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japhet Kashaigili

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Dynamics of Usangu plains wetlands: Use of remote sensing and GIS as management decision tools

Japhet J. Kashaigili [a,*], Boniface P. Mbilinyi [a], Matthew Mccartney [b], Fredrick L. Mwanuzi [c]

[a] *Sokoine University of Agriculture, P.O. Box 3003, Morogoro, Tanzania*
[b] *International Water Management Institute (IWMI), Pretoria, South Africa*
[c] *University of Dar es Salaam, P.O. Box 35131, Dar es Salaam, Tanzania*

Abstract

Wetlands are resources of paramount importance with many values and functions that need proper management for their continued functioning and the delivery of benefits to the community. Sustained functioning of wetlands requires proper use of land and management of water. It is commonly said that increased human activities have had negative impacts on the Usangu Plains wetlands and that these wetlands are on the verge of total collapse due to altered flows. Nevertheless, these beliefs are little supported by quantitative data. A study on the dynamics of Usangu Plains wetlands therefore investigated long-term and seasonal changes that have occurred as a result of human and developmental activities in the study area for the periods between 1973 and 1984, and between 1984 and 2000. Landsat-MSS and Landsat-TM images were used to locate and quantify the changes. The study revealed a 14% increase in area covered by vegetated swamp between 1973 and 1984, and a decline by 77% and 70% in area covered by closed and open woodlands respectively. Between 1984 and 2000, the vegetated swamp cover declined by 67%, while the closed woodland and open woodlands declined by 83% and 77% respectively. It has also been revealed that the differences in spatial resolution could impair the detection of change. The continued decline in wetland covers has the potential to cause irreversible changes in these wetlands. Remote sensing and GIS technologies have proved to be useful tools for assisting decision-makers to locate and quantify changes in land resources, and hence to identify appropriate solutions for sustainable management of wetlands.

Keywords: Land use and cover changes; Remote sensing; Usangu plains; Wetland management

1. Introduction

Wetlands comprise about three to six percent of the earth's land surface area, but they provide a host of goods and services, including water quality maintenance, agricultural production, fisheries, and recreation (Acreman and Hollis, 1996). Other services include floodwater retention, provision of wildlife habitat, and control of soil erosion (Sugumaran et al., 2004). Despite these proven advantages, conversion of wetlands to other land uses has been problematic. Due to the notion that wetlands are wastelands with no uses, wetlands have been destroyed by being drained, irrigated, and polluted. Wetlands are some of the most threatened habitats in the world (Papazoglou, 2000).

The pace, magnitude and spatial reach of human alterations of the land surface are unprecedented (Lambin and Geist, 2001). To understand recent changes and to generate scenarios predicting future modifications of the earth system, the scientific community needs quantitative, spatially explicit data on how land cover has been changed by human use over the years, and how it will be changed in

* Corresponding author. Tel.: +255 023 2601206/0744 207117; fax: +255 023 2601206.
E-mail addresses: jkashaigili@yahoo.co.uk (J.J. Kashaigili), mbly_sua@yahoo.com (B.P. Mbilinyi), m.mccartney@cgiar.org (M. Mccartney), fmwanuzi@yahoo.com (F.L. Mwanuzi).

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future. Such data on land-cover changes need to be relevant for local decision-makers (Lambin and Geist, 2001).

With rapid changes in land cover occurring over large areas, remote sensing has become an essential tool for monitoring such changes. Traditionally, wetlands are delineated using ground surveys, although such surveys are difficult and time-consuming (Yasouka et al., 1995; Lyon, 1993). The remoteness and inaccessible nature of some of the wetlands limits the feasibility of ground-based inventory and monitoring. The type, aerial extent, land cover types, and use of wetlands can be determined through remote sensing and thus enable derivation of cost-effective solution for wetland management (Goldberg, 1998; Lyon and McCarthy, 1995).

The goal of detecting change is to discern those areas on digital images that depict changing features of interest (e.g. forest clearing or changed land cover/land use) between the dates on which two or more images were captured. This paper outlines the procedures adopted for investigating the dynamics of wetlands on the Usangu Plains, and the links between factors causing change, by utilizing remote sensing and GIS. Using images from 1973, 1984 and 2000, this paper examines changes in land-use and cover in the Usangu Plains wetlands as a result of human activities.

2. Description of the study area

The Usangu Plains are located in the south-western part of Tanzania (Fig. 1). They lie between longitudes of 33°E and 35°E, and latitudes of 8°S and 9°30′S, covering an area of approximately 15,560 km^2. The plains lie at an average elevation of 1100 m above mean sea level (amsl), while the surrounding hills are 3000 m amsl. The Usangu wetlands are located at the center of the Usangu Plains. They comprise the western and eastern wetlands—joined by a narrow band of land along the Great Ruaha River at Nyaluhanga. There are also some intermediate swamps

