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Keywords: cluster group, floodplain, hydrology, inland valley, land use, wetlands

I. Introduction

In many parts of Africa, agricultural use of wetlands is intensifying. More and more people are forced to seek new land as a result of land shortages and fertility degradation of upland areas (Wood and van Halsema, 2008). In Eastern Africa, wetlands present an important and so far largely undocumented potential in terms of area and agricultural production. This potential is linked to the availability of water and the quality of soil resources. Recent estimates suggest that wetland cultivation in East Africa provides between 10 to 40% of the annual food needs of the rural population. However, during food shortage periods, its contribution can rise to 100% in some areas (Schuijt, 2002; Rebelo et al., 2010). In the highly populated humid highlands and mid-hill areas, in particular, the dependence on wetlands for food security is larger than in the more sparsely populated lowland plains in the semi arid zones (Dixon and Wood, 2003). Soil attributes as well as agricultural uses are affected by hydrology of the wetland systems. The wetland soils are either formed under flooded conditions or altered by them. Other characteristics of the soil such as texture and organic matter composition and content may also be influenced by the hydrology of the wetland (Tiner, 1999). Farming in wetland areas is characterized by adaptations to various hydric regimes. Extensive inundation seems to restrict human activities in some areas and is responsible for the maintenance of natural vegetation and various soil parameters in other parts of the wetlands (Dixon, 2003). For example, the timing of the wet season's rains and the subsequent flood determine the planting of rice and other wetland crops within floodplain wetlands. The depth and duration of inundation influences the crop varieties that are sown, while the area of inundation controls the location and extent of this form of cultivation (Thompson and Polet, 2000). Several wetland classification approaches in Africa exist. For example, Roggeri (1995) and Windmeijer and Andriesse (1993) classified wetlands based on geomorphological and ecological units which included sources of water and nutrients. Other classifications were based on soil and terrain characteristics (Koohafkan et al., 1998) which resulted to categorization of permanently flooded soils as Gleysols and seasonally flooded and stratified soils as Fluvisols. Although several other studies have been carried out within the East Africa region such as West Usambara in Tanzania (Ndakidemi and Semoka, 2006) and the Laikipia plains in Kenya (Thenya, 2001) none of these studies explicitly investigated the soil diversity and

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characteristics in wetland systems. Furthermore, there is no classification system of the agriculturally used wetlands or their distribution in East Africa.

Thus, this study is aimed at categorizing the wetlands into groups based on biophysical and socio-economic attributes and to assess the major soil attributes (C, N, and P) concentrations as affected by land use and hydrology in the wetland types.

II. Materials and Methods

a) *Study Area and Wetland Selection*

The study region in East Africa was characterized by a gradient from lowland plains to the highlands with undulating topography, which ranged between 300 and 2300m above sea level (masl). Details of site parameters, the major biophysical and socio-economic descriptors and the dominant agricultural activities are presented in Table 1 and the location of the study areas shown in Fig. 1. Further details can be obtained from (Mwita et al., 2012)

The first field reconnaissance was conducted in May 2007 while detailed studies were carried out in 2008 and 2009. The reconnaissance survey was aimed at identifying potential sampling locations and consisted of guided visits by several stakeholders. Additionally, exploration trips were organized using topographical maps and satellite images beginning at the lowland and culminating at the highlands. During this reconnaissance survey, observation of wetland extents, diversity, public access and river/stream characteristics were recorded in conjunction with a review of existing maps.

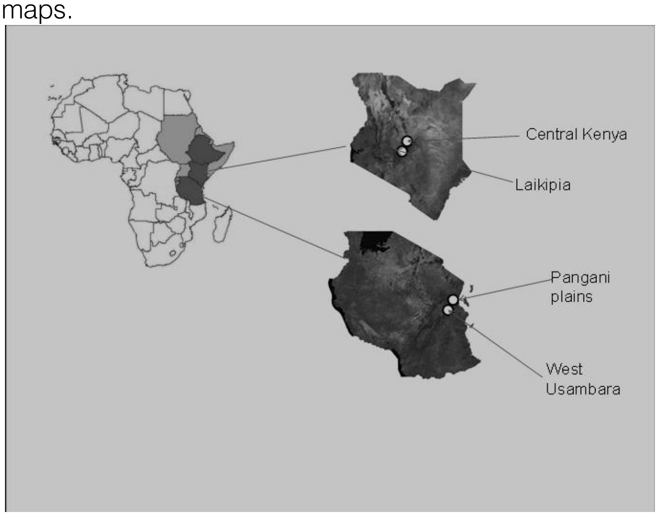

Fig. 1 : Map of the Study Region in East Africa (Kenya And Tanzania). Arrows and Name Tags Identify the Specific Study Areas-Central Kenya and Laikipia in Kenya and West Usambara and Pangani Plains in Tanzania

