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ARTICLE

Classification, Characterisation, and Use of Small Wetlands in East Africa

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Abstract Small wetlands in Kenya and Tanzania cover about 12 million ha and are increasingly converted for agricultural production. There is a need to provide guidelines for their future protection or use, requiring their systematic classification and characterisation. Fifty-one wetlands were inventoried in 2008 in four contrasting sites, covering a surveyed total area of 484 km^2. Each wetland was subdivided into sub-units of 0.5–458 ha based on the predominant land use. The biophysical and socio-economic attributes of the resulting 157 wetland sub-units were determined. The wetland sub-units were categorized using multivariate analyses into five major cluster groups. The main wetland categories comprised: (1) narrow permanently flooded inland valleys that are largely unused; (2) wide permanently flooded inland valleys and highlands floodplains under extensive use; (3) large inland valleys and lowland floodplains with seasonal flooding under medium use intensity; (4) completely drained wide inland valleys and highlands floodplains under intensive food crop production; and (5) narrow drained inland valleys under permanent horticultural production. The wetland types were associated with specific vegetation forms and soil attributes.

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Agricultural land use of wetlands was linked to their physical accessibility and the availability of adjacent upland areas, irrespective of wetland size or soil type.

Keywords Floodplain · Inland valley · Kenya · Tanzania · Wetland typology

Introduction

Wetlands are estimated to cover about 4.7% of the continental area in sub-Saharan Africa (Rebelo et al. 2009), corresponding to approximately 228 million hectares (Matthew and Fung 1987; Bergkamp et al. 2000). In contrast to the large wetlands such as the Lake Victoria basin, the Nile catchment, or the saline coastal swamps and marshes, small wetlands in eastern Africa have received little international research attention (Finlayson et al. 2001). These comprise the spring-fed valley head and mid-section swamps of inland valleys (van der Heyden 2004), peat swamps of the East African highlands (Josten and Clarke 2002), and small lake and river floodplains (Harper and Mavuti 1996). Their size rarely exceeds 500 ha (Dixon 2002). Such small wetlands make up more than 80% of eastern African total wetland area and cover an estimated 12 million hectares in Kenya and Tanzania alone (Kalinga and Shayo 1998; Kiai and Mailu 1998). They present local hotspots for biodiversity (Chapman et al. 2001), fulfill buffering functions (Denny and van Steveninck 2001), and are important sites for a wide range of socio-cultural activities (Gopal et al. 2000). Prolonged periods of water availability and relatively fertile soils provide these wetlands with a large potential for the expansion and intensification of agricultural production (van der Heyden and New 2003). Consequently, wetlands have a substantial potential to contribute to the livelihood of rural communities of the region (Adams 1993).

Agriculture has long been practised on wetlands. However, wetland farming in inland valleys is a more recent activity as compared with that in the floodplains in general (Roberts 1988; Verhoeven and Setter 2010). Wetlands in the eastern African highlands have also been used for agricultural purposes (Wood et al. 2002), but their use changed dramatically over the last three decades (Wood and Dixon 2003). After the initial extensive use for hunting and gathering, the collection of thatching material, and extensive grazing (Scoones 1991), wetland use for agricultural production has recently intensified. This comprises in a first step an extensive cultivation of upland food crop during the dry season or of food crops on the wetland fringes, and of rainfed lowland rice during the wet season. Only after drainage, a complete conversion of the wetland for permanent upland crop production becomes possible. Such drained and intensively used wetlands contribute significantly in many parts of eastern and central Africa to local and regional food security (Wood 1997) and offer increasing potential for income generation through a range of market-oriented production activities (Olindo 1992). However, many of the drained wetlands show declining productivity and, after several years of intense use, may be abandoned to fallow or extensive grazing (McCartney et al. 2005). Determinants of this vulnerability of wetland sites or their sensitivity to anthropogenic interventions are still largely unknown.

Considering the current rate of wetland conversion into sites of production and the diverse ecological, social, and production functions that wetlands fulfill, there is a need to provide guidelines for their future protection or use. Such decision support requires a systematic classification and characterisation of wetlands by identifying the extent and diversity of wetland types and their uses, while providing a better understanding of the physical (landforms, climate, soils, and hydrology), biotic (vegetation), and socio-economic environments within which small wetlands occur.

In the context of wetland classification, both geographical and environmentally-based approaches have been explored (Omernik 1987). A combination of both approaches has been used to classify inland valleys in West Africa (Windmeijer and Andriesse 1993). Only a few studies have also included socio-economic attributes in their classification of production systems (Becker and Diallo 1992) or of wetland types (Andriesse et al. 1994). At present, an easy-to-apply classification system combining biophysical characteristics and socio-economic attributes with land use factors does not exist.

We hypothesise that the diversity of the biophysical characteristics of small wetlands and of the socio-economic attributes of their surrounding environments are determinants of the prevailing wetland use (types, intensity, and duration). The aims of the study were: (i) to capture wetland diversity; (ii) to classify and characterize the identified wetlands based on their biophysical characteristics and socio-economic attributes using multivariate analysis methods; and (iii) to link classification attributes to major land use types.

Methods

The Study Areas and Sites Selection

Major land units within which wetlands occur in East Africa comprise highlands and lowlands in the semi-arid, sub-humid, and humid zones and are found on diverse base rock materials. For the present study, the following landscape units and associated study sites were selected:

(1) the semi-arid highlands on granite (Rumuruti, Laikipia plateau, Kenya); (2) the sub-humid lowlands on fluvial sediments (Korogwe, Pangani plain, Tanzania); (3) the humid mid-hills on gneiss (Lushoto, Usambara mountains, Tanzania); and (4) the humid highlands on volcanic material (Nyeri, Mount Kenya, Kenya). These landscape units are estimated to cover >70% of the East African land area and are hence representative of the environmental and agro-ecological diversity of the region. 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 (Tenge 2005), while the two floodplain environments were located in less populated rural environments and farm sizes tended to be large.

