074	**0.616**	0.011	-0.076	0.099
H	**0.942**	0.101	0.117	0.185	0.053	-0.018
CECsoil	-0.031	-0.131	0.046	0.277	**0.937**	0.057
CECclay	-0.141	0.193	-0.477	-0.811	-0.151	0.032
ECEC	-0.003	-0.128	0.050	0.282	**0.937**	0.057
BSCEC	0.114	**0.930**	0.031	-0.225	-0.258	-0.059
BSECEC	0.088	**0.933**	0.032	-0.224	-0.259	-0.057

Extraction method: Principal Component Analysis; Rotation method: Varimax with Kaiser Normalization
Rotation converged in 10 interactions

Factor 3 was composed of sand, silt, clay, Al, and EC. This component was termed weathering and associated moisture retention factor because of a high positive loading clay (0.950) greater than silt (0.901), moderate positive loading of Al (0.616) and a moderate negative loading of EC (-0.579).

Factor 4 grouped EC, OC, OM, C/N, K, and CECclay*:* the factor was ascribed an organic matter factor because of a high (same) positive loading for organic matter and organic carbon content (0.862) and organic matter quality (0.732) quality(C/N ratio), moderate positive loading from K (0.626); but a high negative loading from CECclay (-0.811). The major source of this component would be the breakdown of natural vegetation in the area.

Factor 5 converged Mg, CECsoil, ECEC, K. The factor had high positive loading from CECsoil (0.937), ECEC (0.937), moderate loading from Mg (0.719) and a moderate negative loading from K (-0.540). This factor was described as a mineral neo-synthesis related component derived mainly from the deposition of Mg eroded from upland in the wetland which gradually replaces K in interlayers of micaceous minerals in the wetlands.

Factor 6 grouped N, available P, and Na. this is a dispersal-mineralization factor influenced by anthropogenic activities of the International Soap Factory (high sodium released) and the Cow slaughter house (high organic matter containing nitrogen which is rapidly mineralized due to dispersion caused Na). The factor had high positive loading from Na (0.818), moderate loading from available phosphorus (0.690) but a negative yet moderate loading from total N (-0.690). Potentially mineralizable nitrogen is an important measure of N supplying capacity in wetland soils, which is most often not calculated. The findings of this component conform with the reports of Mengel and Kirkby [29], and Tabi et al. [37] that nitrogen is one of the most important factors controlling potentially mineralizable N in wetland soils. Generally, the results reported here agree with those of other authors. Salami et al. [38] identified potential fertility, available phosphorus, organic matter, acidity and sand-silt as factors responsible for soil fertility variation in the northern guinea savanna agro-ecological zone of Nigeria. Kosaki and Juo [39] identified inherent fertility status (represented by Mg, Ca, K, sand, silt and clay) and available phosphorus as major factors causing soil variation in wetland fields in southwestern Nigeria. In fact, no sampling site was completely homogeneous in with soil management units.

4. CONCLUSION

From this study, it is concluded that human activities have highly influenced the fluvisols of the Wetland of Bamenda Municipality. The soils are developed from young alluvio-colluvial material of granitic origin. The organic matter just as other physico-chemical properties varied irregularly down the profile. The surface soils of the wetland gardens were slightly acidic to neutral, of low organic matter and nitrogen contents, and moderate to high exchangeable bases. Except for slightly variable pH, soil properties were moderately variable to highly variable. Six principal components (PCs) grouping soils in management units explained 96.240% of the variations observed in the soil properties. The PCs were: base status, organic matter, weathering and moisture retention, acidity, dispersal and N-mineralization, and mineral neo-synthesis factors. The PCs constitute a minimum dataset required to group soils in the Bamenda wetland gardens. We recommend that a detailed mapping of soil properties be carried out for the establishment of a soil fertility map for Bamenda Municipality; fertilizer recommendations should be established for identified soil management units; and farming systems which favors buildup of soil organic matter and use of animal manure should be encouraged. Soil management practices defined for identified units instead of a common management for all units will boost and sustain vegetable yield. Soil characterization and the implementation of some of the findings of these studies are believed to result in increased food production per unit area.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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