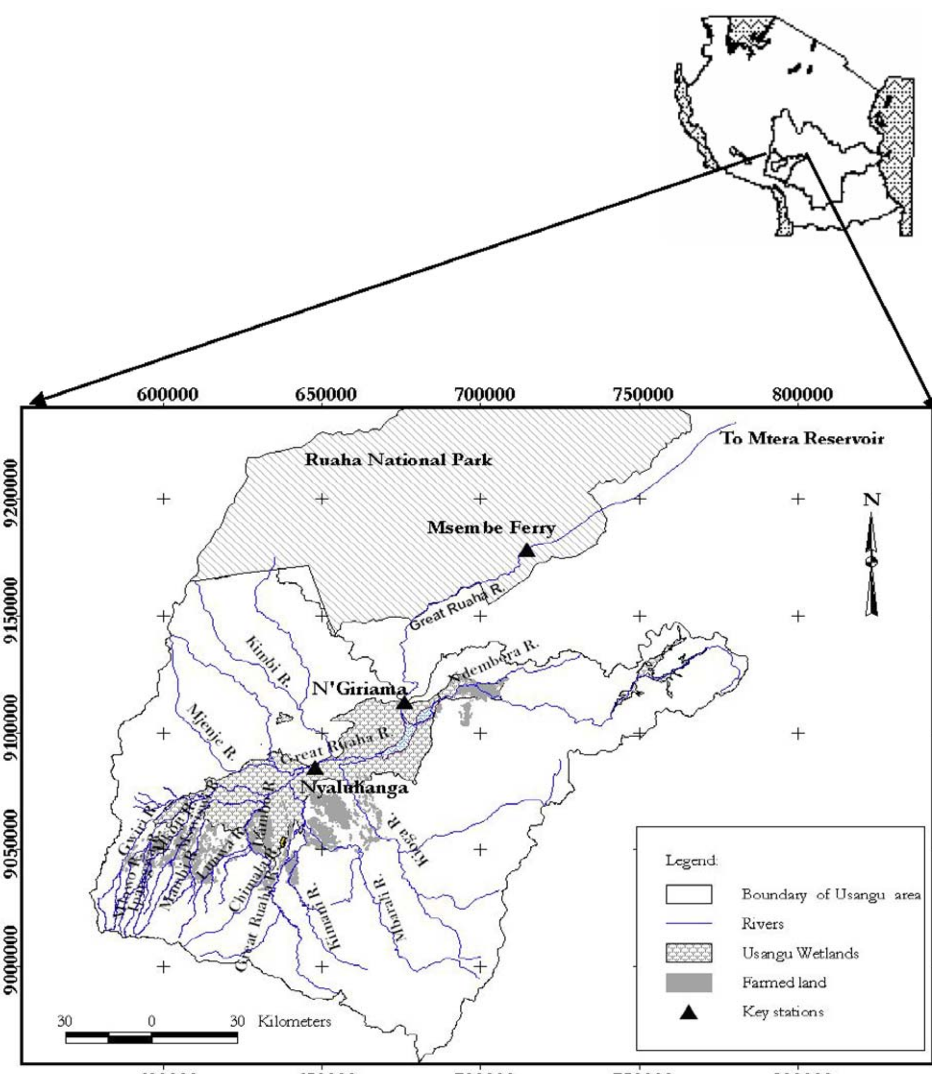

Fig. 1. Map of Tanzania showing location of the Usangu wetlands.

(i.e., the Ifushiro swamp) mostly located in the western wetland.

The major rivers (perennial) draining the Usangu Plains are the Great Ruaha, Mbarali, Kimani, Chimala and Ndembera. The first four account for 70% of average annual flow, while the Ndembera accounts for an additional 15% (SMUWC, 2001). The small rivers include Umrobo, Mkoji, Lunwa, Mlomboji, Ipatagwa, Mambi, Kioga, Mjenje, Kimbi, Itambo and Mswiswi rivers. The major water supplier to the Usangu wetlands is the Great Ruaha River (GRR), which flows as a single river after being joined by other rivers in the western wetland to supply the eastern wetland. A natural rock outcrop at N'Giriama controls the outflow from the eastern wetland. From the Usangu wetlands, the GRR flows through the Ruaha National Park (RNP), serving as the main source of water for the Park, before flowing into the Mtera hydropower reservoir.

The Usangu wetlands are one of the most valuable freshwater resources in the country, providing various services. They harbour hundreds of different types of birds and other living organisms. In the past before the gazettement of the eastern wetland to Usangu Game Reserve in 1999, it was used for fishing, initiation ceremonies, and ritual prayers. Owing to various services and benefits obtained from the Usangu plains and the wetlands there has been increased immigration of people from different regions in the country, namely Mwanza, Shinyanga and Tabora and other neighbouring regions. Most of these people were pastoralists, farmers and business people. As the number of immigrants increased, the Usangu wetlands have been put under pressure from competing uses and vast areas continue to be converted to cultivation and grazing.

The increased competitions for water and utilization of the wetlands have threatened the existence of the wetlands and it is believed that the Usangu wetlands are in danger of depletion. While that has been said no study has been conducted to quantify the changes. This paper therefore examines the changes in land-use and cover in the Usangu Plains wetlands and their implications.

3. Materials and methods

This study investigated the dynamics of the Usangu Plains wetlands through the analysis of changes in land use and cover that occurred between 1973 and 1984, and between 1984 and 2000, using remotely sensed images and GIS. These periods depict the different levels of human and developmental interventions in the region. Table 1 presents the satellite imagery input data used for the study.

