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Analysing decadal land use/cover dynamics of the Lake Basaka catchment (Main Ethiopian Rift) using LANDSAT imagery and GIS

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Abstract

Development of accurate classification methods for rapidly changing catchments like that of Lake Basaka is fundamental to better understanding the catchment dynamics, which were not addressed in previous studies. Thus, the aim of this study was to map the decadal land use/cover (LUC) regimes of the Lake Basaka catchment, utilizing time series of LANDSAT images and to analyse the changes that occurred at different time periods. Both unsupervised and supervised image classification systems were utilized in Earth Resources Data Analysis System (ERDAS) Imagine (9.1). Appropriate pre- and postprocessing also was utilized. Seven major LUC classes were identified in the final land cover maps produced after the supervised (maximum likelihood) classification exercise. The analysis results indicated the Lake Basaka catchment had experienced a drastic change in its LUC conditions over the last 4–5 decades because of rapid increases in human settlement, deforestation, establishment of irrigation schemes and Awash National Park (ANP). Approximately 18 924 ha of forest and 4730 ha of grazing lands were devastated between 1973 and 2008. At the same time, there was a shift in land cover from forests/woodlands to open woodlands, shrub and grazing lands. The land cover classifications generally were achieved at a very high overall accuracy (84.34%) and overall kappa statistics (0.802), substantiating the value of using the classified LUC in this study as an input to hydrological models. This study results provide an opportunity to better understand and quantify the hydrological response regimes of the lake catchment from the perspective of changing LUC conditions during different hydrological periods and the resulting dynamics of the lake water balance.

Key words

accuracy, Basaka Lake, change analysis, image classification, LANDSAT.

INTRODUCTION

Land use–land cover (LUC) changes resulting from both direct and indirect human interventions are the main factors responsible for ecological changes at local, regional and global scales (Etter *et al.* 2006a; Manandhar *et al.* 2009). Different studies (e.g. Nobre *et al.* 1991; Wei and Fu 1999; Pielke *et al.* 2001) have demonstrated that the destruction of natural vegetation cover has been a major cause for the deterioration of regional climates and environment (Fu 2003). Appraisal of the LUC change in Africa by Basset and Zueli (2000) indicated environmental degradation (e.g. loss of forest; soil erosion) increased linearly with population density (Mapedza *et al.* 2003). Thus, it means land use pressures will not decline, especially in developing countries in Africa in the near future, under conditions of a fast growing human population and a fluctuating (progressive/recession) global economy.

Land use–land cover changes have impacts on the atmospheric and subsurface-components of the hydrological cycle (Scanol *et al.* 2005). They can alter the balance between rainfall, evaporation and infiltration and, consequently, the area's run-off response (Costa *et al.* 2003; Jiang *et al.* 2008). The destruction of tropical forests is a major concern, as it has a cumulative impact on biodiversity, regional and global climate, and soil productivity (Laurance 1999; Geist & Lambin 2001; Lambin *et al.* 2003). A simple underlying assumption is that land with sparse vegetation cover is subjected to high surface run-off volumes, low infiltration rates and reduced

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groundwater recharge. The reduced infiltration and groundwater recharge can eventually lead to lowering of water tables and intermittence of once-perennial streams (Bewket & Sterk 2005). An in-depth review of the influences of the presence or absence of forest cover on rainfall, seasonal and total stream flow distribution, and erosion and sediment yields in the humid tropics was provided by Bruijnzeel (2004).

Comprehensive knowledge of LUC dynamics might be useful to reconstruct the past history and to predict future environmental changes (Hietel *et al.* 2004). Understanding the impacts of LUC on hydrological processes (e.g. runoff; erosion; soil loss; water yield) is needed for optimum management of natural resources (Scanlon *et al.* 2007). Thus, such knowledge is helpful to elaborate sustainable management practices to preserve essential landscape functions (Hietel *et al.* 2004). There is a strong need for hydrological modelling tools for assessing the likely effects of LUC changes on the hydrologic processes at the catchment scale (Legesse *et al.* 2003). Understanding and predicting the processes, causes and consequences of LUC changes also are essential to landscape ecology and to regional land use planning and biodiversity conservation, all of which rely heavily on improved LUC change data and models (Lambin *et al.* 2003; DeFries & Eshleman 2004; Etter *et al.* 2006b; Manandhar *et al.* 2009).

