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A rapid assessment of anthropogenic disturbances in East African wetlands

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ABSTRACT

The use of East African freshwater wetlands for agriculture has increased in recent decades, raising concerns about potential impacts on wetlands and the long-term sustainability of such land use trends. WET-health is an indicator-based rapid wetland assessment approach developed in South Africa. It allows determining the conditions of wetlands in four assessment modules (hydrology, geomorphology, vegetation, and water quality) by observing the degree of deviation of a wetland from its anticipated natural reference state. We tested the transferability of the WET-health concept for East African inland valley swamps and floodplain wetlands based on 114 assessment units at four study sites. Due to large wetland areas and different environmental settings in East Africa, we modified the original approach using a random selection of assessment units and an assessment scheme based on disturbance types (Appendices A and B). Estimated WET-health impact scores were matched with biophysical and socioeconomic variables using a generalized linear mixed model. Land use included largely undisturbed wetland units occurring side by side with seasonally cropped or grazed units, and drained, permanently cultivated units. A strong differentiation of impact scores between the four assessment modules was apparent with highest scores for vegetation and lowest scores for geomorphology. Vegetation and water quality responded most sensitively to land use changes. The magnitude of wetland disturbance is predominantly determined by management factors such as land use intensity, soil tillage, drainage intensity, and the application of agrochemicals and influences vegetation attributes and the provision of ecosystem services. The proposed modification of WET-health enables users to assess large wetland areas during relatively short periods of time. While further studies will be required, WET-health appears to be a promising concept to be applied to wetlands in East Africa and possibly beyond.

1. Introduction

Agricultural production in wetlands is increasingly considered to be a potential solution to food security challenges in Africa (Frenken and Mharapara, 2002; UNEP, 2009). Wetlands are characterized by generally nutrient-rich soils and high moisture availability, enabling smallholder farmers to produce crops all year-round (Sakané et al., 2011). Furthermore wetlands contribute a wide range of additional ecosystem services, including the provision of pasture land for livestock grazing during dry seasons (Dixon and Wood, 2003), the regulation of floods and local climate, the

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removal of pollutants, and being habitats of wildlife (Cui et al., 2012). At global scale wetlands cover about 9.2 million km^2 with 1.3 million km^2 being located in Africa (Lehner and Döll, 2004). In Uganda, Rwanda, Tanzania, and Kenya alone, wetlands cover an estimated area of about 0.15 million km^2 (Amler et al., 2015). This study defines wetlands as land surfaces that are/were flooded with freshwater or where the soil is/was saturated permanently or seasonally. Wetlands are thus primarily characterized by the influence of the amount and the spatial–temporal availability of freshwater and of its effects on soil and vegetation.

The use of such freshwater wetlands for agricultural purposes has increased in recent decades (Dixon and Wood, 2003). These land use changes are mainly driven by economic and demographic growth, climate change, and globalization effects (Van Asselen et al., 2013; Wood et al., 2013), but are also related to changed national policy environments and local governance structures (Wetlands International, 2014). The agricultural productivity of upland fields has declined as a result of degraded soils, extreme land fragmentation and increased variability of precipitation (Symeonakis and Drake, 2010). These factors, combined with emerging market opportunities have further fueled the shift from upland to wetland based agricultural production (Sakané et al., 2011; Wood and Van Halsema, 2008). However, in conjunction with non-adapted agricultural uses, wetland conversion into arable land frequently curtails the capacity of wetlands to provide the above mentioned important ecosystem services. Thus, a sustainable increase in food production from wetlands needs to be reconciled with environmental protection. Striking the balance between maximizing benefits of wetland agriculture while minimizing adverse impacts on other ecosystem services has been described as the main dilemma of current wetland policies and management (McCartney et al., 2010). Against this backdrop, there is a need to quantify the current state of disturbance from human impacts in East African wetlands and to identify major hazards to the condition ("health") of wetland ecosystems. This is imperative given that "healthy" wetlands are likely to be robust in playing the role of providing ecosystem services that are important in sustaining people's livelihoods such as food production resources, clean water, livestock pasture, building materials, fiber, esthetic benefits and hosting organisms that provide pollination services. Through these services, wetlands play an important role in assuring food and nutrition security, securing water supply, preserving plant and animal biodiversity and acting as a storm buffer. Disruption of wetland ecosystems through anthropogenic activities is therefore likely to be associated with tremendous economic costs as a result of the lost capacity to provide ecosystem services.

