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Research Article

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Assessment of Land Cover Changes in Lake Olbolosat Region of the Central Kenyan Highlands using Landsat Satellite Imagery Aided by Indigenous Knowledge

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Abstract

The region around Lake Olbolosat in the central Kenyan highlands has witnessed significant land-use changes, which are believed to be major cause of the dwindling Lake volumes. Very few studies have been carried out in the region due to limited observed in-situ data necessary for monitoring the land surface conditions. It is hence important that feasible, straightforward and cost-effective techniques are explored to asses the space and time variations with a view of providing the essential information for improved land and water management. This study investigated the land cover changes around Lake Olbolosat region using data obtained from Landsat satellite remote sensing. Five predominant land cover classes including farmland, floodplain, build-up area, forests and water body were selected for study. Two imageries for 1989 and 2010 when significant changes were witnessed in the area were subsequently selected. The Maximum-Likelihood function of the supervised classification scheme was applied to discern the space and time changes with the support of the indigenous knowledge of the area. From the results obtained, the size of Lake Olbolosat was noted to have significantly shrunk by 68% between the periods of study. Farmlands were noted to have increased by about 31% owing to the rapid rise in commercial and subsistence agriculture favored by the humid tropical climatic conditions of the highlands. The study revealed intense deforestation of the upstream area, which reduced the forested area by about 30% during the study period. The floodplains were also noted to have reduced by about 26%, with a majority of the area being gradually turned to farmland. Built-up area generally increased by about 33% consequent of the rising human population. In summary, the study revealed significant negative land cover changes in the area and hence a critical need for improved land-use planning to curtail further decline of Lake Olbolosat.

Keywords

Lake olbolosat; Landsat satellite; Maximum-likelihood; Supervised classification

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Introduction

In Kenya, land degradation is primarily a consequence of pressure from the increasing population coupled with haphazard land redistribution and limited education on land-use systems essential for appropriate resource management [1,2]. Instrumental and proxy evidence has already demonstrated that the degradation is affecting the development of the concerned regions through dwindling river discharges during periods of low flows, pollution mainly from non-point sources and, in other areas, conflicts and insecurity due to competitive demands for the limited land and water resources [3]. In the headwater catchments of the central Kenya, a prevalent cause of land degradation is unplanned deforestation to allow for human settlements and subsistent agriculture [4,5]. In the highlands of Nyandarua, the ubiquitous land-use changes are believed to be the major cause of the dwindling volumes of Lake Olbolosat, which has recently been declared an endangered water body by the regional government of Kenya. So far, few studies have been carried out on the spatio-temporal lands cover changes possibly affecting the size of Lake Olbolosat largely due to lack of reliable in-situ data. The available datasets are generally scantly and hardly updated on a consistent basis to provide the required thematic information of the changes [6].

However, a cost-effective approach to map land surface alterations in data scanty areas can be achieved through the use of remotely sensed satellite data. Of the satellite systems in existence today, Landsat technology provides medium resolution spatial data that are freely accessible for many regions around the globe. Besides, the satellite system has the longest history of service in providing cost-effective imageries widely used today for various applications related to natural resource management [7]. However, the right application of the datasets requires good understanding of the remote sensing sensing procedures from scene selection to results interpretation in order to minimize possible uncertainties during image processing. This is more so in the tropical regions where spectral signatures of satellite imageries have been noted to display minimal band separabilities amongst the various land-use types [8]. Furthermore, the existences of amorphous land-use patterns, and hence lack of a clear definition between areas that seasonally vary between pasture, agriculture and settlements sometimes tend to complicate the use of historical satellite datasets in the tropics. Consequently, it is inevitable to apply an integrated approach that utilizes every source of information available to support the land cover classification process.

More recently, participatory procedures that integrate community based information with the commonly used scientific classification procedures have been employed to discern historical land cover changes in data scanty areas [9]. The procedure has gained a lot of popularity in the rural parts of Kenya not only due to the need for ground based authentication of the classification accuracies, but also because of the vital role of indigenous knowledge in illustrating the physical change trajectories within their immediate environment [10]. Land cover classification to provide statistical information for enhanced use in decision support can be achieved through various change detection techniques, each with its strengths and limitations [11]. The selection of a technique to apply, therefore, largely depends on the objective of the study, the quality of data available and the ability to reproduce the actual land cover state of the region [12]. Previous studies in the rural Kenya have shown that the parametric Maximum-Likelihood supervised classification technique generally provides good estimates of the land-use patterns [13,14]. Due to the potential need to generate landscape-based metrics for extended assessment of the change effects on interrelated environmental processes, a post classification technique was used together with the supervised classification technique to process the imageries [15].