In all four study areas, agriculture is the main economic activity. The dominant crops differed as a result of altitude and rainfall (Jaetzold and Schmidt 1982; Pfeiffer 1990). Thus, maize (*Zea mays*) and beans (*Phaseolus vulgaris*) are restricted to high-altitude wetlands, while rice (*Oryza sativa*) and cassava (*Manihot esculenta*) are typically grown in the lowlands. Main cash or industrial crops cultivated on uplands adjacent to the wetlands include coffee (*Coffea robusta*) and tea (*Camellia sinensis*) in the high rainfall environments, while sisal (*Agave sisalana*) and cotton (*Gossypium hirsutum*) are typically associated with the semi-arid and sub-humid zones. Livestock systems are largely linked to land availability with zero-grazing dairy systems in densely populated Central Kenya and the Usambara Mountains (Tenge 2005) and free ranging in the Rift Valley (Kohler 1987) and the Pangani plain (Pender et al. 2006). For site parameters, major biophysical and socio-economic descriptors and dominant agricultural activities see Supplementary Material, Table S1.

A multi-stage approach was used to select pilot sites within each of the four study areas. In total, 15 hexagons of 12 km^2 (mountainous landscapes) and 50 km^2 (largely flat landscapes) were selected to cover the prevailing diversity in terms of wetland density (scattered vs. dense), human population density (sparse vs. dense), physical accessibility (easy vs. difficult), and market proximity (rural vs. peri-urban). The 15 pilot sites covered a total area of 484 km^2 and all wetlands occurring within were inventoried (Supplementary Material, Figure S1).

Wetland Definition and Scope

Several wetland definitions exist in the literature and vary with the need, interest, and the user (Tiner 1999; Ramsar Convention Secretariat 2006, page 91). However, within the scope of the current research interest, small wetlands were defined as: "*land units of less than 500 ha that are characterized by permanent or seasonal flooding or by soil moisture availability higher than that of the surrounding uplands*" (Becker et al. 2006). These small wetlands comprise mainly floodplain and inland valley wetlands, potentially able to support agricultural production.

Data Collection and Variables Definition

A reconnaissance survey conducted in May 2007 to select the study areas was followed by a field survey in February to June 2008 to locate all the wetlands in the pilot sites. Wetlands were initially identified using topographic maps, aerial photographs, and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) as well as Landsat satellite images, and their existence and size was validated during the field survey. Data on morphological characteristics of these wetlands were obtained from both the field survey and from digital elevation maps, following the approach by Windmeijer and Andriesse (1993). In total 51 wetlands were identified, and these were included in the characterization exercise. With sizes ranging between 5 and 500 ha, these wetlands were delineated by a global positioning system device and mapped using ARC-GIS. Subsequently, each wetland was divided into sub-units with a minimal size of 0.5 ha, which were categorised based on the dominant land use into unused, grazed, or cropped areas.

The detailed data collection on soil, vegetation, and land use characteristics, as well as attributes of the land users and other socio-economic parameters were based on the 157 identified wetland sub-units. Composite soil samples were taken from eight points along a diagonal of each sub-unit to a depth of 20 cm. Soils were air-dried, ground and sieved (2 mm) prior to analysis. Soil samples were analysed for organic C, total N, available P, pH (H_2O), and particle size distribution following standard methods (ICRAF 1995) and near-infrared spectroscopy (Shepherd and Walsh 2007).

The abundance, prevalence and relative ground cover of dominant vegetation forms and plant species were determined following the approaches of Mack (2007). Within sub-units under cultivation, major crops and dominant associated weed species were recorded.

The type and history of wetland use, wetland hydrological behaviour, and the importance of the wetland to the local communities in relation to the surrounding upland environment were assessed by Rapid Rural Appraisal (RRA). The information was gathered from small groups of 5 to 15 farmers for each wetland, making in total of 51 RRA sessions during the survey. Information on the wetlands original vegetation, flooding regimes, history and duration of use, as well as land and crop management practices were obtained from key informants in each area.

After this, a total of 275 structured questionnaires were administered to village elders, areas chiefs, and to farmers and other wetland users. Secondary data on rainfall, temperature, major crops of the area, demography and market accessibility were obtained from provincial administrations and other government or non-governmental institutions.

The physical and legal accessibility of wetland sub-units was defined based on land tenure/ownership and the wetlands protection status, as well as the ease with which the sub-unit was physically accessible (duration and depth of water logging, presence of fences and prevalence of wildlife). The level of wetland disturbance was assessed according to Pickett and White (1985), referring mainly to anthropologically-influenced factors such as the presence of drainage infrastructure, the level of conversion into cropping land, and absence of natural vegetation. It was estimated by comparing the sub-unit conditions to largely unused sections of the wetland and classified as low for unused and high for completely drained, cultivated or degraded/abandoned sub-units. An index of the flooding regime was developed using information collected from the key informants on flooding depth and frequency in combination with field observations. The land use intensity was classified using information from key informants and farmers on the duration of land use and the number of cropping seasons per year, in combination with production orientation (subsistence vs. sale), the number and type (manual vs. mechanical) of tillage operations, and the use of external inputs (mineral fertilizers, purchased organic amendments, pesticides). Finally, the market accessibility was defined based on the physical market proximity and the available infrastructure (number and condition of roads).

Nominal- versus ordinal-level scale was employed for variable definition. Wetland type (2 categories), flooding regime (3 categories), and the dominant current land use of the wetland (6 categories), as well as of the adjacent upland areas (3 categories) were defined at nominal level. Variables on wetland accessibility, flooding regime, disturbance, use intensity, and market accessibility were defined at an ordinal level along the variable gradient.

Data Analysis

The 157 wetland sub-units were treated as independent sites for the statistical analyses. To ensure a relative independence, selected sub-units within the same wetland were distant by >50 m and were in the case of cultivated sites isolated from the surrounding wetland area by canals, ditches, or fences. Tests of significance were carried out using the SPSS-Inc. version 17.0. Bivariate analyses of the variables were carried using Chi-square and *t*-tests. Significance of differences between wetland sub-units for numeric variables was determined using non-parametric Kruskal-Wallis tests. Nominal variables were simultaneously scaled and assessed for significant differences using categorical regression analysis (Meulman and Heiser 2005). The comparison of wetland uses and sub-unit areas was done by univariate analysis of variance using the Tamhane test for post-hoc comparisons. Finally, regression analysis was used to test for differences of the numeric and categorical variables between wetland sub-units.