Several studies have explored agriculture-wetland interactions in sub-Saharan Africa in view of developing frameworks able to describe the potential of wetlands for agriculture and the concomitant supply or loss of ecosystem services (Acreman and Miller, 2007; Cui et al., 2012; Dixon and Wood, 2003; McCartney and Houghton-Carr, 2009; Van Dam et al., 2013; Wood and Van Halsema, 2008). One of these frameworks is the WET-health approach, developed for South African wetlands, that is a wetland degradation assessment, describing the degree of deviation of a wetland from its natural reference state (Kotze et al., 2012). This degree of deviation will henceforth be called disturbance. The level of disturbance is assessed for the four "assessment modules" hydrology, geomorphology, vegetation, and water quality. WET-health uses a semi-quantitative estimation of impact at a scale ranging from 0 (no deviation from natural conditions) to 10 (complete transformation and absolute loss of wetland properties) (Macfarlane et al., 2009). It is recognized that the natural reference state of a wetland is often not fixed, but depending on the particular situation may be highly dynamic, e.g. a lake fringe wetland where the level of the lake fluctuates markedly at a decadal scale as a result of climatic cycles. Furthermore, completely un-impacted wetlands are virtually absent in East Africa. Thus there is often no true reference site existing and the reference state has to be anticipated from climate, wetland type, and local information on past uses of the wetland. For instance, the reference condition for vegetation corresponds to the properties displayed by plant communities (diversity, structure, etc.) in absence or removal of human impacts (thus pristine vegetation or late succession stages). While the absolute reference state (vegetation stands with no human impact) is hardly to be found in the field, a hypothetical reference state can be approached by observing stands under low levels of disturbances. Such a reference state is known in ecology as potential natural vegetation (Mueller-Dombois and Ellenberg, 1974). The focus of the approach, however, lies on assessing current functionality of wetlands rather than accurate historical classification of reference sites.

While the four assessment modules are strongly interlinked, the WET-health framework provides an impact assessment of anthropogenic disturbances that attempts to reduce double-counting by assessing each WET-health module separately (Kotze et al., 2012). Thus, we consider WET-health to be a user-friendly and cost-effective approach that was developed for similar land uses as present in the wetlands of East Africa. Prior to this study all wetlands to which WET-health had been applied were relatively small (<10 km^2). In the application of Kotze (2011), for example, all examined wetlands were smaller than 1 km^2. The selected sites for this study, on the other hand, are much larger, with areas ranging from 81 to 537 km^2. These sizes present a particular challenge in terms of field coverage. Thus methodological modifications are required to transfer the WET-health assessment approach to East African wetlands. To reduce the sampling size we characterized randomly-selected assessment units within different localities and land use types. We further assigned WET-health impact scores for hydrology, geomorphology, vegetation, and water quality to these assessment units. In order to further reduce field operations this assignment was modified as well, using an assignment scheme based on disturbance types. Additionally, relationships between WET-health scores and biophysical conditions as well as socioeconomic attributes of the wetlands were determined. The adaption of the WET-health concept for East Africa was based on 114 wetland assessment units at four study sites in East Africa.

2. Methods

2.1. Study sites

The study was conducted at four sites in East Africa, namely Kampala (Uganda), Kigali (Rwanda), Ifakara (Tanzania), and Rumuruti (Kenya) (Fig. 1). The four sites were selected as East African freshwater wetlands used for agricultural purposes and representing primary intervention environments of national wetland policies in the target countries. They are contrasting in their geomorphological, bioclimatic and economical properties and cover the two major geomorphological wetland types, the inland valley swamps and the floodplains. The Kampala (Uganda) study site is located in the humid zone, covering an area of 117 km^2. It comprises a large number of small inland valleys located on transects along an urban-to-rural gradient at a mean elevation of 1100 m a.s.l. At an altitude of 1500 m, the Kigali (Rwanda) site covers 129 km^2 in the sub-humid zone and comprises both inland valleys within the Lake Muhazi catchment and floodplains of the Nyabarongo River. The Ifakara (Tanzania) site lies in the sub-humid to semi-arid lowlands at 250 m altitude, within the Kilombero catchment, covering an area of 537 km^2, and representing a typical lowland floodplain wetland. The Rumuruti (Kenya) site is located on the semi-arid Laikipia