Areas considered primary candidates for wetland sampling were identified and marked. The following landscape units and associated study sites were selected (1) the semi-arid highlands in Kenya comprising the Laikipia plateau; (2) the sub-humid lowlands of Pangani plains in Tanzaniae; (3) the humid mid-hills in West Usambaras in Tanzania; and (4) the humid highlands in Central Kenya) (Fig. 1). These landscape units were estimated to cover >30% of the East African land area and are hence representative of the environmental and agro-ecological diversity of the region.

b) *Characteristics of the Study Sites*

In addition to the climate and the parent rock, sites differed regarding population density, average farm size and market accessibility. The two mountainous sites at Mount Kenya and the Usambara Mountains had high population densities, good market access and tended to experience land shortages (small farm sizes), while the two floodplain environments were located in less populated rural environments and farm sizes tended to be large. Within all four study areas, agriculture is the main economic activity. Both the dominant food and cash crops differ as a result of altitude and rainfall. Thus, maize, beans and vegetables are mainly restricted to the highland areas, while rice is typical for the tropical lowlands in Pangani plains (Jaetzold et al., 2006; MOA-URT, 2006). In the adjacent uplands, coffee and tea are typical cash crops in the high rainfall environments while sisal and cotton are restricted to the semi-arid and sub-humid zones. Livestock systems in the adjacent uplands are largely linked to land availability with zero-grazing dairy systems in Central Kenya and the Usambara Mountains and free ranging in the Rift Valley and the Pangani plains.

c) *Sampling Strategy*

Field sampling was then carried out between February and July 2008. A multi-stage approach was used to select the pilot sites as outlined by Sakane et al., (2011). Selected wetlands were sub-divided into 'sub units' based on (i) hydrological regime: comprising the upland zone and hydro-morphic fringe (the seasonally flooded sections) and central zone (or bottom valley) (ii) major land use, management practices and cropping intensity (unused with natural vegetation, grazing, fallow, subsistence crops, horticulture, and anaerobic cropped fields). The sub units ranged in size between 20-300m^2. In each sub unit, 9-20 soil cores were obtained from ±2-15 cm depth using a 5-cm diameter stainless steel hand-held soil auger. The soil was mixed together, air dried and sieved to pass through a 2mm sieve. The sampling approach was designed to address the diversity of the soils in various land uses under different hydric regimes.

d) *Soil Chemical and Physical Analysis*

Soil samples were analyzed for organic C, total N and available P contents, and textural classes at the World Agroforestry Centre (ICRAF), Plant and Soil

Laboratory using standard methods described in ICRAF, (1995) lab manual and near infrared spectroscopy (NIR) (Shepherd and Walsh, 2007).

e) Variable Definitions

Data collected included soil information on nutrient levels, hydrology, land use and socio-economic environments. Soil information comprised soil texture, soil contents of N, C and P, land use intensity, use types and hydric regime within the wetland sub units. Land use intensity was defined based on field observations on use type at the time of sampling, existence of drainage infrastructure, number of cropping seasons, production orientation, and related crop management including tillage and input use. Wetland use types were either cropped or unused (not cultivated) while flooding regime comprised the permanent flooded or seasonally wet categories. The variables used to define the wetland characterization process were biophysical (soil parameters C, N, P, hydric regimes), land use types, and socio-economic attributes as described in Sakane et al., (2011) and Kamiri et al., (2013).

i. Data Analysis

Several multivariate techniques were used to determine whether the wetlands and wetland subunits belonged to the same group and whether the variation in the wetlands was associated with land use types, hydrology, soil and socio-economic factors. Cluster and disriminant analysis were performed to derive a wetland typology or characterization which grouped together related wetlands based on socio-economic and biophysical attributes. In addition, principal component analysis (PCA) was conducted to determine the main factors explaining the variable patterns and loadings. These cluster groups were then related to current types of land uses and finally the cluster groups were examined based on the soil parameters C, N and P.