The area of Lake Basaka is increasing at a rapid rate, resulting in various economic, social and environmental problems. The expanding lake has already inundated more than 41 km^2 of grazing land (Olumana 2010), seriously affecting the indigenous Karrayyuu people (pastoralists and semi-pastoralists) in terms of human displacement and the loss of human and animal life. This reality is challenging pastoralism in the area (Gebre 2004, 2009; Elias 2008; Olumana 2010). The lake expansion also is affecting the production and productivity of a nearby sugar estate (Olumana *et al.* 2009; Olumana 2010), as well as interfering with major highway and railway line structures. Prior to the introduction of irrigated agriculture in the region (as per information obtained from elders of the locality), Matahara plains and the surrounding escarpments (including Basaka Lake catchment) were covered by relatively thick forests and woods, containing different plant and animal species. The ecosystem was more or less protected and well balanced at that time. All the surrounding escarpments are currently seriously degraded, however, because of significant human interventions in the area. Thus, identifying the type and extent of land cover in the area during different decades is extremely important in regard to understanding the hydrological regime processes in the catchment and the resulting lake water balance dynamics. None of the studies conducted thus far on the lake expansion have considered the decadal LUC change that has occurred in its catchment since the 1970s, while analysing the changing hydrological regime processes and lake water balance dynamics. Although detailed LUC mapping for Basaka Lake catchment was recently completed by the WWDCE (1999), the resulting map only indicates the LUC condition during the year 2000.

The aim of this study, therefore, was to map the spatiotemporal LUC dynamics of the Lake Basaka catchment from time-series LANDSAT images and subsequently analyse the changes that have occurred during different time periods. This study is based on the premise that remote sensing and GIS techniques, combined with the use of ancillary data, are a powerful tool for extracting various land cover features from satellites images.

STUDY AREA

Lake Basaka (8°51.5′N, 39°51.5′E, 950 m.a.s.l.) is located in the Matahara Plain, Fantalle Woreda of the Oromiya region, approximately 200 km south-east of Addis Ababa, Ethiopia (Fig. 1). It is a volcanically dammed, endorheic, terminal lake situated in the northern part of the Main Ethiopian Rift (MER) near to the Afar triangle, which is a triple junction where three subplates (*Arabian*, *Nubian* and *Somalian*) are pulling away from each other along the East African Rifts (EARs) to form new oceanic crust (Belay 2009). The lake is bound by the Matahara Sugar Estate (MSE) along the south and south-east side and Awash National Park (ANP) to the east (Fig. 1). The lake catchment has a variable altitude, ranging from 950 m at Basaka Lake to over 1700 m at the Fentalle Crater (volcanic mountain). As a result of the location of the Matahara area in the central Rift Valley region (upper part of Main Ethiopian Rift, MER), it is vulnerable to the impacts of different tectonic and volcanic activities. This is evident from the vast lava extrusions at the foot slope of Fentalle Mountain (volcanic crater), the dots of extensive scoriceous hills in the locality (Mohr, 1971), the lava flows produced by the eruption in the northern part of the lake in the 1980s (Halcrow 1989) and the availability of a number of hot springs discharging into Basaka Lake (Olumana 2010). The salinity/alkalinity level of the lake is very high, not being tolerable to most plants and animals. The lake catchment area is about 500 km^2 and receives an annual rainfall of approximately 0.28 billion m^3.

Analysis of long-term (1966–2009) weather data of the area indicates the Matahara Plain is characterized by an erratic, bimodal rainfall distribution pattern. The major