Relationships between land use and socio-economic attributes as well as biophysical characteristics were analysed by multivariate techniques. The analysis consisted of three steps. First, cluster analysis was used to derive a typology of wetland sub-units based on independent variables. Second, this typology was related to the independent variable on current land use. Third, the dependent variable on current wetland land use was related to independent variables using non-parametric correlations. Based on a factor correlation matrix derived from the principal component analysis (Jongman et al. 1995), 14 independent variables related to wetland geomorphology, land use, and socio-economic attributes (excluding land use itself) were selected for further analyses (Supplementary Material, Table S2). Land use was linked to the extracted principal components using six categories of the dependent variable. Relationships between land use categories were determined by ordination techniques, mainly redundancy analysis (RDA) in combination with Monte Carlo permutation testing (Lepš and Šmilauer 2003). Finally, data-sets on dependent and independent variables were subjected to Spearman non-parametric correlation analysis to explore the relationships between land use categories and the biophysical and socio-economic variables.

Results

Inventory and Distribution of Small Wetland

In total, 51 wetlands were identified and surveyed. These wetlands were subdivided into 157 sub-units based on dominant land uses. The occurrence, density of distribution, as well as the type and size of the wetlands varied between environments. The main wetland types were inland valleys and floodplains. Inland valley swamps dominated the humid mid-hills and highlands, whereas floodplains were the dominant wetland type in the semi-arid and sub-humid zones. Inland valleys accounted for 87% of all surveyed wetlands and covered 58% (2115 ha) of the total surveyed wetland area. Individual wetland sub-unit sizes differed significantly ($P<0.001$) among wetland types and ranged from 0.5 to 458 ha. Inland valley wetlands were generally narrow with areas ranging between 0.5 and 35 ha, while floodplain wetlands were larger and their area size varied between 10 and 458 ha. The percent area share of wetlands in the total land area per site was generally <0.5% and tended to be lower in the humid mid-hills and highlands than in the semi-arid highlands and the sub-humid lowlands (Table 1).

Biophysical Characteristics of Wetlands

The main wetland types were associated with geo-morphological characteristics of the location, and were reflected in soil types, hydrological regimes, and in dominant vegetation forms. Most inland valleys developed on gneiss and volcanic base rock, and were characterized by permanent to seasonal flooding regimes with water originating from springs or (subsurface) inter-flow. Dominant soil types were sandy loam to clay loam Gleysols or Histosols. Floodplains, on the other hand, developed on fluvial sediments or granite. They were sporadically or seasonally flooded by overflowing rivers, and were characterised by clay or loamy clay Fluvisols and Vertisols. The topsoil of the inland valley wetlands had generally higher organic C (23.8 gkg^{-1}), and total N (2.5 $gkg^{-1)}$ and lower available P (10 mg kg^{-1}) contents than floodplain wetlands with 15.4 gC kg^{-1}, 1.4 gN kg^{-1}, and 14 mg Pkg^{-1} (Table 1).

Some 340 plant species were recorded at the study sites. Across wetland types, Cyperaceae and Typhaceae families dominated the natural vegetation. *Cyperus papyrus* was associated exclusively with less-disturbed and permanently flooded sections of oligotrophic floodplains while *Typha capensis* was restricted to permanently flooded sections of eutrophic valley bottoms and floodplains. In seasonally flooded wetlands which were largely unused, common species included *Paspalum vaginatum* in inland valleys and *Cyperus exaltatus* in the floodplains. In grazed and fallow sections within seasonally flooded floodplains and inland valleys *Cyperus rotundus* and *Cynodon dactylon,* were generally abundant. *Leersia hexandra* and *Fimbristylis buchananii* were restricted to extensively cultivated wetlands with seasonal flooding in both valley swamps and floodplains, while *Chenopodium* spp., *Bidens pilosa*, and *Commelina benghalensis* were associated with permanent cropping in completely drained inland valleys.

Socio-economic Attributes

The main socio-economic attributes that differed both between and within the study sites and that were hypothesised to influence wetland use were population density, wetland accessibility, market proximity, and livelihood level. Population density was high in humid mid-hills and highlands and low in the semi-arid highlands and the sub-humid lowlands. However, it showed no apparent effect on wetland use. For instance, more than 80% of the unused wetland sub-units were located within areas with medium to high population densities. Location attributes that drive livelihood strategies showed variability between and within

Table 1 Proportions and mean of biophysical characteristics per wetland type in the rapid survey (sample size=157) conducted in Kenya and Tanzania

	Variable	Inland valley	Floodplain	*F* value
Geomorphology/ hydrology	Sample size	87%, *n*=136	13%; *n*=21	
	Altitude (masl)	1490±58	887±163	13.96***
	Area size (ha)	17.0±2	79.9±23.2	37.12***
	Wetland shape	Concave (72)	Flat (100)	0.142 ns
	Adjacent uplands slope	Gentle (44)	None (100)	0.715 ns
	Main water source	Runoff (37), spring (34), river (15)	River (39), runoff (31)	0.522 ns
	Flooding regime	Permanent (48)	Sporadic (57), seasonal (24)	0.248 ns
Vegetation/soil	Dominant natural vegetation	*Cyperus* spp. (57), *Typha* spp. (10)	*Cyperus* spp. (71), *C. papyrus* (24)	0.005 ns
	Soil type (FAO)	Gleysol, Histosol	Fluvisol, Vertisol	
	Parent material	Gneiss, granite and volcanic material	Sediments, granite	
	Texture	Sandy clay (57), Clayey loam (24)	Clay (53), Loamy clay (47)	0.127 ns
	Organic C (g kg^{-1})	23.8±0.12	15.4±0.08	7.67**
	Total N (g kg^{-1})	2.5±0.02	1.4±0.01	5.413***
	Available P (mg kg^{-1})	10.1±0.49	14.1±1.02	2.22*
	pH (H_2O:1: 2.5)	6.0±0.06	7.0±0.1	33.04***

* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$, ns: not significant; Numbers in parentheses represent the percentage of the indicated attribute in the total sample; ± Standard error of the mean; masl: meters above sea level

locations. These attributes comprised infrastructure (road conditions, electricity availability), physical accessibility (remoteness of the area, presence of fences, and depth of flooding), services availability, and market accessibility. Wetlands in urban and peri-urban settings (e.g., Nyeri-Municipality and Lushoto Township) had better infrastructure and easier market access than the wetlands in rural and remote areas (e.g. Rumuruti and Magoma). More of the surveyed wetlands were located in rural (64%; n=100) than in peri-urban areas (33%; n=52). Livelihood and location attribute influenced wetland use and use intensity. More than 98% of the unused or extensively grazed wetland sub-units were located in rural settings while intensive horticultural uses were generally associated with medium livelihood levels and market proximity. However, the market accessibility was not always related to wetland uses. For instance, about 70% of the extensively used wetland sub-units were close to the market. A low agricultural use of these wetlands was related to an unfavourable hydrology with prolonged and deep flooding.