The methods for the images analysis combined both visual and digital image processing. Before image processing began, field observations were made to establish accurate locational point data for each land-use and land-cover class included in the classification. A base map and colour composite image from the 7th September 2000 image was used for ground-truthing, which was done at the peak of the dry season. With the aid of Global Positioning System (GPS) equipment, maps and key informants, the various land uses and covers were located in the field and their positions recorded. During the ground-truthing, the following major land-cover classes were identified: closed woodland, open woodland, vegetated swamp, closed bushland, open bushland, bushed grassland, open bushland, cultivated land and bare land.

Table 1
Landsat images used in the analysis of land-cover change

Image	Path/row	Date of acquisition	Season	Cloud cover (%)
Landsat MSS[a]	181/66	4th September 1973	Dry	0
Landsat TM[b]	169/66	15th June 1984	Wet	11
Landsat TM	169/66	3rd September 1984	Dry	0
Landsat ETM+	169/66	26th May 2000	Wet	8
Landsat ETM+	169/66	7th September 2000	Dry	10

ETM+ = enhanced thematic mapper plus.
[a] MSS = multi-spectral scanner.
[b] TM = thematic mapper.

3.1. Image pre-processing and classification

Images were geometrically rectified and registered to the UTM map coordinate system UTM zone 36 South, Spheroid Clarke 1880, Datum Arc 1960, based on a previous georeferenced Landsat TM image of 14th August 1994. An ERDAS image processing system was used for all image data processing. The unsupervised image classification was used for all images. Twenty classes were formulated and confirmed through the use of ground-truth data and colour-composite images. Misclassified classes were interpreted visually and the results combined to respective classes. Similar classes were joined and recoded into general classes based on the Pratt and Gwynne (1977) classification system with additional modification. Ten classes for the 1973 and 1984 images and 12 classes for the 2000 images were formulated. The classes of interest included closed woodland, open woodland, closed bushland, open bushland, bushed grassland, cultivated land, bare soil sandy with cultivation, bare soil vertisal with cultivation, vegetated swamp, Kapunga farms and top–tail enders to Kapunga farms. However, the spectral reflectance for cultivated land, bare soil sandy with cultivation, and bare soil vertisal with cultivation, were difficult to differentiate. Hence the three classes were aggregated into one, resulting in eight classes for the 1973 and 1984 images and ten classes for the 2000 images.

3.2. Detection of change

Change detection analysis entails finding the type, extent and location of changes in land-use (Yeh et al., 1996). Various algorithms are available (Singh, 1989; Jensen, 1996; ERDAS, 1999). This study uses post-classification comparisons to assess land-use and land-cover changes. The approach identifies changes by comparing independently classified multi-date images pixel by pixel using a change-detection matrix. The matrix analysis produces a thematic layer that contains a separate class for every coincidence of classes in multi-date dataset. Although, the use of a change-detection matrix provides detailed information on the nature of changes, misclassification and misregistration may affect the accuracy of the results.

4. Results

The vegetation types that best represent change in wetland cover are vegetated swamp, closed woodland and open woodland. Table 2 presents the proportion of the total area under different land cover types in 1973, 1984, and 2000, while Figs. 2 and 3 are the land use/cover change maps.

Table 2
Proportion of the area (%) under different land cover types in 1973, 1984, and 2000

Land cover type	1973	1984	2000
Vegetated swamp	5.0	8.5	3.0
Closed woodland	10.5	7.5	6.0
Open woodland	43.0	24.0	21.0
Other covers	41.5	60.0	70.0

The total area of vegetated swamp which occupied 15,455 ha (5% of the total geographical study area of 316,979 ha) in 1973, increased to 26,928 ha (8.5%) in 1984, indicating an increase in vegetated swamp area of about 3.5%, while in 2000, the area covered by vegetated swamp decreased to 8778 ha (3% of the total study area) signifying a 67% reduction in vegetated swamp area between 1984 and 2000. In other words, the area covered by vegetated swamp, about 8.5% of the total study area in 1984, declined at a rate of 4.2% annually, assuming a linear decline.

While vegetated swamp cover increased in area between 1973 and 1984, and decreased tremendously in 2000, both closed and open woodland areas registered a decline in areal extent. Closed woodland declined from 10.5% of total areal cover in 1973 to 7.5% in 1984 and 6% in 2000 and open woodland declined from 43% in 1973 to 24% in 1984 and 21% in 2000, Other covers ('others') increased in areal extent from 41.5% in 1973 to 60% in 1984 and 70% in 2000.