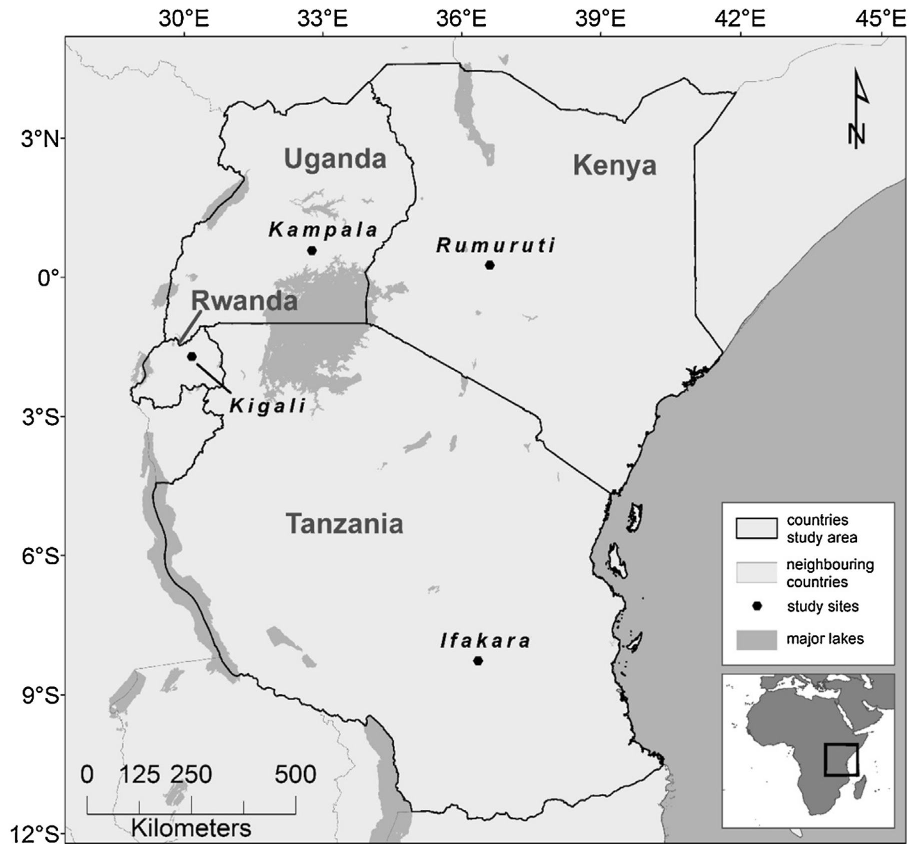

Fig. 1. Location of study sites in East Africa.

plateau on the western side of Mount Kenya at around 1800 m altitude. This site contains the Ewaso Narok swamp with an area of 81 km^2 and represents a typical highland floodplain.

While the floodplain of Ifakara is located in thick sedimentary sequences (Geological Survey of Tanganyika, 1962), the wetlands of Kampala, Kigali and Rumuruti are underlain by thin alluvial sediments that cover an underlying crystalline basement. This basement is represented by granitoides and gneisses in Kampala (GTK Consortium, 2009), various metamorphic rocks (e.g. micaschists, granitoides, quartzites) in Kigali (IGNB, 1981) and volcanic phonolites in Rumuruti (Heinrichs, 2001). According to the Köppen–Geiger classification (Peel et al., 2007), the bioclimate of the study sites belongs to the "Tropical Savannah" type (Aw), except for Kampala belonging to the "Tropical Rainforest" type (Af). The respective temperatures and annual rainfalls are 22 °C and 1291 mm in Kampala, 20 °C and 990 mm in Kigali, 25 °C and 1427 mm in Ifakara, and 17 °C and 714 mm in Rumuruti (Hijmans et al., 2005). The potential natural vegetation is represented by semi-evergreen rainforests in Kampala, evergreen and semi-evergreen bush lands and thickets in Kigali and Rumuruti, and woodlands and edaphic grasslands in Ifakara (Lillesø et al., 2011). Wetland vegetation has an azonal character (occurrence determined by extreme soil conditions; Mueller-Dombois and Ellenberg, 1974) and is thus embedded in the previously mentioned units. The most important vegetation units in wetlands are represented by papyrus marshes, which are very common in the headwaters of the Nile River (Denny, 1993), including the Kampala, Kigali and Rumuruti sites under permanently flooded conditions (Thenya, 2001). Wetland vegetation in the Ifakara site is represented by communities dominated by tall grasses, such as *Phragmites australis*, *Panicum fluviicola* and *Hyparrhenia* spp. (Hood et al., 2002). All four sites have been increasingly exploited during the past decade for food and cash crop production, but also for fishing, brick making, and the extraction of peat and building or thatching materials.

2.2. Wetlands mapping and selection of assessment units

To define sampling areas for field assessment, we generated maps delineating the borders of the wetland ecosystems. The criteria used for delineation were the occurrence of depressions in the landscape (Bwangoy et al., 2010) and vegetation that differs from the surrounding uplands (Semeniuk and Semeniuk, 1995). To detect potential wetland landscapes, the digital elevation model (DEM) of the Shuttle Radar Topography Mission (SRTM) was used at a spatial resolution of 90 m (Jarvis et al., 2008). After calculating slopes in ESRI ARC GIS®, pixels with slope values lower than 2° were extracted. Subsequently, wetland depressions were discriminated from upland flats according to their altitude. For the Kenyan site (Rumuruti), the delineation of the Ewaso Narok swamp was improved using high resolution satellite image composites provided on Google Earth®. In this case, the greenness of vegetation was considered as an indicator of seasonal and permanent flooding. For the Tanzanian site (Ifakara), we masked manually the urban areas within the Kilombero floodplain using Rapid Eye® imagery (acquisition date 8/10/2013, 5 m spatial resolution).

Delineated wetlands were overlain with a grid of squares of 250 m by 250 m (henceforth called "tiles"). This dimension was determined in previous field tests to represent a suitable size for mapping and sampling activities. A random sample of wetland tiles was selected, representing about 2% of the total wetland surface area at each site. A subsequent refinement of selected tiles reduced the investigated area to approximately 1% of the total wetland surface, representing 52 tiles. This step was done on-site and was based on accessibility, security issues, knowledge of local residents, and representative coverage of wetland diversity regarding land uses and vegetation cover.

In each sampled tile, polygons representing units of homogeneous and predominant land use type and vegetation cover were mapped. These polygons are henceforth called "assessment units", whereby between one and four such units could occur within one single tile. For tiles situated at the borders of the wetland, only assessment units within the wetland were considered. In total, 114 assessment units were mapped, with 37 occurring in Kampala, 28 in Kigali, 28 in Ifakara, and 21 in Rumuruti. The total covered area was 2.2 km^2 with 0.52 km^2 in Kampala, 0.74 km^2 in Kigali, 0.62 km^2 in Ifakara, and 0.32 km^2 in Rumuruti.