Wetland Uses

Most of the wetland sub-units (74%; n=116) were agriculturally used and covered 87% of the total surveyed area. Only 17% of the wetland area (26% of wetland sub-units) was unused and dominated by natural vegetation. About 3% of the area was under other uses, mainly as sites for sporadic settlements. Such settlement areas occupied up to 9% of the wetlands in the peri-urban and urban localities of Nyahururu and Nyeri in Kenya.

The type of (agricultural) land use was largely linked to the hydrological regime of the sub-unit. Permanent flooding was associated with non-use and natural vegetation. Seasonally flooded sub-units occupied 56% of the surveyed area (n=88 sub-units) and occurred in both floodplains and on the fringes of inland valleys. Dominant land uses were subsistence crop production and dry season grazing. Fully drained wetland sub-units were mainly used for a market-oriented intensive horticultural production. While these agricultural land uses did not differ between wetland types, the identified categories varied in terms of area (Table 2A). Across wetland types, crop production was the dominant land use occupying 41% of the surveyed area. The type of crop and the seasonality of cropping was largely determined by the wetland hydrology. Subsistence food crop production was most common and included mainly maize (*Zea mays)*, beans (*Phaseolus vulgaris*), and sweet potato (*Ipomoea batatas*) in the drier wetland fringe or during the dry season and the flood-tolerant arrow root (*Colocasia esculenta*) in the wet valley sections, and rainfed lowland rice (*Oryza sativa*) in the floodplain centre during the rainy season. Market-oriented upland food and cash crop production (mainly vegetables) were largely restricted to seasonally flooded wetlands or those that had been completely drained. The market-oriented production of irrigated lowland rice was only encountered in the downstream section of large inland valleys and in lowland floodplains and was linked to the presence of development projects that have provided the initial investments for drainage and irrigation infrastructure.

Thirty-three per cent of total wetland area was used for grazing, which was the second most important use type after crop production (Table 2A). Ruminants were grazed year-round on the dry fringes of both valleys and floodplains and in the centre of seasonal floodplains during the dry season. Some 6% of the wetland area was abandoned or left fallow due to soil degradation (mainly nutrient depletion) or heavy infestation with (perennial) problem weeds. These fallow lands were mainly located in sections that had formerly been fully drained and used for (subsistence) upland crop production for extended periods.

Soil attributes differed as a function of wetland type, hydric regime, and land use. Permanent flooding resulted in the accumulation of organic matter and soil C and N contents were nearly double those of drained inland valley or seasonally inundated floodplain wetlands. Soil C contents tended to be higher in highland than in lowland areas and were generally lower in coarse-textured floodplain than in the fine-textured valley wetlands. Land use differentially affected soil attributes. While intensely tilled plots with low-input subsistence crops showed lower soil C, N, and P contents than soil in unused areas, market-oriented production areas receiving organic amendments and mineral fertilizers tended to have similar C and N and much higher P contents than the unused sub-units (Table 2B).

Categorisation of Wetland

Variables Selection

Wetland sub-units (n=157) were categorised into homogeneous cluster groups with specific geomorphologic characteristics and socio-economic attributes. Main indicators were derived from the principal component analysis. The first four principal components (PC) explained 69% of the biophysical and socio-economic variation within the dataset. PC1 was the most important component, explaining 33% of the variability, and comprised geo-morphological characteristics and market accessibility. PC2 explained 17% of the variability and referred to land use factors such as wetland use intensity, flooding regime, and land use of adjacent upland areas. The prevailing type of wetland use was significantly positively correlated (P<0.001) with wetland size (r=0.36) and market accessibility (r=−0.23) and negatively with the steepness of upland slope (acces-

Table 2 Main wetland use categories identified during the field survey in Kenya and Tanzania: (A) distribution, area size and share per wetland type and; (B) effects of hydrological regimes and land use on wetland soil characteristics (CNP contents)

Wetland type	Use type	Distribution of uses		Area (ha)	[a]Area share (%)
		(n)	(%)		
(A)					
Inland valley	Unused	38	28	14	13.4
	Grazing	29	21	20	14.5
	Fallow	7	5	34	6.0
	Subsistence food crop	33	24	13	10.6
	Lowland rice	4	3	55	5.5
	Horticulture	16	12	12	5.0
	Other uses	9	7	14	3.1
	SED (Use type)			*2.0*	
Floodplain	Unused	3	14	48	3.6
	Grazing	6	29	125	18.8
	Fallow	0	0	0	0.0
	Subsistence food crop	6	29	49	7.3
	Lowland rice	5	24	83	10.4
	Horticulture	1	5	76	2.0
	Other uses	0	0	0	0.0
	SED (Use type)			*23.2*	
	Significance (*P* values)				
	Use type (U)			0.031	
	Wetland Type (WT)			<0.001	
	Interaction U × WT			0.054	
(B)					
Flooding regime	Use type	Sample size (*n*)	Soil C (g kg^{-1})	Soil N (g kg^{-1})	Soil P (mg kg^{-1})
Permanently flooded	Unused	38	25.4	3.2	12.5
	Cropped	13	16.2	1.4	10.3
	SED (Use type)		*1.81*	*0.34*	*0.67*
	Use type (*P* values)		0.020	0.012	ns
Seasonally flooded	Unused	3	14.0	1.2	12.6
	Cropped	51	22.1	1.8	12.2
	SED (Use type)		*1.46*	*0.14*	*0.83*
	Use type (*P* values)		ns	ns	ns
	Significance (*P* values)				
	Flooding regime (FR)		ns	ns	ns
	Use type (U)		ns	ns	ns
	Interaction FR × U		0.030	0.053	ns

[a] Calculated as the percentage of area size per land use type over the surveyed total area size; SED: Standard error of the differences; ns: not significant

sibility, r=−0.35). The use intensity of the wetland was correlated with the flooding regime (r=0.51), and the physical accessibility of the wetland (r=0.39).