Table 3 summarises change in cover of vegetated swamp, closed woodland and open woodland for the periods 1973–1984 and 1984–2000 in the dry season, and for

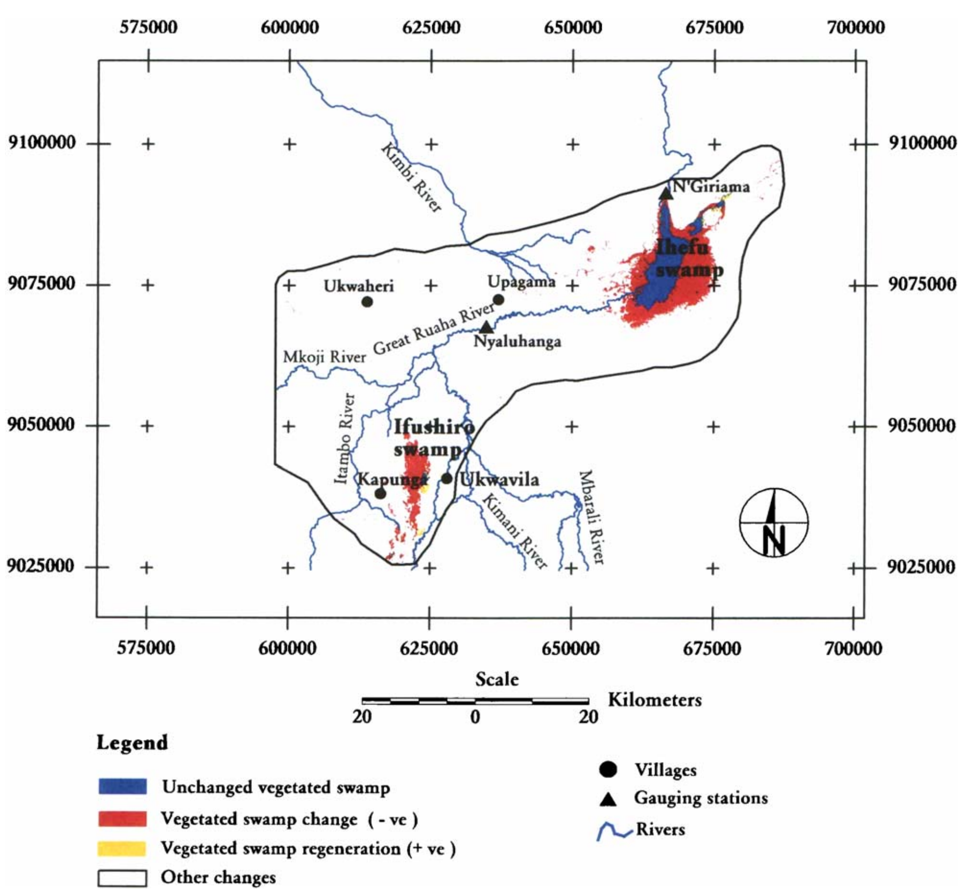

Fig. 2. Land use/cover change map for selected covers from 1984 to 2000 in the dry season for vegetated perennial swamp.

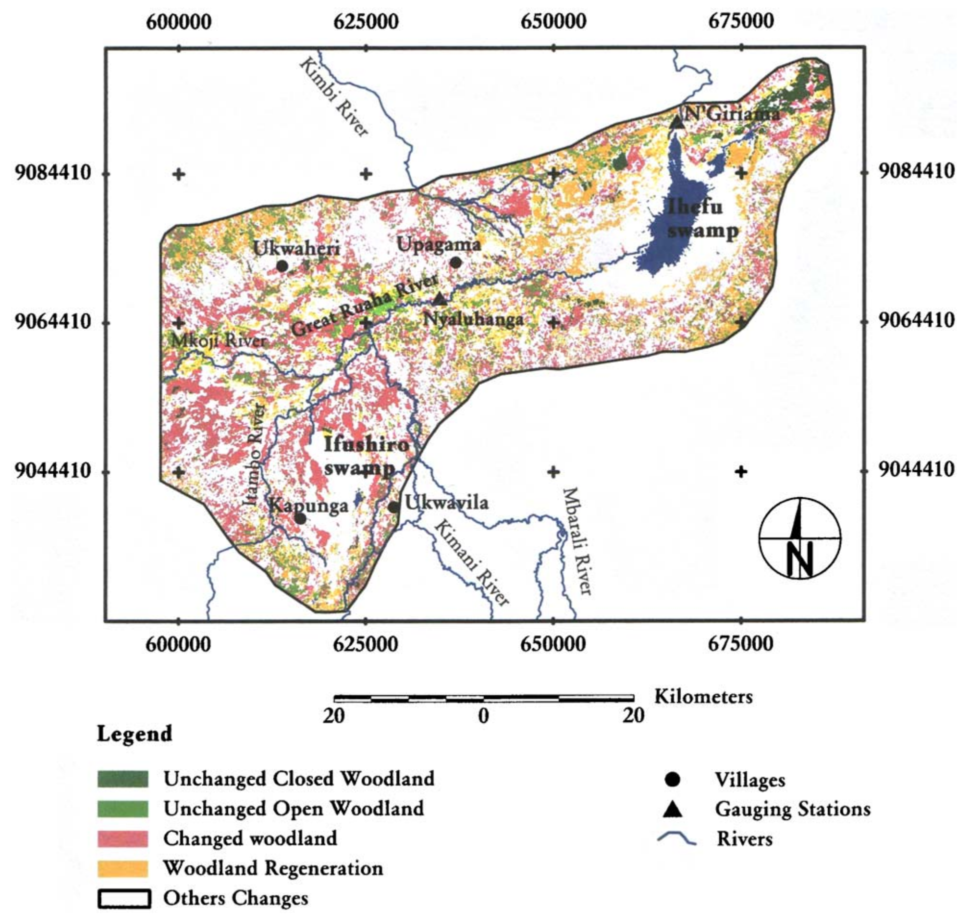

Fig. 3. Land use/cover change map for selected covers from 1984 to 2000 in the dry season for woodland.

the period 1984–2000 in the wet season. The percentage changed indicates the percentage area of a particular cover which changed to other covers while the percentage unchanged represents the percentage area of the original area of a particular cover which remained unchanged for a given period.