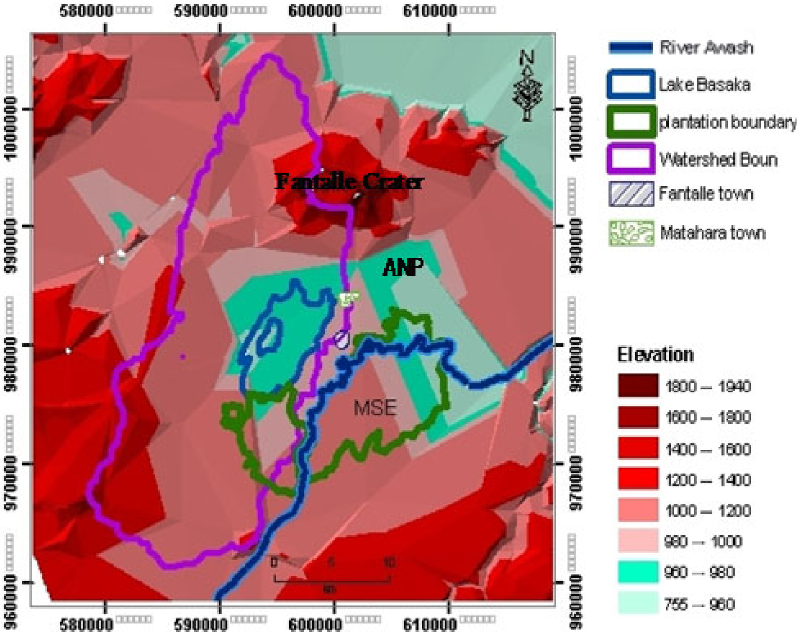

Fig. 1. Topographic view from DEM of Matahara Plain and surrounding landscape.

rainy season occurs from July to September, with the minor, occasional rain occurring between February and May (Fig. 2). The potential evapotranspiration and temperature are always greater than the rainfall except during July and August. Thus, irrigation is necessary in the area for about 9 to 10 months, as the quantity and distribution of rainfall is not adequate for agricultural activities. The long-term mean annual rainfall is about 543.7 mm, while the mean maximum and minimum temperatures are 32.9 and 17.5°C, respectively. The regional climate is generally classified as semi-arid (Olumana 2010).

Based on detailed characterization of the soil and LUC units for the Lake Basaka catchment by the WWDSE (1999), there are nine soil types in the catchment (Fig. 3a). Based on decreasing areal coverage, the soil types are Lepthosols (33%), TMP$_{\text{L}}$ (17%), Cambisols (13%), Podzoluvisols (6%), Luvisols (5%), Podzols (5%), Fluvisols (4%) and Solnchaks (2%) (Olumana 2010). The remaining proportion (≈15%) of the drainage basin is covered by the lake itself, island and lava flow. Lepthosols, the predominate catchment soil type, are characterized as the coarse-textured, shallow soil with weakly developed soil structure, which occupies the western part of the catchment, and is mainly covered by open bushy woodlands (Fig. 3b). Cambisols is a well-drained, deep- and medium- to coarse-textured soil unit mainly occupying the northern part of the watershed (west part of the lake), which is mainly covered by open grassland and bush lands. TMP$_{\text{L}}$ are mountain soils found mainly in the Fantalle Crater in the northern part of the catchment,

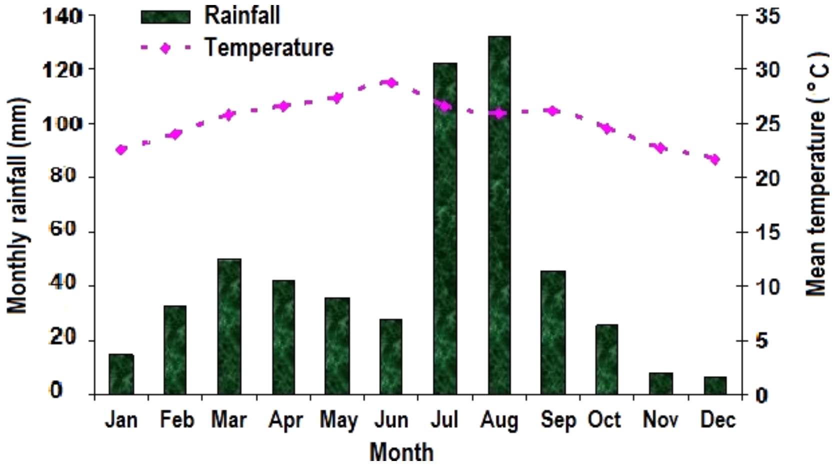

Fig. 2. Mean annual seasonal rainfall and temperature variability in Matahara area, 1966–2009.