2.3. Data and sample collection

Data and sample collection was carried out by a multidisciplinary team, combining a series of techniques to gather information on biophysical attributes, vegetation characteristics, and human activities. Data were collected through a Rapid Appraisal approach (Wilkins et al., 2004) to capture large quantities of data within a short period of time. All collected data and samples were related to a specific georeferenced assessment unit.

Based on expert estimations and information collected during interviews, we classified each assessment unit according to the predominant current land use and the respective flooding regime. Four major land use types were assigned: cropland (units currently under cultivation), grazing land (units used for frequent feeding of ruminants), fallow (croplands that had not been cultivated for a period of at least three months), and natural vegetation (mainly semi-aquatic vegetation representing long-term regeneration stages of the natural vegetation). This classification corresponds to the one suggested by Alvarez et al. (2012) for wetland ecosystems of Kenya and Tanzania. Other types of uses, such as mining and settlements, were less important in frequency and extent, and therefore discarded from the analysis. Nevertheless, these types of land use are of qualitative importance for some of the study sites. For characterizing flooding regimes, four classes were defined: permanently flooded, seasonally flooded (>1 month but <1 year), sporadically flooded (few consecutive days) and non-flooded (though seasonally saturated).

Additionally, a set of variables on biophysical features, agricultural production and household socioeconomic attributes was collected using interviews and expert assessments (Table 1). The interview respondents were drawn from households that currently use or had been using the assessment unit in the year preceding the assessment. Agronomic variables included soil tillage, land use intensity, input uses (fertilizers and pesticides), grazing intensity and the degree of agricultural commercialization (subsistence compared with production for markets). Socioeconomic variables on wetland users included household size, household welfare, the number of ecosystem services derived from the wetland, and land tenure. In addition, expert assessments defined artificial drainage intensity and vegetation attributes. Drainage intensity was assessed based on the presence and abundance of drainage infrastructure, the depth of drainage channels, the slope, and the soil texture within each assessment unit (Macfarlane et al., 2009). Properties of standing vegetation were estimated regarding total percentage cover (excluding agricultural crops), proportion of annual plant species, and vegetation structure according to the occurrence of different layers (i.e. grasses, herbs, shrubs or trees) (Dengler et al., 2008; Mueller-Dombois and Ellenberg, 1974).

2.4. Assessment of wetland disturbance

The level of anthropogenic disturbance in all assessment units was estimated following a modified WET-health approach, observing the degree of deviation from the natural reference state in the four modules hydrology, geomorphology, vegetation, and water quality. While the original WET-health approach differentiates assessment units by geomorphic settings, water sources and patterns of water flow (Kotze et al., 2012), our study used land use types and vegetation cover as differentiating criteria. In addition, the assessments were not applied to whole wetlands but to assessment units within randomly selected tiles. Finally, we restricted the hydrological assessment to "on-site scores" based on direct observations in the wetland, while the original WET-health approach also considers "off-site scores", which are not directly associated with land use changes and would reduce differences between units within localities.

Impact scores ranging from 0 (no deviation from natural conditions) to 10 (complete transformation and total loss of wetland properties) were assigned to each assessment unit according to the rapid assessment scheme suggested for each of the four WET-health modules (Appendix A). This scheme is based on the assignment of disturbance types and its rationale is available in Appendix B. The scores for each disturbance type were subsequently validated and revised based on field observations. Such adjustments were in some cases required, as the classification was made for currently existing land uses, but neglecting former land use types and intensities. Thus, an assessment unit classified as cropland may have been assigned a hydrology impact score of 7 based on drainage intensity and the type of crops grown (Appendix A). This score was subsequently reduced when the drainage infrastructure was ill-maintained or abandoned, and it was increased when the land had been used in the past for mining (excavation of soil subsequently refilling) which considerably alters hydrological conditions. Furthermore, adjustments of water quality impact scores were carried out, if grazing occurred in the assessment units, depending on the type and number of animals. Impact scores for all modules were increased if roads were crossing assessment units according to the impact scores suggested for infrastructure (Appendix A).

Table 1
Description of variables collected through rapid appraisal in each assessment unit, sorted by source of information.

Variables by source of information	Type	Description
Expert judgements		
Vegetation cover	Continuous	Estimated cover of vegetation in percentage, excluding crops
Share of annual plants	Continuous	Proportion of annual species in the vegetation cover
Vegetation structure	Discrete	Complexity of vegetation according to observed layers
Drainage intensity	Categorical	Intensity of drainage
Interview schedules		
Land use intensity	Categorical	Estimated intensity of land use
Soil tillage	Categorical	Degree of disturbance by land preparation
Input use	Discrete	Number of applications of agrochemicals
Presence of grazing	Binary	Presence of ruminants
Household size	Discrete	Average number members per household
Household welfare	Continuous	Welfare index capturing household endowments
Land tenure	Categorical	Security of tenure based on land tenure systems
Commercialization	Binary	Subsistence or market orientation of production
Ecosystem services	Discrete	Number of services provided by the assessment unit (provisioning, supporting, regulating, cultural)