Wetland Typology

Five major wetland cluster groups were identified by hierarchical cluster analysis (Supplementary Material, Figure S2). These cluster groups comprise: (1) narrow permanently flooded inland valleys under natural vegetation (16%; n=25); (2) wide permanently flooded inland valley and highland floodplain with extensive use for grazing and some subsistence food crop cultivation (26%; n=41); (3) large inland valleys and lowland floodplains with sporadic to seasonal flooding under medium land use intensity for subsistence food crops, lowland rice, and grazing (24%; n=

37); (4) wide completely drained valley bottoms and highland floodplains under permanent intensive crop use (17% n=26); and (5) narrow drained inland valleys with intensive permanent horticultural production (18%; n=28). This classification scheme was tested by discriminant analysis whereby 96% of the original 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. The wetlands in cluster groups with similar geo-morphological characteristics (groups 1 and 5 as well as groups 3 and 4), differed primarily in terms of their hydrology and soil characteristics (Table 3).

Characterisation of Wetland Cluster Groups

The wetland cluster group and their main distinctive characteristics are presented in Table 3. Cluster 1 consisted of narrow, permanently flooded inland valleys under (semi-) natural vegetation with limited accessibility. These included small (average=12 ha) convex valley heads and concave midstream sections in the humid highlands with gentle slopes. Small sections (usually the seasonally flooded fringe areas) of some of these wetlands had been extensively used in the past for subsistence crop production and had been abandoned for more than 10 years. These areas were covered by a regenerated close-to-natural vegetation, dominated by *Typha capensis*, *Cyperus laevigatus*, and *Polygonum* spp.. Due to extended fallow periods and the permanent soil flooding regime, the fertility of the generally coarse-textured soils had time to regenerate, showing mean values of 36.9 gkg^{-1} of organic C, 4.6 g kg^{-1} of total N, and up to 26 mg kg^{-1} of available P. These wetlands were mainly located in rural areas with low to moderate population density and poor market accessibility. Most of the adjacent upland areas were covered by forest.

Cluster 2 grouped wide, permanently flooded inland valleys in the highlands (1800–2400 m) and seasonally flooded lowland floodplains (200–400 m) that were extensively used for grazing and for subsistence crops cultivation on the wetland fringes during the dry season. These wetlands had an average area of about 21 ha. Soil texture was mixed sandy clay to clay loam and the common soil types were Vertisols and Fluvisols in the lowland floodplain and Gleysols in the highland inland valley. The soil organic C content ranged between 8.0 to 69.6 gkg^{-1} whereas total N contents ranged from 0.9 to 10.9 gkg^{-1}. The availability of soil P was moderate with an average of 15 mg kg^{-1}. Inaccessible sections of these wetlands (22%) were permanently flooded and covered by *Cyperus papyrus* in oligotrophic and by *Typha domingensis* in eutrophic environments. The segments of the wetland that were accessible (46%) were extensively grazed or partially drained for subsistence crop cultivation. In these parts, the vegetation was dominated by *Cyperus laevigatus*, *Leersia hexandra*, and *Fimbristylis buchananii.* These wetlands were mainly located in rural areas (83%) where the adjacent uplands were largely unused or extensively grazed by nomadic pastoralists, and in few cases, extensively used for dryland food crops.

Cluster 3 comprised both large downstream sections of inland valleys in the semi-arid to humid highland as well as large floodplains in the lowland areas. Both the wetland and the surrounding landscape was flat and dominated by heavy clay Dystric Fluvisols and some Vertisols. Most parts of these wetlands were seasonally flooded (92%), generally by overflowing of a river or the stream during the rainy season or by surface run-off from adjacent uplands. The average size of these wetlands was very large with 56 ha. The anthropogenic use pressure was relatively low, with subsistence food crops cultivated on the wetland fringes during the dry season and rainfed lowland rice close to the wetland centre during the wet season. Mean soil C and N contents are low with 17.3 gC kg^{-1} and 1.6 gN kg^{-1} while soil P content was relatively high with 16 mg kg^{-1}. The natural vegetation was characterized by *Polygonum* spp., *Pennisetum mezianum*, *Cyperus exaltatus*, and *Sporobolus pyramidalis* in the largely unused section or in the areas used for wet season rice, and by *Cyperus rotundus* and *Cynodon dactylon* in the fringes where upland crops are cultivated. Surrounding upland areas were moderately grazed and cultivated with either subsistence food crops (highlands), or sisal plantations (lowlands).

Cluster 4 consisted of wide valleys and highland floodplains located in rural areas. These wetlands occurred at high altitudes with an average area size of 26 ha. These wetlands were dominated by sandy clay to clay soil texture and were completely drained for intensive low-input (subsistence) upland crop production. Soils showed the lowest nutrient contents of all wetland types, with a mean value of 17.1 gkg^{-1} organic C, 1.6 gkg^{-1} total N, and 11 mg kg^{-1} available P. Before their drainage these oligotrophic environments were dominated by *Cyperus papyrus*. Under cultivation, upland weeds such as *Paspalum vaginatum* and *Bidens pilosa* were associated with crops, while *Leersia hexandra* and *Ipomoea aquatica* occupied the drainage canals. Due to their easy accessibility and the low production potential of the semi-arid to sub-humid surroundings, most of the wetland area is cultivated with subsistence food crops with a low use of fertilisers. Some portions of these wetlands had been abandoned to fallow.