Table 3
Changes in percentage cover of vegetated swamp, closed woodland and open woodland over the study period

	% Cover unchanged	% Cover changed
Dry season		
VS cover for 1973–1984	86	14
CW cover for 1973–1984	23	77
OW cover for 1973–1984	30	70
Dry season		
VS cover for 1984–2000	33	67
CW cover for 1984–2000	17	83
OW cover for 1984–2000	23	77
Wet season		
VS cover for 1984–2000	58	42
CW cover for 1984–2000	6	94
OW cover for 1984–2000	27	73

VS = vegetated swamp, CW = closed woodland and OW = open woodland.

Considering the dry season, the coverage by vegetated swamp increased by 14% from 1973 to 1984, while closed woodland decreased to 23% and open woodland to 30% of the original extent. Between 1984 and 2000, 33% of vegetated swamp coverage remained unchanged, likewise 17% and 23% for closed and open woodland respectively. This implies that almost all the selected covers have undergone a significant change in that period. The wet season indicated different land cover dynamics from those seen in the dry season. For instance, the vegetated swamp coverage showed a 42% decline from 1984 to 2000 with 58% remaining unchanged. The differences between wet and dry season changes are mainly attributable to different plant phenological effects as a result of variations in moisture content. During wet season, most areas become wet and green and spectral separability become difficult. Therefore there is a possibility of overestimation of cover coverage during wet season unlike the dry seasons.

Tables 4–6 present the change detection matrices while Table 7 presents the detected changes in various covers for both dry and wet seasons for the periods 1973–1984, and 1984–2000 deduced from the change detection matrices (Tables 4–6).

The arrow in each row indicates a conversion "*from* ... *to*". Considering the dry season for the period 1973–1984,

Table 4
Change detection matrix for the period 1973–1984 during the dry season

Cover 1973 (ha)	Cover in 1984 (ha) dry season								
	CW	OW	CB	OB	BG	OG	CL + BS	VS	Total
CW	7563	4226	10,583	2635	530	2992	1966	2669	33,164
OW	8543	40,469	48,050	13,320	10,378	1455	13,366	1311	136,893
CB	3378	16,732	23,367	4696	3856	729	3951	430	57,139
OB	1443	7749	9928	2319	1128	508	1183	468	24,726
BG	1978	5167	5947	1281	663	210	724	129	16,099
OG	674	1200	5460	2605	92	2545	206	8606	21,388
CL + BS	0	0	685	519	443	7	10,450	12	12,116
VS	39	81	349	110	327	1236	8	13,303	15,455
Total	23,618	75,624	104,370	27,484	17,417	9683	31,855	26,928	316,979

CW = closed woodland; OW = open woodland; CB = closed bushland; OB = open bushland; BG = bushed grassland; OG = open grassland, CL + BS = cultivation plus bare surface; VS = vegetated swamp.

Table 5
Change detection matrix for the period 1984–2000 during the dry season

Cover 1984 (ha)	Cover 2000 (ha) dry season										
	CW	OW	CB	OB	BG	OG	CL+BS	VS	KRF	TTC	Total
CW	4080	5306	3031	2256	1164	1579	4446	151	1285	320	23,618
OW	3772	17,684	12,818	11,494	4613	3420	21,018	48	329	428	75,624
CB	6256	33,426	18,474	14,053	4728	10,538	14,683	221	1475	517	104,370
OB	1861	6713	6340	3909	1817	2264	4218	25	134	202	27,484
BG	571	2432	5371	663	1759	395	6103	28	31	63	17,417
OG	1252	1394	632	667	163	3610	354	280	1331	2	9683
CL + BS	0	0	5029	608	2399	836	22,953	4	10	16	31,854
VS	0	0	1093	1112	195	15,839	150	8020	518	1	26,928
Total	17,792	66,954	52,788	34,762	16,838	38,482	73,924	8778	5113	1549	316,979

CW = closed woodland; OW = open woodland; CB = closed bushland; OB = open bushland; BG = bushed grassland; OG = open grassland, CL + BS = cultivation plus bare surface; VS = vegetated swamp; KRF = Kapunga rice farms; TTC = tail & top end cultivation.