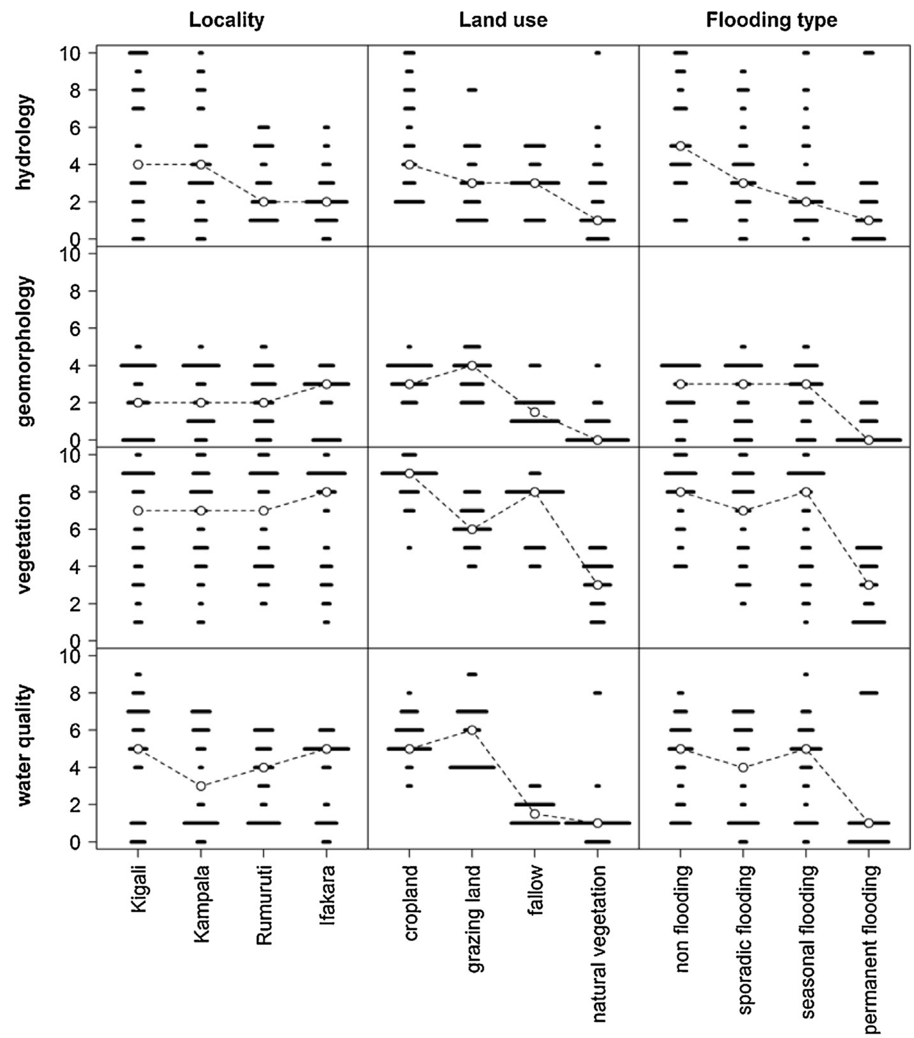

Fig. 2. Tendencies of WET-health impact scores observed in the sampling localities, land use types, and flooding regimes according to the four modules. Width of segments corresponds to the relative frequency of each score value. Circles connected by dashed lines indicate the median for each group of observation.

2.5. Data analyses

Tendencies in WET-health impact scores are presented by the median, while the concentration index is used to express distribution of impact scores among localities, land uses and flooding regimes. Such parameters are considered more adequate for categorical values than mean and standard deviation (Alvarez et al., 2013).

In order to test the effects of locality, land use, and flooding regime on the WET-health scores, we applied a generalized linear mixed model (GLMM) for repeated measures (Bates et al., 2015; Bolker et al., 2008). In the model the locality was considered as a random effect. While all previously mentioned classifications were set as between-subjects effects, the four WET-health modules were included as within-subjects effects. Herewith the subjects are the single assessment units. Significance of effects was tested by using the Satterthwaite's approximation (see documentation of package "lmerTest" in R). To determine correlations between WET-health impact scores and further variables collected in the field (Table 1), we calculated the gamma rank correlation coefficient using a permutation analysis with 1000 repetitions (Bodenhofer and Klawonn, 2008).

All statistical analyses were carried out in R (https://cran.r-project.org), including the packages "lme4" and "lmerTest" for fitting the GLMM, and the package "rococo" for calculating correlation coefficients and their significance.

3. Results

The wetland assessment units in the study showed a wide range of land uses and flooding regimes. At all localities, largely undisturbed units occurred side by side with seasonally cropped or grazed units, drained and permanently cultivated units, and occasional units within which the wetland had been destroyed by mining or settlement activities. WET-health impact scores were determined using the modified approach for 114 wetland assessment units. Additionally, biophysical and socioeconomic variables were assessed for the same units.