Cluster 5 comprised narrow valley swamps in mountainous areas under intensive horticultural use. These were typically small (average=15 ha) midstream sections of inland valleys in the humid highlands (1300 m to 1835 m altitude with 900–1500 mm annual rainfall). Valleys have a concave shape with gentle slopes and are associated with

Table 3 Ecological characteristics and socio-economic attributes of wetland sub-units cluster groups identified in the study areas in East Africa (Kenya and Tanzania)

Wetland type	Inland valleys and highland floodplains	Narrow valleys in mid-hills and highlands	Inland valleys and lowland floodplains	Inland valleys and floodplains	Narrow valleys in mid-hills and highlands
Use intensity	Extensive	Extensive	Medium	Intensive	Intensive
[a]Cluster group	1	2	3	4	5
Sample size (n)	25	41	26	37	28
Sites in Kenya	Nyeri	Nyahururu, Rumuruti	Nyahururu	Karatina, Rumuruti	Karatina, Nyeri
Sites in Tanzania	Lushoto, Magamba	Magoma, Malinda	Malinda, Silabu	Korogwe township	Bumbuli, Lukozi
Regions	Central Kenya, Western Usambaras	Rift Valley, Usambara Mountains	Pangani bassin, Rift Valley	Central Kenya, Rift Valley, Pangani bassin	Central Kenya, Western Usambaras
Morphology	Convex valley heads with gentle slopes	Concave valleys and floodplains	Flat downstream valley sections	Concave highland valleys and plains	Concave valleys with gentle slopes
Wetland size (ha)	20.7±4.8	12.4±2.4	56±11.5	25.8±12.4	15.1±3.5
Hydrology	Permanent flooding	Permanent flooding	Seasonal flooding	Seasonal flooding	No flooding
Source of water	Spring	Run-off and river overflow	Run-off and river overflow	Run-off and river overflow	Springs and run-off
Soil type	Gleysols	Gleysols and Luvisols	Fluvisols and Vertisols	Gleysols and Luvisols	Fluvisols
pH (H_2O: 1:2.5)	5.6±0.2	6.2±0.1	6.6±0.2	6.1±0.1	6.1±0.1
C_{org} (g kg^{-1})	36.7±0.3	19.2±0.2	17.3±0.2	17.1±0.1	26.4±0.2
N_{tot} (g kg^{-1})	4.6±0.06	2.6±0.03	1.6±0.01	1.6±0.01	1.9±0.02
P_{avail} (mg kg^{-1})	11±0.9	14±0.8	16±1.0	11±1.0	10±0.8
Dominant vegetation	*Cyperaceae*, *Typhaceae*, and *Polygonum* spp.	*Cyperaceae*, *Leersia hexandra*, and *Fimbristylis buchananii*	*Polygonum* spp., *Cynondon dactylon*, *Pennisetum mezianum* and *Sporobolus pyramidalis*	*Paspalum vaginatum*, *Bidens pilosa*, *Leersia hexandra*, and *Ipomoea aquatica*)	*Galinsoga parviflora*, *Chenopodium* spp., *Commelina benghalensis*, *Cyperus rotundus*, and *Bidens pilosa*
Land use	Largely unused or extensively grazed	Largely unused or extensively grazed	Low-input rice, grazing and fallow	Medium intensity, food crops, inputs	Intensive horticulture, high input use
Location characteristics	Moderate accessibility Rural/peri-urban areas	Poor accessibility	Easy access	Easy access,	Easy access
	Not drained	Remote rural areas	Rural areas	Rural areas	Peri-urban areas
	Uplands under agroforestry	Largely not drained	Partially drained	Partially drained	Completely drained
		Uplands unused under natural vegetation	Uplands under food crops or grazing	Uplands largely cultivated	Uplands intensively cropped

[a] Cluster groups: 1 = Narrow permanently flooded inland valleys under natural vegetation Wide permanently flooded inland valleys and highland floodplain with extensive use; 2 = Wide permanently flooded inland valleys and highlands floodplains under extensive use for grazing and subsistence crops cultivation; 3 = Large inland valleys and lowland floodplains with sporadic to seasonal flooding under medium use intensity for upland food crops and lowland rice; 4 = Wide seasonally flooded valleys and highlands floodplains, completely drained for intensive food crop production; and 5 = Narrow seasonally flooded highlands inland valleys and completely drained intensive horticultural production; ± Standard error of the mean

Dystric Fluvisols with generally coarse-textured topsoil. These wetlands were originally permanently flooded but are now completely drained for intensive year-round horticultural production with a high use organic and inorganic fertilisers. Due to their permanent year-round use, soil fertility is moderate to low with organic C and total N contents averaging at 26 and 1.9 gkg^{-1}, respectively. Despite moderate to high application rates of fertilisers, soil available P was low with 10.2 mg kg^{-1}. In these valleys, vegetable crops are associated with upland weed species such as *Galinsoga parviflora, Chenopodium* spp., *Commelina benghalensis, Cyperus rotundus*, and *Bidens pilosa*. These valleys are located in densely populated highland areas with good market access. Surrounding upland areas are intensively used for both cash and subsistence crops production.

Wetland Type - Land Use Relationship

Spearman correlations between land use and the classificatory variables revealed a weak relation of land use type with wetland size (r=0.17), wetland shape (r=0.35), and disturbance (r=0.29). However, a significant (P<0.001) negative relation with the steepness of valley slopes (r=−0.20), market proximity (r=−0.28), wetland accessibility (r=−0.33), and particularly the flooding regime (r=−0.46) was observed. On this basis, PC2 differentiated the land use types into the less used (un-drained, permanently flooded) and the intensively cropped ones (drained or seasonally flooded).

The first two axes of the principal component analysis explained 33 (axis 1) and 31% (axis 2) of the total variance in land use. Axis 1 discriminated positively the unused or extensive use types and negatively the moderate to intensive use types, primarily based on wetland accessibility (r=0.50), flooding regime (r=0.46), fertiliser use (r=−0.72), and the type of use of the adjacent or surrounding upland areas (r=−0.59). Axis 2 differentiated land use types mainly based on valley size (r=0.40), disturbance (r=0.25) and wetland accessibility (r=−0.49). In general, the physical accessibility and the flooding regime of wetland were strongly associated with the conversion of wetlands into sites for agricultural production (Fig. 1). Consequently, unused wetlands were associated with permanent flooding and difficult physical accessibility. Grazing and other extensive uses of wetlands were related to the steepness of the surrounding slopes (wetlands with gentle slopes are easily accessible by livestock). Fallow areas or abandoned portions were associated with soil type, fertility attributes and land use duration. Finally, year-round and intensive cropping was associated with wetland drainage, intense use of adjacent areas for crop production, and application of fertiliser. Relative shares of major land uses in the different wetland sub-units groups are presented in Fig. 2.