III. Results

a) Size and Distribution of Agriculturally Used Wetlands in East Africa

East Africa has a diversity of wetlands most of which are under agricultural use. They vary in size and land uses based on a variety of factors. In this study fifty one (51) wetlands which were a representation of the wetlands in Kenyan and Tanzania were surveyed. The wetlands were subdivided were subdivided into 157 sub units based on dominant land use, soil type and soil moisture. Wetland type and size varied between environments with individual areas ranging between 0.5 ha and 458 ha. The two dominant wetland types comprised inland valley swamps and floodplains, with inland valleys accounting for 87% of all wetlands but covering only 58% of the wetland area (2115 ha). While the inland valleys dominated the humid mid-hills and highlands, floodplains were the dominant wetland type in the semi-arid and sub-humid zones.

The inland valley swamps had sizes ranging from 0.5 ha to 35 ha (average = 17 ha), while the floodplains ranged between 10 ha to 458 ha (average = 79 ha) (Table 2).

b) Characterization of Wetland Land Uses

The studied wetlands were observed to undergo an evolution from unused state (undisturbed) to extensively use either through grazing or continuous cropping. Our investigation into ways in which wetlands are used revealed that wetlands in the studied regions could be categorized into several classes based on current land uses. These included:

1. Wetlands which had not been cultivated are undisturbed (or were under natural wetland vegetation);
2. Wetlands which were partially cleared and drained, under grazing;
3. Partially drained wetlands which were under grazing and partial cultivation (under anaerobic conditions);
4. Fully drained wetlands which were under intense cultivation and in some instances irrigation (grown with upland crops);
5. Wetlands which had previously been cultivated but have been abandoned or extensively grazed.

The largest share of undisturbed wetland sites representing 24% of the total wetland land uses occurred in the highlands of Kenya Table 3. The largest share of the anaerobic crop cultivation was observed in the Pangani plains and in Central Kenya representing 48% and 44% respectively while cultivation of upland crops under aerobic soil conditions dominated the west Usambara areas (73%). Overall, the largest share of wetland area (43%) was used for the cultivation of upland crops after complete drainage of the fields while abandoned and grazed land accounted for less than 20% of the wetland land uses.

c) Wetland Characterization Based on Soil and Hydrologic Properties

Carbon and N levels were differentiated between the unused and cropped land uses in flooded (permanently or seasonal) condition. These values were relatively high in the unused than in the cropped (and flooded) wetlands and ranged between 16.3 to 25.5 g kg-1 for C and 1.4 to 3.1 g kg-1 for N. High levels of C and N contents in the cropped seasonally wet areas were linked to management whereby crop residue incorporation is only possible in dry soil but not in flooded soil. Differences in P were however minimal between the land uses and the hydric regimes and ranged between 9.9 to 12.9 mg P kg-1 in the flooded soils and 12.0 to 12.9 mg P kg-1 in the seasonally wet soils.

Differentiation of wetlands based on hydrology showed that majority of the wetland subunits were seasonally wet (56%, n=157) with most of these occurring in the floodplain areas and fringe of inland valleys. Cultivation in the permanently flooded fields was mainly for wetland crops such as rice (Oryza sativa) in the lowlands and taro (Colocasia esculenta) in the highlands while in the seasonally wet areas, vegetable and cereal-legumes were the main crops.

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d) Wetland Clusters Based on a Combination of Variables

Five major wetland cluster groups were identified by a combination of land use, hydrology, soil and socio-economic attributes using hierarchical cluster analysis method.

This classification scheme was tested by discriminant analysis whereby 96% of the original five group cases were classified correctly. The percentages of their predicted group membership were 96, 95, 93, 96 and 100% for cluster groups 1, 2, 3, 4, and 5, respectively as described by Sakane et al., (2011). The cluster groups identified included:

Table 1 : Topographical, Biophysical and Agricultural Characteristics of the Study Regions in East Africa (Tanzania and Kenya)