3.1. Diversity of anthropogenic disturbances – WET-health impact scores

The distribution of WET-health impact scores among different localities, land use types, and flooding regimes is shown in Fig. 2, while medians and concentration indices are listed in Table 2. Medians of WET-health scores varied from 0 (geomorphology module in natural vegetation and permanent flooding) to 9 (vegetation

Table 2
Descriptive statistics for the WET-health impact scores in three classifications of assessment units (locality, land use, and flooding regime) according to the four modules. The tendency was calculated by the median and the distribution of scores by the concentration index (value in parenthesis).

	WET-health impact scores			
	Hydrology	Geomorphology	Vegetation	Water quality
Locality				
Kigali	4 (0.32)	2 (0.49)	7 (0.37)	5 (0.43)
Kampala	4 (0.47)	2 (0.48)	7 (0.41)	3 (0.34)
Rumuruti	2 (0.53)	2 (0.53)	7 (0.34)	4 (0.47)
Ifakara	2 (0.67)	3 (0.66)	8 (0.47)	5 (0.64)
Land use				
Cropland	4 (0.41)	3 (0.68)	9 (0.77)	5 (0.68)
Grazing land	3 (0.51)	4 (0.65)	6 (0.65)	6 (0.48)
Fallow	3 (0.68)	2 (0.63)	8 (0.72)	2 (0.64)
Natural vegetation	1 (0.60)	0 (0.80)	3 (0.59)	1 (0.81)
Flooding regime				
Non-flooding	5 (0.45)	3 (0.52)	8 (0.56)	5 (0.50)
Sporadic flooding	3 (0.51)	3 (0.49)	7 (0.43)	4 (0.35)
Seasonal flooding	2 (0.59)	3 (0.60)	8 (0.42)	5 (0.54)
Permanent flooding	1 (0.56)	0 (0.81)	3 (0.49)	1 (0.65)

module in croplands), representing non-disturbed to highly disturbed units (Table 2). In general, median values of impact scores were highest for vegetation and lowest for geomorphology. The distribution of impact scores among localities was characterized by relatively low values of the concentration index, indicating a generally large diversity of wetland disturbance situations in each study site. However, for the hydrology module medians were slightly higher for Kigali and Kampala than for Rumuruti and Ifakara.

The median values of impact scores among land use types were relatively low and uniform for geomorphology and hydrology, while strong contrasts were observed for vegetation and water quality (Table 2). Especially for the water quality module, there was a strong contrast between the pairs "cropland-grazing land" with higher scores and "fallow-natural vegetation" with lower scores. Considering the distribution patterns of impact scores among localities (Fig. 2), the effect of land use on the hydrology module was lower than on the other three modules. Especially, the class "cropland" showed no distinct trend and was highly variable as indicated by a low concentration index (Table 2). Nevertheless, for all modules a general reduction of scores is shown for land uses from croplands to natural vegetation units (Fig. 2). For the flooding regime, a general reduction of WET-health impact scores from non-flooded to permanent flooded units was observed, most distinctly in the hydrology module.

According to the GLMM, *P*-values were significant for all random and fixed effects (locality, WET-health modules, land use type, and flooding regime) (Table 3). This highlights the influence of locality, land use, and flooding regime on WET-health impact scores. Flooding regime resulted in a lower but still significant *P*-value. Impact scores were also significantly different among modules of the WET-health assessment.

Table 3
Output table from the generalized linear mixed models (GLMM).

Random effects		Chi square	*P*-value
Locality		18.98	0.00*
Fixed effects	**Mean square**	**F-value**	**P-value**
WET-health module	353.76	135.15	0.000*
Land use	1146.33	437.94	0.000*
Flooding regime	12.57	4.8	0.029*
Least square means (modules)	**Estimate**	**t-Value**	**P-value**
Hydrology	3.57	13.01	0.000*
Geomorphology	2.29	8.33	0.000*
Vegetation	6.48	23.57	0.000*
Water quality	3.78	13.75	0.000*

* Significant effects ($P < 0.05$).

Table 4
Correlations between collected variables and impact scores of the four WET-health modules. Values correspond to the gamma rank correlation coefficient. Values and significance were calculated after a permutation with 1000 repetitions.

Variables	WET-health modules			
	Hydrology	Geomorphology	Vegetation	Water quality
Vegetation cover	−0.34*	−0.40*	−0.61*	−0.44*
Share of annual plants	0.35*	0.49*	0.74*	0.48*
Vegetation structure	−0.27*	−0.58*	−0.58*	−0.54*
Drainage intensity	0.91*	0.45*	0.39*	0.46*
Land use intensity	0.50*	0.59*	0.78*	0.60*
Soil tillage	0.39*	0.64*	0.68*	0.65*
Input use	0.52*	0.64*	0.62*	0.57*
Presence of grazing	−0.25	0.17	0.02	0.13
Household size	−0.16	−0.06	−0.09	−0.07
Household welfare	0.14	0.12	0.02	0.01
Land tenure	0.01	0.06	0.02	0.00
Commercialization	0.66*	0.75*	0.77*	0.69*
Ecosystem services	−0.48*	−0.69*	−0.71*	−0.76*

* Significant values ($P < 0.05$).