Discussion

The combined use of different approaches for data collection and statistical analyses was important to be able to relate the wetland systems to their use by the local people who live in these rural areas. The combination of social and environmental approaches for collecting data improved the

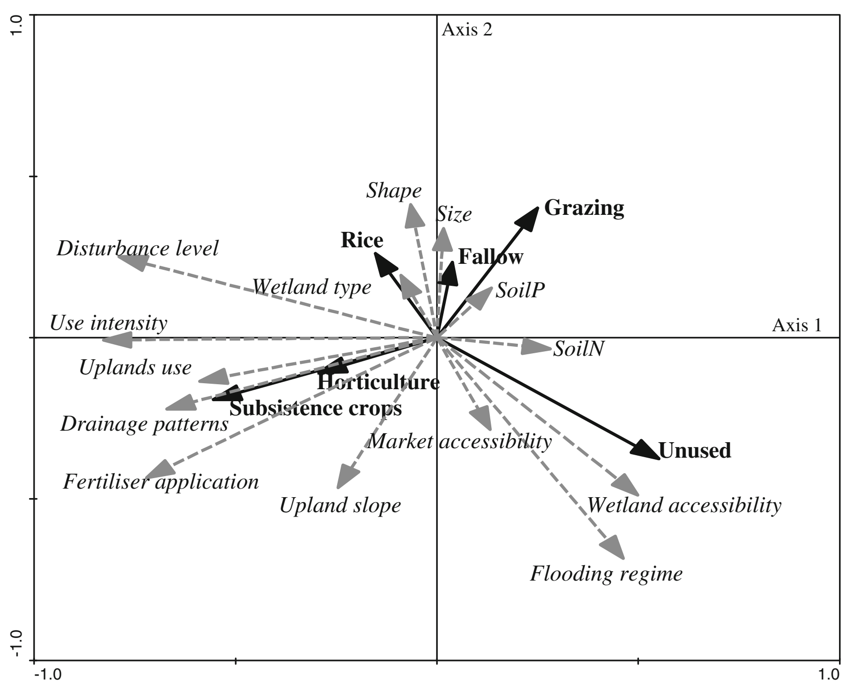

Fig. 1 Redundancy analysis ordination diagrams of the major land use categories with the independent variables for small wetlands characteristics. Land use categories are represented by bold solid arrows and the explanatory variables are in dashed arrows

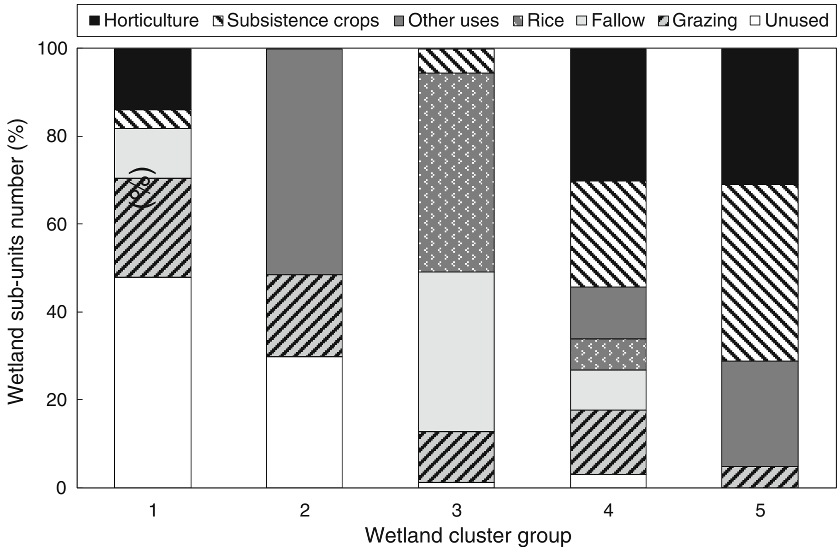

Fig. 2 Percentage wetlands allocation to defined land uses per wetland typology in the study area. Colour and pattern gradients denote the intensity of land use intensity from unused (*plain white*) to intensive use (*plain black*). Cluster groups: 1 = Narrow permanently flooded inland valleys under natural vegetation 2 = Wide permanently flooded inland valleys and highlands floodplains under extensive use for grazing and subsistence crops cultivation; 3 = Large inland valleys and lowland floodplains with sporadic to seasonal flooding under medium use intensity for upland food crops and lowland rice; 4 = Wide seasonally flooded valleys and highlands floodplains, completely drained for intensive food crop production 5 = Narrow seasonally flooded highlands inland valleys and completely drained intensive horticultural production

understanding of wetland functioning, which is critical for future management initiatives. The local knowledge of wetland communities on the flooding behavior of the wetland and changes in land use over time and space highly contributed to the definition of determining factors. The development of wetland typology is a step forward to capture key characteristic distinguishing the small wetlands, their use factors, and the socio-economic contexts of their surrounding environments. The typology allowed the linkage between the biophysical characteristics of the wetlands and the socio-economic factors and hence created socio-ecological niches for specific wetland uses in the study area. This typology can be used to structure the large variability in observed land use decision making (Giller et al. 2011; Le et al. 2010; Wiggins and Proctor 2001).

Wetland Uses

The study identified different wetland use by local people living in contrasting rural areas. Such differences may reflect the diversity of these areas where farmers operate and the heterogeneity that characterise land-users and their land use decisions (Busck 2002; Köbrich et al. 2003; Siebert et al. 2006). The kind, diversity and intensity of land use varied with wetland type, the prevailing hydrological regime and the physical accessibility as reported elsewhere (Adams 1993; Rebelo et al. 2010). Use intensity and production objectives (i.e. extensive grazing or subsistence food crops vs. market-oriented production of lowland rice or horticultural crops) are generally driven by socio-economic determinants such as land availability (Schuijt 2002) and the market proximity (Drechsel et al. 2001; Balasubramanian et al. 2007) as also observed in the present study. However, land shortages in urban or peri-urban areas combined with an easy access to input/output markets are likely to accelerate wetland conversion and an input-intensive year-round production of high-value crops. This production is likely to increasingly compete with non-crop uses of wetlands, such as water abstraction for households and industry and the use for settlements as observed in the case of the study sites in Nyahururu and Nyeri in Kenya.