Country	Tanzania		Kenya	
Wetland location	Pangani plains	West Usambara	Laikipia plateau	Central Kenya highlands
Wetland type	Floodplain	Inland valley	Floodplain	Inland valley
Longitude	38^{0}19'32"E to 38^{0}21'28"E	38^{0}13'54"E to 38^{0}16'22"E	36^{0}34'59"E to 36^{0}32'26"E	37^{0}6'7"E to 37^{0}5'57"E
Latitude	5^{0}4'29"S to 5^{0}6'57"S	4^{0}38'18"S to 4^{0}40'12"S	0^{0}19'16"N to 0^{0}15'17"N	0^{0}27'58"S to 0^{0}28'51"S
Altitude (masl)	300-400	800-1200	1900-2280	1200-1780
Annual rainfall range (mm)	500-800	1200-1500	400-1000	950-1500
Temperature range (^{0}C)	19-35	9-30	14-29	11-27
Soils-uplands[a]	Acrisols, Luvisols	Nitisols, Acrisols	Planosols	Nitisols
Bottom valley[a] soils	Fluvisols Vertisols,	Gleysols Fluvisols	Fluvisols Planosols	Gleysols Histosols
Parent material	alluvial sediments	Granite and gneiss, colluvial	Basalts, granite	volcanic
Soil Texture	Sandy clay, Clay	Sandy clay loam to clay loam	Clay and clay loam	Clay loam to clay
Main activity	Subsistence cropping, rice cultivation	vegetables, fruits, market oriented	Cattle ranching, subsistence oriented farming	Subsistence cropping
Population density (persons km^{-2})	74 - 83	133 - 241	192 - 603	40 -160
Market accessibility[b]	Medium	High	Low	Medium

a: FAO-UNESCO, (1997) , b: Time taken to reach the market: High (0-2 hours); medium (2-4 hours)

Cluster Group 1: These were wide, permanently flooded valleys and highland floodplain that were largely unused but with some extensive grazing and some subsistence food crop cultivation on the wetland fringe during the dry season. Average size was 21ha, were commonly found in floodplain areas at an altitude range of 400-1500masl. Soil nutrient levels were moderate to high while variation within the group was large. Carbon ranged from 8.0 to 69.6 g C kg-1 whereas N content ranged between 0.9 - 10.9 g N kg-1. The semi-arid to sub-humid adjacent upland areas were used for ranching and extensive cattle rearing.

Cluster Group 2: This cluster comprised the permanently flooded inland valley wetlands, which were narrow and unused or under natural wetland vegetation and with limited access. Average wetland size were small (12 ha). Soil concentrations of C, N and P were high at 36.9 and 4.6 g kg-1 C and N respectively, and available P of 26 mg kg-1 (Fig. 2). Soil variability within the group was considerable with C ranging between 10.3 - 70.8 g C kg-1 and N between 0.7 - 12.0 g N kg-1. These wetlands were located in rural areas with low to moderate population density and poor market accessibility. Most of the adjacent upland areas were covered by forest.

Table 2 : Selected Biophysical Characteristics of the Wetlands Studied in East Africa (Tanzania And Kenya).

Variable	Inland valleys	Floodplains
Proportion of sample size (n = 157)	87%	13%
Altitude range (masl)	1490 ± 58	887 ± 163
Average wetland size (ha)	17.0 ± 2	79.9 ± 23.2
Adjacent upland slopes	Gentle to steep	None
Parent material	Gneiss, granite and volcanic material	Sediments, granite
Soil texture	Clay to Clay loam	Sandy clay to clay
Major land uses	Horticulture, mixed cropping	Rice, grazing and mixed cropping

±*Standard Error of the Mean*

Cluster Group 3: Comprises large inland valleys and lowland floodplains with moderate land use intensity, mainly for subsistence cropping. This cluster group had the largest group size and comprised large wetlands with an average size of 56 ha. They were seasonally flooded and segments of the wetland were cultivated to food crops on the valley fringes and rainfed lowland rice in the permanently flooded sections. Due to their large sizes, pressure on these wetlands was low. Soil C and N concentrations were low at average of 17.3 g C and 1.6 g N kg-1 and available P of 15.9 mg P kg-1 (Fig. 2). Dominant soil types are the heavy clays (Vertisols) in the lowland areas and Gleysols on the valley fringes.

Table 3 : Relative Proportion of Agricultural Land Uses in Reference to Total Wetland Land Use Types in Selected Areas in East Africa.

	Tanzania		Kenya	
	Pangani plains	West Usambara	Laikipia	Central Kenya
Land use type[1]	% of total wetland land uses			
Natural vegetation- (unused areas)	7	7	24	6
Grazed	25	13	18	9
Anaerobic crops	48	0	0	44
Aerobic crops	11	73	48	38
Abandoned fields	9	7	10	3

Unused: Uncultivated areas with natural wetland vegetation; grazed: grazed areas recently cleared of natural wetland vegetation; Anaerobic: fields grown to anaerobic crops such as rice or taro; Aerobic: completely drained and grown to upland crops; Abandoned: areas left to fallow after cultivation.