Objectively, this study quantified spatio-temporal land cover changes of the Lake Olbolosat region of the central Kenyan highlands, with the view to elaborate how the size of the Lake changed over the study period. Landsat satellite data, supported by indigenous knowledge, were used to discern the changes around a selected polygon encompassing the Lake and neighboring Nyandarua highlands that have witnessed significant deforestation over the last three decades.

Study Area

This study was carried out in the region around Lake Olbolosat situated around a latitude of 0º 09'S and longitude 36º 26'E in Nyandarua county in the central part of Kenya. The lake has a surface area of about 43 Km^2 and lies at an average altitude of about 2340 m in a wedge shaped rift valley floor, known as Ongata Pusi pusi, sloping sloping in the eastward – northward direction. The region enjoys favorable climate for most periods of the year, with temperatures ranging between 10º and 28ºC. The climate is sub-humid and is strongly influenced by local topography of the surrounding central highlands. The mean annual rainfall of the area is about 980 mm and increasing southwards and westwards. Rainfall is bimodal, with long peaks between April and June and the shorter peaks between October and November [16,17]. The entire catchment area of Lake Olbolosat is approximately 4800 km^2, encompassing Nyandarua Ranges, Satima Escarpment and Ndundori Hills. The water from the basin flows northwards through Thomson's Falls into the northern part of Ewaso Nyiro River. Generally, the region of Lake Olbolosat has a history of colonial settlements when the major land-uses were large scale livestock rearing and crop production. In the recent past however, the area has gone through considerable land-use changes under the national settlement fund trustees, resulting into significant land subdivision and fragmentation, especially after 1993. Presently, the majority of people living in the area are small scale farmers who grow subsistent crops and rear domestic livestock on land parcels ranging from 0.5 to 8 acres. The human population density of the area is approximately 202 per km^2. Table 1 provides the approximate population in the administrative divisions of the region [18,19]. The typical land-use patterns of the study area are illustrated in Figures 1A and 1B.

Tools and Methods

Spatial datasets

Topographic maps with sufficient accuracies for the periods of study were not available from the respective authorities in Kenya. An attempt was hence made to use Landsat satellite imageries since they exhibit the longest history of service with medium resolution data capable of detailing the spatial changes. Consequently, two Landsat images for January 1989 and February 2010 were obtained from the free Global Orthorectified Landsat Data (http://glovis.usgs.gov). The paths/rows for the 1989 Landsat Thematic Mapper (TM) and 2010 Landsat Enhanced Thematic Mapper Plus (ETM+) imageries were 180/54 and 168/54, respectively. The selected images were cloud free and approximately for the same periods of time in order to minimize variations in the state of land cover due to seasonality and phenology.

Table 1: Estimated population in the divisions of Lake Olbolosat region from 2008-2013.

Division	Year					
	2008	2009	2010	2011	2012	2013
Ol Kalou	133000	137500	142000	146800	151700	156800
Oljoro Orok	87800	90700	93800	96900	100200	103500
Ndaragwa	114700	118600	112600	126700	130900	135300
Total	335500	346800	348400	370400	382800	395600

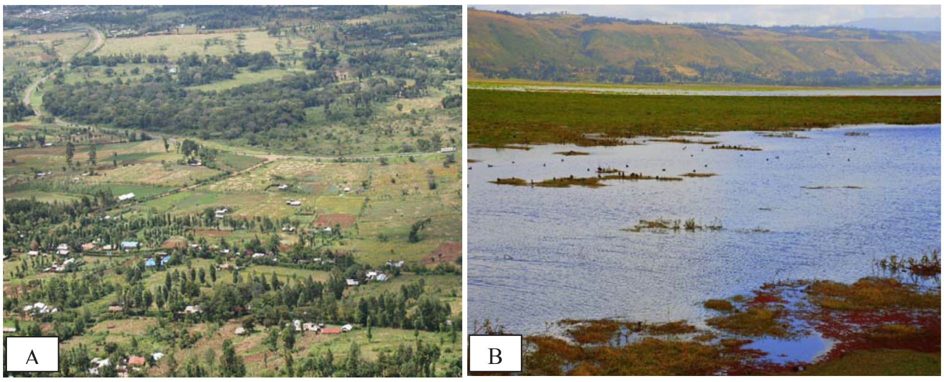

Figure 1: (A) Typical Land-use and settlement patterns around Lake Olbolossat and **(B)** Degraded land water surface of Lake Olbolossat.