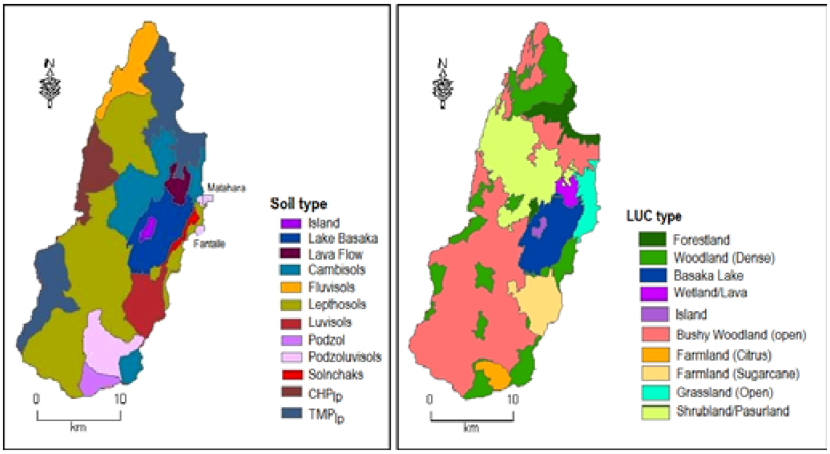

Fig. 3. Pedogenic (left) and land cover (right) characteristics of Lake Basaka catchment (LUC is for year 2000; modified from WWDSE).

which is occupied by forestlands and dense woodlands. Podzoluvisols are a well-drained, medium- to coarse-textured soil, very deep with moderately developed structures. It is found mainly in the south-eastern part of the catchment. The southern part of the lake (Abadir side) is occupied by Luvisols, with the immediate northern part occupied by lava flow (WWDSE 1999; Belay 2009; Olumana 2010).

METHODS

Landsat and ancillary data

An attempt was made in this study to use LANDSAT imagery, with observations beginning in the early 1970s. Four series of LANDSAT images (1973 MSS, 1986 TM, 2000 ETM+ and 2008 ETM+) were acquired from the FREE Global Orthorectified Landsat Data via FTP (http://glovis.usgs.gov). The selected images were all cloud free and cover the study area and its surroundings. The acquired images reflect the non-rainy season (Table 1).

Ancillary data, such as Digital Elevation Model (DEM), digital plantation (base) map and topographical maps, were collected from different sources. The DEM (90 m resolution) was downloaded from the NASA Shuttle Radar Topography Mission (SRTM), through the National Map Seamless Data Distribution System site (http://www2.jpl.nasa.gov/srtm/), and processed in ArcGIS 9.2 (ESRI 2006) for the study area and surrounding landscape. The digital plantation base maps (CAD format) illustrating all the roads, irrigation and drainage networks, field plots and Awash River were collected from MSE. The 1975 Matahara toposheet (scale 1:50 000) was purchased from the Ethiopian Mapping Authority (EMA). Meteorological data were collected from the database of the sugar estate and from friends of the researcher. Other secondary data (soil maps; LUC information) also were obtained from other reports (e.g. WWDSE 1999; Ayenew 1998, 2007), FAO Soils (FAO, 1990) and Ethio-GIS. Oral information regarding the lake condition since its formation also was obtained from the indigenous Karrayyuu people, the management body of Middle Awash Control Authority and MSE professionals. The condition of lake and its catchment also was observed by this author during the field work period (2007–2010).

Table 1. Satellite data used in Lake Basaka study

Sensor	Path/row	Cloud cover (%)	Resolution (pixel size)	Acquisition time
Landsat – MSS	180/54	0	57 m × 57 m	Jan, 1973
Landsat – TM	168/54	0	30 m × 30 m	Jan, 1986
Landsat – ETM+	168/54	0	28.5 m × 28.5 m	Dec, 2000
Landsat – ETM+	168/54	0	28.5 m × 28.5 m	Feb, 2008

Preprocessing of data

An intensive preprocessing, such as geoferencing, layer stacking, resolution merge and subsetting, was carried out to orthorectify the satellite images into UTM coordinates (WGS 1984, Adindan) and to remove such disturbances as haze, noise, steep slope effects and radiometric variations between acquisition dates. The satellite images were registered with the available topographical map of the project area and the digital plantation base map in ArcGIS, by matching some identifiable features (e.g. crossing of roads; railways; river; irrigation canals; bridges) on both the base map and the satellite images. All the images were referenced to the required accuracy (RMSE<5 m) by selecting 10 representative points exhibiting a good distribution. The images were then processed in Earth Resources Data Analysis System (ERDAS) Imagine 9.1 (ERDAS 2006). The raw multiple satellite images were imported and stored in *.img format in the ERDAS Imagine 9.1.