Cluster Group 4: These wetlands were narrow inland valleys, moderate in size (average = 26 ha), seasonally wet and intensively used for horticultural production. The majority occurred at high altitudes of 1600 to 2400 masl. Due to their high use intensity, soil nutrient levels were low with total soil C and N of 17.0 and 1.6 g kg-1 respectively (Fig. 2). Soil available P was below critical level of 10 mg P kg-1 (Okalebo et al., 2002).

The wetlands were dominated by sandy clay to clay texture and were completely drained for intensive upland crop production. Due to low soil carbon and nutrient levels (N and P), some of these wetlands had been abandoned to fallow and some of them were under grazing.

Table 1 : Soil Hydrologic Regimes and Land Use Intensity Effect on Wetland Soil Characteristics in the Studied Wetlands in East Africa

Soil variables	Permanently flooded (n = 69)		Seasonally wet (n = 88)	
	Unused† (n=15)	Cropped (n=15)	Unused (n= 37)	Cropped (n=45)
Total C (g kg^{-1})	25.5 ± 2.2	16.3 ± 1.4	22.3± 2.4	22.5 ± 1.7
Total N (g kg^{-1})	3.1 ± 0.4	1.4 ± 0.1	2.2 ± 0.3	1.8 ± 0.2
Available P (mg kg^{-1})	12.9 ± 0.8	9.9 ± 1.1	12.9 ± 0.8	12.0 ± 1.0

± Standard error of the mean (n = 69-88)

†Land use defined as unused (no cropping, natural wetland vegetation, permanent flooded) and cropped (drained, high intense cropping)

Cluster Group 5: The group comprised the intensively used lower sections of inland valley bottoms. They occurred mainly in the mid hills at an altitude range of 1300m to 1835m and were small in size (average = 15 ha). These wetlands had originally been permanently flooded but were completely drained for intensive horticultural crop production with a high use of external inputs both organic and inorganic. Due to their permanent year-round use, and intense use of fertilizers, soil fertility level was moderate to high with C and N contents of 26 and 1.9 g kg-1 respectively. However, soil available P was generally low with a mean value of 10.2 mg P kg-1 (Fig. 2). The soils in this cluster group are of sandy clay texture, and are mainly found in highly populated highland areas with good market access.

e) Comparative Assessment of Wetland Soil Properties

The changes in soil C and N contents for the different wetland groups were then placed in a larger context by examining the observed values of each parameter in a cluster, relative to the range of values for all the cluster groups. This was done by comparing the box plots for different wetland groups (Fig. 2). For organic C and N, the median levels for cluster group 1 (permanent flooded with low use intensity) are clearly falling above the range of the other wetland groups (>25 g C kg-1 and >1.9 g N kg-1) (except group 5) hence the wetlands in this cluster group (1) were segregated on their own with unique characteristics such as flooded conditions and high C and N as shown in Fig. 3. In cluster group 3 and 4, majority of wetlands are seasonally wet with a C content <20.0 g C kg-1 and N <1.9 g N kg-1 reflecting lower soil resource availability. Phosphorus was however not differentiated according to the wetland groups though most wetlands in cluster group 4 and 5 had P below the critical P level of tropical soils (10 mg P kg-1 - Okalebo et al., 2002). High variability in soil attributes resulted to outlier values (either high or low values plotted above or below the box plots in Fig. 2 which were exceptional cases and were included in this data analysis to allow for the interpretation of soil variability within the wetlands.

IV. Discussion

Wetlands were successfully categorized into clusters using biophysical, socio-economic (Sakane et al., 2011) and soil quality attributes.

Because soil characteristics vary independently along environmental gradients, it was not surprising that there were substantial overlap of cluster groups assigned to different sub units occurring in the same wetland. Nevertheless, we were successful in identifying the factors correlated with soil variations in these wetlands.

Our results suggest that flooding (or no flooding) as well as land use (cropped or no cropped) can affect soil chemical characteristics of the wetland soils in East Africa.

a) Wetland Categorization Based on Soil Properties and Moisture

The wetland characterization based on soil and moisture regimes was developed in recognition of the diversity among wetlands in terms of use intensity, management and soil characteristics.