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Data processing

The acquired images were processed in ERDAS™ image processing software (ERDAS 2002). The spatial changes were discriminated based on a per-pixel image processing procedure. Multi-layer composites were obtained through a layer stacking procedure and afterwards subset to an area of interest encompassing a selected region around the Lake. This procedure was preferred to the catchment based approach since it would not only capture the targeted spatial changes, but also the land-uses likely to be abstracting water from the Lake through small scale water usage. Consequently a rectangular area of about 1744 km^2 was selected to capture part of the Nyandarua forest that has witnessed significant deforestation in the last three decades. Five major (Level I) land cover classes predominant in the area were selected for the study. The land cover types and their general characteristics are provided in Table 2. To minimize spectral distortions associated with mosaicking multi-date images before classification, the subset satellite images were processed independently and a mosaic performed on the final classifications.

Due the amorphous land cover patterns of the study area, feature space selection to identify the optimal bands to be used in the classification was achieved using the statistical transformed divergence technique [20]. The training areas for use in the supervised classification technique were visually selected in the images and their actual land cover types identified and further confirmed through a comprehensive ground truthing involving indigenous knowledge of the local communities about the historical states of the regions during the time periods [10]. At least five representative polygons for each land cover class were delineated on the selected color composite images. To reproduce the land cover patterns of the area, the parametric Maximum-Likelihood classifier was used without apriori probability weights assigned to the land cover classes. A 3x3 majority filter was subsequently applied to the classified maps to remove small isolated pixels due to the classification. Since there was no reliable land cover data to be used for accuracy assessment for the two periods of study, it was not possible to statistically authenticate the classified maps. However, FAO-Africover land cover data [21] produced through comprehensive visual interpretation of land cover polygons between 1995 and 2002 was used for plausibility checks supported by the community based mapping technique involving local knowledge of the indigenous communities.

Results and Discussions

Generally, the community based approach of identifying and labeling training sites through indigenous knowledge proved sufficient and reliable in assessing the historical land cover states, in as much as it was not possible to statistically provide the classification accuracies. From the transformed divergence technique, band combination 4-3-2 proved optimal for discriminating a majority of the land cover classes, with forest and waterbody indicating the highest average separabilities. Farmland and floodplain on the other hand provided the lowest average separability due to their amorphous occurrence and close spectral characteristics. In such a case, proximity of the land cover classes to the waterbody coupled with comprehensive indigenous knowledge of the area provided very good lead towards distinguishing the two land cover classes. Table 3 below provides the area in hectares (Ha) and percentage of the classified land cover classes. Also in the table are the spatial changes relative to 1989 expressed in hectares and equivalent percentage values.

From Table 3, the area under water was noted to have reduced from 2127 ha in 1989 to 674 ha in 2010, translating into a 68% reduction during this epoch. Several activities around the lake could have contributed to this contraction of the Lake size. Predominant amongst these however is the increased settlements and farming activities in the lake's riparian land. In addition, the need for fertile land for cultivation areas has led to encroachment into the lands left fallow as the Lake recedes, beginning with livestock grazing around the lakes wetland area. Moreover, farming as far as to the floor of the lake has resulted to high levels of eutrophication as minerals from fertilizer are eroded to the lake from non-point sources. In the recent past, some farmers around Lake Olbolosat region have begun planting of Eucalyptus trees around the lake. This activity is likely to create further damage due to the high water absorption associated with the tree species. A summary of the relative changes of the land

Table 2: Characteristics of the Land cover types selected for the study.

Land cover classes	Characteristics
Farmland	Very open shrubs with closed to open fields, includes sparse vegetation cover that is likely to change to other uses in the near future.
Floodplain	Mainly areas surrounding the lake that floods during rain seasons, and include the regions covered by short graminoidal plants and grasses.
Built-up area	Areas occupied by settlement both in urban and rural areas, other land-uses that may contribute to this area are roads and airstrips.
Forest	Closed broadleaved trees with closed to open shrubs/herbaceous plants.
Water	Perennial/Non-perennial, standing/flowing Water bodies

Table 3: Relative change of the classified maps for 1989 and 2010.