Table 6
Change detection matrix for the period 1984–2000 during the wet season

Cover 1984 (ha)	Cover 2000 (ha) wet season										
	CW	OW	CB	OB	BG	OG	CL + BS	VS	KRF	TTC	Total
CW	1590	5395	1710	1939	2870	2511	3843	3324	1280	365	24,826
OW	6139	21,643	7130	7976	9568	5387	19,635	1843	332	515	80,170
CB	9760	32,872	13,985	11,070	15,289	6457	23,506	2223	504	756	116,423
OB	840	5176	910	470	1134	882	1215	418	249	118	11,413
BG	839	3081	1047	1455	1297	920	1628	471	1	0	10,739
OG	622	773	358	17	687	261	414	85	0	0	3217
CL + BS	0	0	224	177	651	735	7437	11	0	2	9237
VS	2545	7033	1496	1205	2268	6188	1804	35,591	2783	39	60,954
Total	22,335	75,974	26,859	24,310	33,764	23,342	59,483	43,966	5150	1795	316,979

CW = closed woodland; OW = open woodland; CB = closed bushland; OB = open bushland; BG = bushed grassland; OG = open grassland, CL + BS = cultivation plus bare surface; VS = vegetated swamp; KRF = Kapunga rice farms; TTC = tail and top end cultivation.

39 ha (0.2%) of vegetated swamp were converted to closed woodland while 81 ha (1%) were converted to open woodland. There is a significant change from closed woodland (50% between 1973 and 1984, 34% between 1984 and 2000 in the dry season and 36% between 1984 and 2000 in the wet season) to closed bushland, open bushland, bushed grassland and/or open grassland. The same has been detected for vegetated swamp: a change of 13% between 1973 and 1984, of 68% between 1984 and 2000 in the dry season and of 18% in the wet season to closed bushland, open bushland, bushed grassland and/or open grassland. These data imply encroachment by other non-woodland or non-wetland species. Between 1984 and 2000, 519 ha of an intermediate swamp were converted to

Table 7
Detected changes in percentage cover of vegetated swamp (VS), open woodland (OW) and closed woodland (CW) in both dry and wet seasons for the study subset area

Change (from–to)	1973–1984 Dry season		1984–2000 Dry season		1984–2000 Wet season	
	Area (ha)	% of the cover	Area (ha)	% of the cover	Area (ha)	% of the cover
CW → OW	4226	13	5306	22	5395	22
CW → CB, OB, BG, OG	16,740	50	8051	34	9029	36
CW → CL + BS	1966	6	4446	19	3843	15
CW → KRF, TTC	–		1606	7	1645	7
OW → CB, OB, BG, OG	73,204	53	32,416	43	30,062	37
OW → CL + BS	13,366	10	21,018	28	19,635	24
OW → KRF, TTC	–		757	1	847	1
VS → CW	39	0.2	0	0	2545	4
VS → OW	81	1	0	0	7033	12
VS → CB, OB, BG, OG	2023	13	18,241	68	11,158	18
VS → CL + BS	8	0.1	150	1	1804	3
VS → KRF, TTC	–		519	2	2823	5

Kapunga rice farm (KRF) and top–tail–enders (TTC). Likewise on the same period 1606 ha of closed woodland and 757 ha of open woodland were converted.

5. Discussion

5.1. Variations on detected changes and interpretations

In this study, some variations on the detected changes have been noted. For instance, an increase in cover of vegetated swamp for the period between 1973 and 1984 has been detected which contravene the detected decline in area coverage after 1984. Nevertheless, it is highly acknowledged that ecosystems dynamics response is non-linear and depends on many drivers/factors but most arguably the variation in rainfall pattern and distribution. A linear trend analysis on annual rainfall data in the Usangu plains for the period 1973 to 1984 revealed that there was not statistically significant increase in rainfall amount between 1973 and 1984 at the 95% confidence level. Likewise, no significant change on temporal distribution of rainfall was revealed (Kashaigili et al., 2006). Therefore, it is unlikely that the apparent increase in vegetated swamp area between 1973 and 1984 can be attributed to an increase in rainfall. It is possible that the change variations were due to plant phenological effects and spectral resolutions.

The different plant phenological effects are related to the season to which an image is acquired on the ground by the satellite. Studies have shown that the dry period is the most desirable period for image change analysis. As noted by Burns and Joyce (1981), selecting the driest period of the year for change analysis will enhance spectral separability and yet minimize spectral similarity due to excessive wetness prevailing during other periods of the year. The wet season spectral separability, which is responsible for class assignment, becomes somewhat difficult and may result into misclassification of some of the classes, which results into under- or over-classification. But this is unlikely to be a source of variation as images used for this study were obtained in the dry season (Table 1) though at different dates. As highlighted above, the variation could also be caused by the use of images with different spatial resolution. In this study images of different resolutions were used (i.e., Landsat MSS of 1973 had 79 m × 79 m while Landsat TM of 2000 had 30 m × 30 m) since it was very difficult to get good resolution images in 1973. A course resolution tends to lump features on the ground and reduces details. In that regard, affects the accuracy of change detection and this has also been discussed by other scholars. For example, Zhou et al. (2004a) when detecting and modelling land use change using multi-temporal and multi-sensor imagery concluded that poor classification results were found in association with lower spatial resolution, demonstrated by the higher fluctuation of area statistics results. More details on influence of spatial resolution on change detection could be found in Zhou et al. (2004b), Benson and MacKenzie (1995), and Frohn (1998). Therefore, it is possible that the apparent increase in vegetated swamp cover area between 1973 and 1984 is an artefact of the different resolutions of the two images.