3.2. Biophysical and socioeconomic variables in relation to WET-health impact scores

Most of the correlation coefficients calculated between biophysical and socioeconomic variables and the WET-health impact scores were significantly different from 0 (Table 4). The highest positive correlation coefficients were observed between drainage intensity and the impact scores of the hydrology module (0.91) and between impact scores of the vegetation module compared with land use intensity (0.78) and the degree of agricultural commercialization (0.77). The strongest negative correlations were observed for ecosystem services compared with the impact scores of the water quality (−0.76), vegetation (−0.71), and geomorphology (−0.69) modules. WET-health impact scores of all four modules showed significant correlations with the degree of agricultural commercialization, the provision of ecosystem services, crop and land management strategies (drainage intensity, land use intensity, soil tillage, and crop input uses), and vegetation attributes (vegetation cover, share of annual plants, and vegetation structure). The variables presence of grazing, household size, household welfare, and land tenure were not significantly correlated with any of the WET-health modules.

4. Discussion

4.1. Impacts of wetland disturbances and their relation to biophysical and socioeconomic variables

Anthropogenic disturbances are clearly reflected in WET-health impact scores. Among all assessment modules the impact scores were highest for vegetation, highlighting the sensitivity of vegetation to human interventions and hence the suitability of vegetation as a sensitive indicator for change (Bockstaller et al., 2008; Stapanian et al., 2013). Similar trends were observed by Kotze (2011) in wetlands of Malawi. In contrast to vegetation, the impact scores for hydrology showed a higher variability particularly for croplands, reflecting the diversity in cropping strategies. Thus, production systems in wetlands range from strict upland crops such as maize and vegetables with large hydrology impact scores to water-saturated or even irrigated lowland crops such as taro and rice, yielding relatively low hydrology impact scores.

Geomorphology scores were generally low and largely similar across locations. This low response of geomorphology to anthropogenic disturbances appears to be a specific attribute of the observed East African wetlands. Furthermore, the scale of this study (assessment unit scale) does maybe not represent the geomorphological alteration of the entire wetland site, since geomorphology impact scores deviate from previous observations from South African wetlands (Kotze et al., 2012). This may be explained by the rare occurrence of units with main disturbances altering wetland geomorphology like mining or land filling and the neglection of such units in the present study. However, more urban wetlands like e.g. the inland valleys close to Kampala show a distinct geomorphological alteration mainly due to an increasing wetland use for mining, settlements, industrial estates, and dumping sites (Schuyt, 2005). It is most likely that these wetland uses will increase depending on the respective economic development. Nevertheless, when focusing on agricultural disturbance in East African wetlands, it may be considered to further simplify WET-health by focusing on only three of the four assessment modules, namely hydrology, vegetation, and water quality.

Both, distribution patterns and GLMM, demonstrate a strong relationship between land use and anthropogenic disturbances affecting vegetation and water quality and, to a lesser extent, geomorphology and hydrology. This observed relationship is expected, as land use changes are the dominant anthropogenic disturbance type in wetlands and entail further modifications such as the removal of vegetation and establishment of drainage infrastructure. Thus, impact scores are inferred primarily based on land use rather than being independent measures of biotic responses to stressors (Appendices A and B). Vegetation, as highlighted before, responds most strongly to altered land uses and is likely to affect the provision of ecosystem services (Isbell et al., 2011). Vegetation impact scores in agricultural used areas show consistently high values due to complete alteration of natural vegetation in croplands and, to a lesser extent, vegetation removal by animals in grazing land. On the other hand, the high impact scores associated with grazing in the present study are not solely related to grazing intensity. Many abandoned but formerly cropped and in some instances mined wetland areas are used as grazing land during the dry season and hence reflect a combined effect of former land use and current grazing regimes.

Compared to vegetation and water quality, hydrology impact scores showed only weak relationships to classes of land use. Drainage intensity is mainly determining the hydrology impact scores and it can be high or low in each land use class, depending on the seasonality of cropping and the crop type. Cropped, non-flooded assessment units tend to have high drainage intensities, leading to high hydrological impact scores. On the other hand, lowland rice fields tend to be permanently flooded and the presence of drainage channels is compensated by concomitant irrigation infrastructure leading to low impact scores. In terms of locality, hydrology impact scores tend to be higher for inland valley wetlands in Kampala and Kigali than for floodplain wetlands in Ifakara and Rumuruti. This does not infer that inland valley wetlands are more vulnerable to anthropogenic interventions than floodplains (Kamiri et al., 2013). Inland valleys in our sample tend to be generally more intensively used than the seasonally cropped or grazed floodplains (Rodenburg et al., 2013) and are often characterized by traditional open drainage systems (Kannan, 2007) that are responsible for assigning high impact scores. On the other hand, the highland floodplain in Kenya has nearly a century-long history of hydrological modifications for water provision to livestock and small-scale agricultural crop uses of small holder farmers (Thenya, 2001). The un-impacted reference (score of 0) may thus represent a disturbed or secondary recovery stage that results in low to moderate impact scores for Rumuruti. Also, low hydrological impact scores in floodplain wetlands (Ifakara, Rumuruti, and parts of Kigali) are associated with their sheer size and the impossibility to regulate water flows. Finally, low hydrology impact scores contrasted with very high vegetation impact scores. These are related to the high sensitivity of the grassy floodplain vegetation to diverse farming interventions, like wet season rice and dry season maize or cassava in Ifakara (Mombo et al., 2011). Such kind of differences in use may explain the significant effect of localities on WET-health scores as obtained by GLMM.