This characterization gave insight into how wetlands are grouped in terms of the soil resource base and the influence that land uses and hydrology have on the soil properties. Although every wetland is unique, the wetlands within each group had more similar attributes than wetlands in other groups or clusters. The biophysical and socio-economic conditions under which the inland valley and floodplain wetlands existed contrasted strongly in each region. Whereas floodplain wetlands were found on relatively low and flat topography, the wetland sizes were equally large (79 ha) which contrasted with inland valleys wetlands on narrow, and often small sizes (17 ha) but forming the majority of the wetlands.

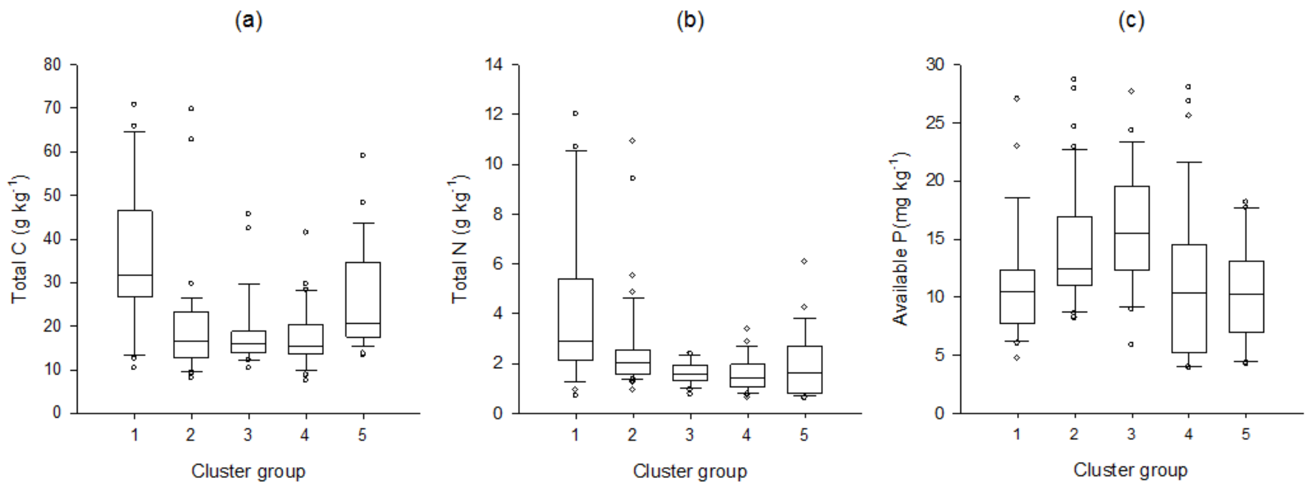

Fig. 2 : Ranges of (A) Total Soil C, (B) Total N and (C) Available P for Wetland Cluster Groups Identified in East Africa *Cluster Groups:* 1= Wide permanently flooded inland valleys and highland floodplain with extensive use for grazing and subsistence crops cultivation; 2 = Narrow permanently flooded inland valleys under natural vegetation; 3 = Large inland valleys and lowland floodplains with sporadic to seasonal flooding under medium land use intensity; 4 = Wide seasonally wet valleys and highland floodplains with intensive use; 5 = Narrow completely drained valley bottoms with intensive horticultural land use.

In Sub-Saharan Africa the inland valleys form close to 36% of the total wetland area (Balasubramanian et al., 2007). Most inland valley wetlands are concentrated in high altitude areas with fertile soil including the Gleysols (when drained) Entisols and Fluvisols on the valley fringes and superior rainfall (usually above 700mm) and are therefore important sites for horticultural and subsistence crop production (Schuijt, 2002). The wide and flat floodplains have been used for extensive grazing (Thenya, 2001), fallowing and for cultivation of cash crops. In other areas floodplain wetlands are extensively used for rice cultivation both as lowland rice and irrigated rice (Balasubramanian et al., 2007). Wetland uses are however highly influenced by the ability of adjacent upland areas to sustain food crop production. Therefore in instances of steep slopes like those realized in this study (>45%) production is likely to be lowered by high erosion rates (Labin et al., 2003) and hence leading to shifts from upland cropping to relatively flat wetland areas for cultivation. It is thus evident that utilization of these wetlands because of their sizes in relation to potential resources will have a role in agricultural development in increasing crop area and food production.