5.2. Anthropogenic activities—detected changes linkages and implications

There is a close link between ecosystem change and the increased anthropogenic activities. The increase in anthropogenic activities reflects an increased population (Fig. 4). The growth in population reflects on the water consumption and diversification of human socio-economic activities that require more water use. Since the available surface water resource is almost constant the abstraction for socio-economic activities results to denial of water to other down stream users such as wetlands. The Usangu plains have undergone different phases of development that could be broken into three time horizons namely; pre-1974 (natural period with less human disturbance), between 1974 and 1985 (intermediate period—some intervention and developmental activities started) and post-1985 (present

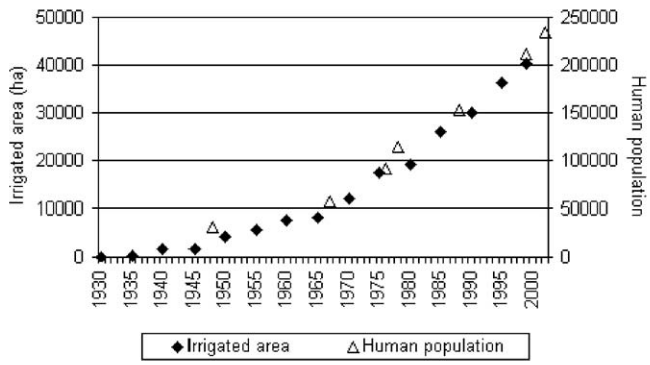

Fig. 4. Population and irrigated area dynamics in the Usangu Plains. *Sources*: Population and housing sensus website (http://www.tanzania.go.tz/census/) and SMUWC (2001).

period characterised intensive water abstraction as a result of increased population growth, increased irrigable areas, increased pastoral activities, increased catchment degradation, expanded market and increased conflict over the available resources). All these demanded for more water, which led to reduction in inflows into the wetlands especially in the dry season, leading to reduced outflow volumes (Figs. 5 and 6). The reduction in inflows had a bearing on the size of the wetland (Kashaigili et al., 2006).

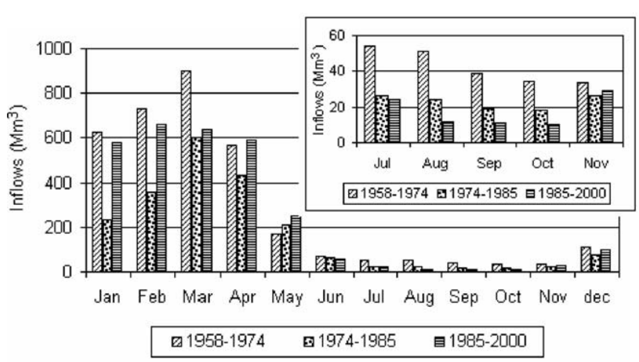

Fig. 5. Mean monthly inflows to the Eastern wetland, with the dry season magnified. *Source*: Kashaigili et al. (2006).

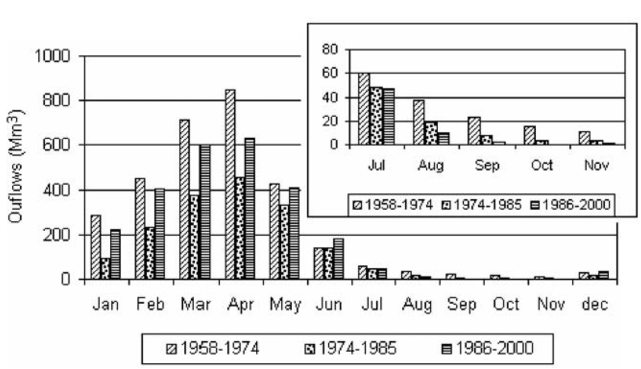

Fig. 6. Mean monthly outflow from the Eastern wetland, with the dry season magnified. *Source*: Kashaigili et al. (2006).

Land cover clearance which involved tree felling is one of the activities associated with expansions in agriculture. The results showed that, expansion of agricultural activities was associated with conversion of closed and open woodland to other forms of land cover. Interviews with farmers and ground-truthing exercise ascertained this, and most woodland and bushland areas were found cleared for agriculture. Also felling of trees for economic timber production was found to be a dominant activity in villages close to forests.

The developments that took place after the 1984 included large areas of the wetlands. This phenomenon has been confirmed by interviews with key informants around Kapunga, who also reported that the present-day Ifushiro swamp and the Kapunga areas previously supported huge forests as well as other natural vegetation. The implication is that the wetlands have to a great extent been disturbed and in consequence that the hydrological balance has been changed due to draining. It is important realizing that any draining of the wetlands will have an impact on the hydrological balance, which ultimately affects the ecological balance for the wetland. The ability of the wetlands to store water in the wet season and release it in the dry season for downstream users decreases with wetlands draining, unless done carefully. The problems of decreased dry-season flows at the exit of the Usangu wetland (Fig. 6) to Ruaha National Park might be attributable to this phenomenon. At present the wetlands are continuing to shrink in size and if the current situation prevails, it is likely that they will undergo an irreversible change.