Since land use intensity and the degree of agricultural commercialization have a high correlation coefficient with the impact scores for the vegetation module, cropping activities may implicate a strong impact on the status of wetland vegetation. Effects of cropping activities are not only expressed in changes of vegetation cover and structure, which are negatively correlated with impact scores, but also in a shift toward higher shares of annual plant species (Galatowitsch et al., 2000). Negative correlations of all impact scores with the provision of ecosystem services are associated with negative effects in the human impact (lower impact scores mean higher provision of ecosystem services by the wetland units). Such findings agree largely with results of previous studies in East African wetlands (Alvarez et al., 2012; Kamiri et al., 2013; Sakané et al., 2011).

4.2. Applicability and transferability of the modified WET-health approach to East African wetlands

The assessment of WET-health based on the suggested scheme (Appendix A) is applicable for East African wetlands. However, former land uses need to be considered as well as their impacts, which are sometimes still recognizable after long times. Furthermore, an assessment based on biophysical and socioeconomic variables could complement or even replace the assessment based on that scheme. Nine out of 13 collected variables seem to be suitable for those purposes regarding their significant correlations to the WET-health impact scores. Three of them (vegetation cover, vegetation structure, and ecosystem services) are indicative of good conditions of the assessment units (higher values mean lower impact of human activities). The other six variables (share of annual plants, drainage intensity, land use intensity, soil tillage, input use, and degree of agricultural commercialization) are direct indicators of impact, analogous to the WET-health impact scores.

Though hydrological off-site factors were not considered in this study, they may alter water inputs to the assessment units (Kotze et al., 2012). For instance, adjacent slopes in inland valleys and wider catchments in floodplains are typical external systems influencing the internal conditions such as flooding regimes and other stressors of wetland health (Macfarlane et al., 2009). These off-site factors should also be considered in terms of water quality, as hydrological connectivity outside the assessment units or even outside the wetland boundaries can influence the amounts of nutrient and sediment inputs. The assessment of the water quality module in WET-health is very difficult in the context of a rapid appraisal due to the low accessibility to data required for the estimation of a reference state. Furthermore, some indicators of water quality (e.g. electrical conductivity, nitrate content) can be derived from anthropogenic impacts as well as from water-rock interactions (geogenic background). This geogenic background is highly variable depending on the respective geological setting and thus impedes the definition of a reference state. Therefore a further implementation of this module may consider an intensive data collection a priori to define proper reference conditions and impact scores.

In contrast to South African wetlands, dams and ponds play a tangential role in East African wetlands and could thus be removed from the suggested scheme (Appendix A). Nevertheless, it needs to be mentioned that quantifying wetland status always entails inherent challenges, because the concept of ecological health is a qualitative construct, which is then expressed in quantitative terms by the practice of ecological integrity assessments (Deberry, 2015). Therefore WET-health should be considered rather as a semi-quantitative method designed to make a normative description of the ecological status of a wetland, which may potentially be used as input to a stakeholder process, e.g. as part of an environmental impact assessment. WET-health provides a systematic process of representing plausible ranges of impacts, and includes simple deterministic models, but, as is the case for Brinson and Rheinhardt (1996), these models are used in deriving indices representing deviation from a reference state rather than being simulation models in the strict sense.

5. Conclusions

The rapid assessment approach combining a random selection of assessment units and a modified determination of WET-health impact scores could successfully describe the degree of disturbance of wetlands in East Africa. While wetlands under permanent flooding and with natural vegetation received lowest impact scores, agricultural uses entailing large-scale drainage yielded highest disturbance scores. Some biophysical and socioeconomic attributes of wetland uses were strongly related to impact scores. Management factors (land use intensity, soil tillage, drainage intensity, and input use) as well as the degree of agricultural commercialization are key factors determining the magnitude of anthropogenic wetland disturbance that is highly associated with land use. Vegetation and water quality responded most sensitively to land use changes.

WET-health is an approach allowing for a rapid comparative assessment of the "health" state of wetlands. The developed modifications enable users to assess large wetland areas during relatively short periods of time. While WET-health is a tool to help planners, stakeholders, and decision makers to understand the linkages between anthropogenic impacts and the ecological condition of a wetland, the novel approach provides only a snapshot of current wetland conditions or health states. Also the representativeness of sampling 1% of the wetland area through the proposed tile-based approach needs confirmation from a larger sample. A strong advantage of the tile-based approach lies in its systematic procedure, which helps to avoid bias based on the subjective selection of which areas to examine for spatially extensive wetlands which cannot be examined in their entirety. Nine additional variables collected by a rapid assessment in this study are suitable either to complement the WET-health approach or for cross-check purposes. While further studies will be required, WET-health appears to be a promising concept to be transferred and applied to wetlands in East Africa and possibly beyond.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2016.03.034.

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