Wetlands that are unused and still largely covered by (semi-)natural vegetation forms have in common a difficult physical accessibility and/or the fact that they are flooded all year round. This can be attributed to difficulties in regulating the water level (i.e. by drainage) or the fact that such regulatory measures require large infrastructure investments (Roberts 1988; IVC/WARDA 1997). Such permanently flooded wetlands (or sections of wetlands) are suitable as biodiversity conservation areas and for regulatory functions in the foreseeable future.

When wetlands are only seasonally flooded or their fringes become physically accessible, extensive land use, like small-scale traditional subsistence farming or temporary seasonal grazing, was observed. Thus, wetlands can serve as grazing grounds during the dry season when forage is scarce on the uplands. Alternatively, the non-flooded fringe areas can be partially converted to sites of subsistence food production, mainly during the dry season, when upland cropping is restricted by lack of rainfall. In addition, some wetlands support traditional rainfed food crops where water is scarce, where upland soils are degraded and/or where other cropping area is lacking. Consequently, this type of wetland use is mainly encountered in the sub-humid and semi-arid rural savannah environments of East Africa and in areas where traditional pastoralism and an extensive sedentary production of livestock and crops occur.

An intensive use of wetlands is always linked to infrastructure measures to regulate water levels, involving either large-scale drainage or the provision of irrigation. Such investments occur either in the proximity to an input/output market, where the production of perishable high value crops such as vegetables justify investments in drainage and external input use, or in environments where severe upland shortages occur (Hollis 1990; Olindo 1992). Thus, in densely populated areas (large parts of the East African highlands), demographic growth as well as in-migration and resettlement schemes (Oucho and Gould 1993) have created conditions of high pressure on land resources, leading to small landholdings and frequently to degradation of the soil resource base as a result of intensive use without conservation measures or the replenishment of removed nutrients (Oldeman et al. 1991). In these environments, farmers need to exploit all possible niches for crop growth and tend to move more rapidly into wetlands than in environments where the uplands can still sustain rural livelihoods.

An additional factor of intensive but low-input use of wetlands is linked to climatic conditions. In semi-arid areas, in savannah environments with extended dry seasons, and possibly also in environments with increasingly variable climatic conditions, agricultural uses of wetlands intensify, even in very remote and rural areas. Such land use trends are likely to further accelerate in the face of projected climate change phenomena (Smith et al. 2001).

Intensively used wetlands appear to differ in their ability to sustain long-term crop production. Thus, the intensive vegetable production systems appear to be highly productive, despite frequently coarse-textured soils with low nutrient reserves and a heavy infestation of the crop fields with weeds. The situation is rather different in the wetlands of cluster group 4 where, intensive agriculture focuses on (subsistence) food crops with a low use of farm input. In these production systems, longer-term cropping appears to be restricted to soils with high organic C and nutrient contents. In wetland sub-units with coarse-textured soils and low soil nutrient reserves, crop fields are frequently interspersed with fallow areas, where farmers have abandoned production due to declining crop yields and increased weed infestation, as found in the RRA. Presumably, some wetland sub-units under natural vegetation of cluster group 1 (low soil fertility, previously cropped) may have belonged to this wetland type in the past.

We can conclude that wetlands differ in their suitability for agricultural production. Permanent soil flooding reduces use pressure and contributes to wetland conservation. Demographic growth and climate change are likely to stimulate wetland uses due to their potential negative effects on the availability and productivity of upland resources. The vulnerability of wetlands to anthropogenic interventions appears to be linked to soil fertility and to crop management. Thus, low-input crop production can only be sustained at a reasonable level on deep clay soils, while in coarse-textured poorer soils under intensive production requires high use of farm inputs and consequently the proximity to a market.

Wetland Categorization

Based on the social-ecological attributes that are associated with different wetland use types, it is possible to define areas where wetlands will remain "undisturbed" (under natural vegetation, not drained, waterlogged with thus difficult accessibility) or be converted to production sites (upland shortage, fertile clay soils, and seasonally flooded sites). It is also possible to advise on which wetland sites should be protected as agricultural use is likely to result in wetland degradation and hence the destruction of a valuable landscape element (wetlands with poor coarse-textured soils that are seasonally flooded or wetland covered by papyrus as an indicator species of permanently flooded oligotrophic environments). Finally, seasonally flooded, drainable inland valley and floodplain fringes in peri-urban areas are considered to play a key role in sustaining livelihoods and improving food security, particularly in areas where upland environments are degraded and/or where climate change phenomena increase the riskiness of upland production.

In considering both social and biophysical attributes, the proposed typology provides not just a classification of environments but also considers land uses and production potential and thus contributes to the definition of social-ecological niche of current and future land use (Gunderson et al. 2006). Each category combines the biophysical characteristics and the socio-economic attributes of the surveyed wetlands and provides a more comprehensive socio-ecological classification than those based mainly on land use factors (Andriesse and Fresco 1991), those focusing on crop management practices in rice (Becker and Diallo 1992) or on ecosystem classification (Andriesse et al. 1994), or those providing a strictly hydro-geomorphological classification (Windmeijer and Andriesse 1993). The proposed typology will be used to guide the selection of representative wetlands for multi-disciplinary in-depth studies and to define socio-ecological niches for specific wetland uses.

Conclusion

The identified wetland types differ in terms of land use and social-ecological attributes. Wetland type and hydrological regime are associated with specific vegetation forms and soil attributes. Their agricultural use is partly linked to the physical accessibility and the seasonality of flooding besides the population growth, market opportunities, government policies, and the dynamics of rural livelihoods. The analyses presented in this study can provide the framework for a comprehensive assessment of wetland diversity and a tool for the targeting of technology interventions. While the presented findings are based on only four regions in East Africa, the study sites represent the major biophysical and socio-economic settings. In addition the reported wetland use types have also been reported from West Africa (Becker and Diallo 1992), southern Africa and parts of Central Africa (Hughes and Hughes 1992). The proposed characterization and typology of small wetlands may thus be applicable to a much wider range of environments and be extrapolated and scaled up to other areas within sub-Saharan Africa.

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