6. Conclusions

This study investigated the dynamics of Usangu wetlands and neighbouring areas. The vegetated swamp cover which is the main component of the Usangu wetlands was found to be decreasing with time, and more changes have occurred during dry season. Comparing the two time periods (1973–1984 and 1984–2000), more changes in the cover areas occurred during the 1984–2000 period which is characterised by different human interventions including introduction of large irrigation schemes. These human interventions required more water use which resulted into reducing the amount of inflows that used to maintain the Usangu wetlands and the outflows for downstream needs. This concludes the assertion that the area of the Usangu wetlands was decreasing.

Therefore, proper management interventions are needed to reverse these trends. The information presented in this paper could be used to inform various stakeholders on the need for sustainable management of the wetlands and their resources. There is thus a need for change in catchment management and for formulation of implementable strategies for the sustainability of the Usangu wetlands resources. Such strategies should balance agricultural production and the environment in a more rational manner through proper institutional arrangements that allows local communities to participate in formulation and implementation of management strategies that will promote conservation of the wetlands resources.

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References

Acreman, M.C., Hollis, G.E., 1996. Water Management and Wetlands in Sub-Saharan Africa. IUCN, Gland, Switzerland.

Benson, B.J., MacKenzie, M.D., 1995. Effect of sensor spatial resolution on landscape structure parameters. Landscape Ecology 10 (2), 113–120.

Burns, G., Joyce, A., 1981. Evaluation of land cover change detection techniques using landsat MSS data. In: Proceeding of 7th Pecora Symposium, 1981, Sioux Falls, South Dakota. pp. 1127–1134.

ERDAS Field Guide, 1999. Earth Resources Data Analysis System. ERDAS Inc., Atlanta, GA, 628 p.

Frohn, R.C., 1998. Remote Sensing for Landscape Ecology: New Metric Indicators for Monitoring, Modelling, and Assessment of Ecosystems. Lewis Publishers, Boca Raton.

Goldberg, J., 1998. Remote Sensing of Wetlands: Procedures and Considerations. Available from: <http://www.vims.edu/rmap/cers/tutorial/rsceol.htm>. Site viewed on 25/05/2004.

Jensen, J.R., 1996. Introductory Digital Image Processing: A Remote Sensing Perspective, 2nd ed. Prentice Hall, 316 p.

Kashaigili, J.J., McCartney, M.P., Mahoo, H.F., Lankford, B.A., Mbilinyi, B.P., Yawson, D.K., Tumbo, S.D., 2006. Use of a hydrological model for environmental management of the Usangu Wetlands, Tanzania. Research Report. 37 p.

Lambin, E.F., Geist, H.J., 2001. Global land-use and land-cover change: what have we learned so far? Available from: <http://www.geo.ucl.ac.be/LUCC/pdf/Pages%20from%20NL%2046.pdf>. Site viewed on 20/06/2003.

Lyon, J.G., 1993. Practical Handbook for Wetland Identification and Delineation. Lewis Publishers, Ann Arbor, 157 p.

Lyon, J.G., McCarthy, J., 1995. Wetland and Environmental Applications of GIS. Lewis Publishers, 373 p.

Papazoglou, C. 2000. The role of protected areas in promoting wetland functions and values. In: Proceeding Seminar 2: The Role of Wetlands in River Basin Management. WWF/EC Seminar Series—Implementing the EU Water Framework Directive, Brussels, 9th–10th November, 2000. pp. 47–53.

Pratt, D.J., Gwynne, M.V., 1977. Rangeland Management and Ecology in East Africa. Hodder and Stoughton, UK.

Singh, A., 1989. Digital change detection techniques using remotely sensed data. International Journal of Remote Sensing 10 (6), 989–1003.

SMUWC (Sustainable Management of Usangu Wetlands and its Catchment), 2001. Main report – Annex 1: The Usangu Catchment – Baseline 2001. Available from: <http://www.usangu.org/>]. Site viewed on 20/07/2004.

Sugumaran, R., Harken, J., Gerjevic, J., 2004. Using Remote Sensing Data to Study Wetland Dynamics in Iowa, January 2004. Available from: <http://www.ia.spacegrant.org/RES_INF/VRR2003/Sugu-SEED.pdf>. Site viewed on 26/06/2004.

Yasouka, Y., Yamagata, Y., Tamura, M., Sugita, M., Pornprasertchai, J., Polngam, S., Sripumin, R., Oguma, H., Li, X., 1995. Monitoring of wetland vegetation distribution and change by using microwave sensor data. In: Proceedings of ACRS. Available from: <http://www.gisdevelopment.net/aars/acrs/1995/ts1/ts1001pf.htm>. Site viewed on 21/06/2003.

Yeh, A., Gar, O., Xia, L., 1996. Urban growth management in Pearl river delta: an integrated remote sensing and GIS approach. ITC Journal 1, 77–86.

Zhou, Q., Li, B., Zhou, C. 2004a. Detecting and modelling dynamic landuse change using multi-temporal and multi-sensor imagery. Available from: <www.isprs.org/istanbul2004/comm2/papers/217.pdf>. Site viewed on 20/12/2004.

Zhou, Q., Li, B., Zhou, C., 2004b. Studying spatio-temporal pattern of landuse change in arid environment of China. In: Li, Z., Zhou, Q., Kainz, W. (Eds.), Advances in Spatial Analysis and Decision Making. Swets and Zeitlinger, Lisse, pp. 189–200.