Land Cover Class	Classified Areas				Relative Change	
	1989		2010			
	(Area)		(Area)		(Area)	
	(Ha)	(%)	(Ha)	(%)	(Ha)	(%)
Farmland	58002	33.3	76200	43.7	18198	+31.4
Floodplain	50674	29.0	37295	21.4	13379	-26.4
Built-up land	24964	14.3	33309	19.1	8345	+33.4
Forest land	38657	22.2	26946	15.5	11711	-30.3
Water	2127	1.2	674	0.4	1453	-68.3

cover classes for the study period are provided in Figure 2.

In terms of other land covers, the Floodplains size changed from 50674 ha to 37295 ha over the same interval indicating a 26% reduction. This is largely because of the fact that a majority of the area is slowly being swallowed-up by the need for increased farm land to supplement the needs of the rising local population in Manguo, Kanguo and Ziwani areas located adjacent to the Lake's flood plain. During the period of study, built-up land was noted to have risen by an area of about 8345 ha representing a 33% increment. This phenomenal growth of settlements is attributed to increased population coupled with internal migration from the neighboring districts. The migration was augment a lot by the influx of internally displaced people, popularly known as IDPs in Kenya, following ethnic tension due to competition for land and water resources. The other reason likely to be associated with the change is the rise in commercial floriculture from such farms as Suera and Primarosa, requiring more man powers and human resource for the expanded agricultural activity.

Forest land was noted to decline from 38657 ha in 1989 to 26946 ha in 2010 representing a 30% reduction in the coverage. The encroachment into the Aberdare and Ndaragua forests started through the abuse of *Shamba* system which is introduced by the Kenyan Government in mid 1980s to allow farmers living in the highland areas to inter crop annual crops with targeted tree seedlings capable of preserving the indigenous forest environment. The failure of this system was largely promoted by inadequate law enforcement and regulations and, in other areas, political influence and interference. This led to cultivation of forest land for long periods resulting to permanent occupation of forest land, concealed and illegal tree felling for timber and charcoal production in some regions, especially in the region around Ndaragua forests. Generally, the region between 1980 and 2000 witnessed a lot of deforestation in most headwater catchments in Kenya as has been revealed by other similar studies [22,23]. The results obtained in this study therefore, compare very well with other studies indicating reliability of the spatial estimates despite the limited reliable data for environmental assessment.

Conclusion and Recommendation

This study explored the possibility of using Landsat satellite data, supported by indigenous knowledge, to detect and discern space and time land cover changes of the Lake Olbolosat region. Noteworthy from the results obtained is the significant drop in the size of the Lake, a consequent of the rigorous anthropogenic influences around the region. The degradation arises largely from increased deforestation, human settlements and agricultural activities instituted for socio-economic reasons. Generally, this study successfully outlined the concerned changes and hence the need for a comprehensive restoration strategy for the region. An essential step to salvage dwindling Lake Ecosystem is for the concerned county authorities to delineate and set up a buffer zone around the Lake to safeguard further human encroachment. This can be achieved through a collaborative and integrated effort of the concerned stakeholders, including the National Environmental Management Authority (NEMA), the Nyandarua county government and the local communities directly depending on the Lake services for livelihood. Future objectives to preserve the natural resources should target increased education on improved and better ways for land and water management. Other alternative ways for economic sustenance such as eco-tourism should be targeted to involve the poor rural communities. Research studies in the region should explore other possible causes of the dwindling lake size besides the land-use activity, if any, and better ways to redress the existing environmental degradation with a view for restoration.

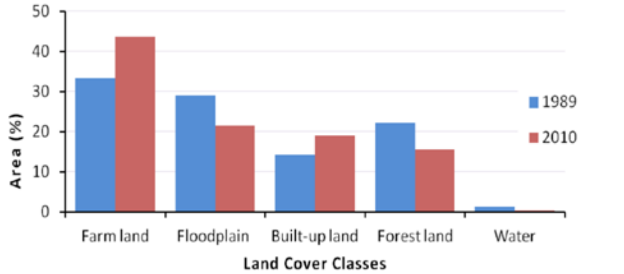

Figure 2: Comparison of the percentage changes of the land cover classes for 1989 and 2010.

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