b) Biophysical Characteristics

The main wetland types were associated with geomorphological characteristics of the location and were reflected in soil types and hydrologic regimes. Most inland valleys developed on gneiss and volcanic base rock, had permanent to seasonal flooding regimes with water originating from springs or (subsurface) interflow. Floodplains, on the other hand, predominated on sediments and granite, were sporadically or seasonally wet by overflowing rivers and were characterized by sandy clay and Vertisols. The fertile soils dominating the inland valleys are derived from volcanic rocks and are usually clay in texture while the less fertile alluvial deposits arising from overflow of rivers and streams are dominating in the floodplains (Tiner, 1999).

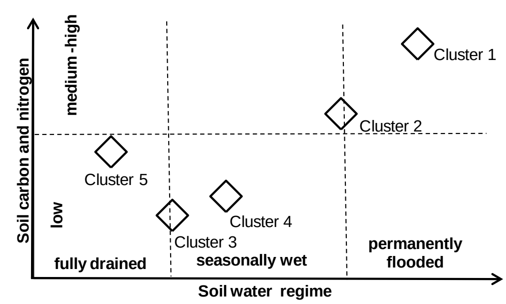

Fig. 3 : Schematic Presentation of Soil Cluster Groupings in Relation to Hydric Regime and Soil Parameters (C And N).

Within the wetlands, hydrology and land use (cropping, inputs and management) were observed to influence the C and N content of the soils. In the inland valley systems, comprising the narrow highland swamps, and associated valley bottoms, soils have deeper profiles, are more fertile with flooded or seasonally wet conditions.

These wetlands are cropped with different crops depending on the hydrology. They may include vegetables and cereals on the valley margins while the more flood intolerant crops such as taro are cropped on the valley centre. In contrast, soils in the floodplain areas are in some cases less fertile with incidence of seasonal or sporadic flooding and higher proportions of sand (Windmeijer and Andriesse, 1993).

Land use vary depending on the wetland type with greater diversity in the floodplain than in the inland valleys which could be attributed to the wetland size and accessibility as available land in the wetlands could allow for diversification of land uses (Rebelo et al., 2010). Wetland use has also been linked to distance from the market (Drechsel et al., 2001). Wetlands located in remote areas are usually unused and in some instances partially grazed or cultivated on the margins (Kiai and Mailu, 1998). Results of hydric regimes and land use relationships in the present study were generally consistent to previous published descriptions of floodplain wetlands and inland valleys in that land use and hydrology are highly correlated with soil characteristics (Dixon, 2003). These results also emphasize the suggestions by Balasubramanian et al., (2007) and Wood and van Halsema, (2008) that wetlands are relatively fertile when compared to upland areas. However, our results also indicate that land use types and intensity of use may be important in structuring the soil characteristics within a wetland sub unit.

Factors that tend to be responsible for an increase of organic C in wetland soils and particularly in the flooded and unused wetlands in Cluster group 1 and 2 could be summed up as lower rate of decomposition in anaerobic conditions, and a high level of litter fall from the wetland vegetation (Handa et al., 2012). Alternate wetting and drying and tillage may stimulate microbial activity and cause rapid decomposition of organic matter thus resulting to reduced C contents in cultivated wetlands such as those observed in Cluster group 3 and 4.

Cluster groups identified as those under low or extensive use (Cluster 1) contained high C contents which were above 25 g C kg-1 while those which had been under intensive use (Cluster 3 and 4) reported remarkably low C and N concentrations. Among these wetlands were those under natural vegetation (unused) and those under extensive use for subsistence cropping or for grazing. Low N and P levels (<2 g N kg-1 and <10 mg P kg-1) were an indicator of possible N and P deficiency in majority of the intensively cultivated wetlands (Becker et al., 2007).

V. Conclusion

Five cluster groups were identified which differentiated the wetlands according to hydrology, socio-economic attributes and differed in soil characteristics. Wetland hydrology (flooding or no flooding) as well as land use (no use or cultivation) determined soil chemical characteristics in the wetlands. Soil C and N were the most important factors in differentiating and categorizing the wetland types. High C and N contents in wetland soils were associated with flooded conditions which were unused or were under low use intensity. Completely drained wetlands were in most instances intensively cultivated which resulted to low contents of soil C, N and P.

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