Satellite image processing

Both supervised and unsupervised image classification systems were employed for the Lake Basaka catchment and surrounding area. The hybrid classification system was adopted in such a way that the unsupervised classification is reclassified by supervised type, to minimize the drawbacks of each system. The surface area of the lake was then delineated from the classified image. The unsupervised classification was first carried out to select the training areas for the supervised classification system. Before making the LUC classifications, different enhancement techniques were utilized, including focal analysis, histogram equalization/decorrelation stretch, etc.

Unsupervised classification

Unsupervised classification was made for the enhanced images. ISODATA (Iterative Self-Organizing Data Analysis Technique) clustering technique was first performed to group the similar pixels into clusters, by setting 50 spectral classes with maximum iteration of 15 and convergence threshold of 0.95. False colour composite (FCC), or pseudocolour, of the mask file was created for each satellite image, using appropriate band combinations as all the images were taken during dry seasons (December to February) (Table 1). It was used as an indicator for the different land cover categorizations, based on the visual elements. Thus, visual interpretability of the colour composite (FCC/TCC) is a prerequisite for image classifications, playing a significant role in regard to the success of land cover classifications.

The signatures from unsupervised classification were aggregated into LUC categories, according to the descriptions presented in Table 2. The easily identifiable classes were then categorized into LUC units, to create appropriate signatures for the supervised classifications. Those classes difficult to separate were retained without assignment into land cover categories. Some unidentified similar classes were cluster-busted into the other identified classes, utilizing user-defined training identification technique.

Supervised classification

To evaluate the aforementioned classes prior to performing supervised classifications, the signature separation was calculated using transformed divergence. The transformed divergence gives an exponentially decreasing weight to increasing distance between the classes (Jensen 2005). The scale of the numerical divergence values was interpreted as per Jensen's (1996) general rule; namely, the classes can be separated very well above a value of 1900; the separation is fairly good between 1700 and 1900; and the separation is poor below a value of 1700.

In addition to the training samples obtained from unsupervised classification, user-defined training sites (pixel-wise) were defined on an area of interest (AOI) for known cover types. These training sites were necessary to define classes that did not get uniquely classified during the unsupervised classification (Shetty *et al.* 2005). The 1973 MSS image in particular classified the lake and wetland/lava flow into the same cluster, being subsequently re-clustered into different land cover categories

Table 2. Characteristics of land cover classes identified in Lake Basaka watershed

Land use/cover	Description
Forest	Areas covered with dense growth of trees that form nearly-closed canopies (70–100%). Dense woodlands and riverine forests also are included in this category
Bushy Woodland (open)	Areas with sparse trees, mixed with short bushes, grasses and open areas. Bare/degraded land with little or no grass cover (exposed rocks), but with same tone on aerial photographs also are classified in this category
Shrubland	Areas covered with shrubs, bushes and small trees, with sparse wood (acacia), mixed with some grasses
Grassland	Areas used for communal grazing, as well as bare lands (or rocks) with little or no grass cover
Marshland	Areas critically waterlogged and swampy in the wet season, and relatively dry in the dry season, as well as lava flows
Farmland	Areas used for crop cultivation (sugarcane + citrus) and different settlements (villages) and factory closely associated with the cultivated fields. Some trees (mainly eucalypts & acacia) commonly found around homesteads and cane plantation also were included in this category

Water is not described.

by user-defined clustering sets. Appropriate band combinations were obtained and adopted (by trial and error procedure) when demarcating the training sites. The results of the signatures sets obtained by the unsupervised classification and the developed additional training signatures were used for the supervised classification. The images were classified through the classical maximum likelihood (ML) parametric decision rule. ML classifiers are the conventional image classification algorithms widely employed in most LUC change monitoring studies (Rogan & Chen 2004).

Accuracy assessment

Accuracy assessment of the classification was performed for the LANDSAT ETM+ 2000 images, using the accuracy assessment tool available in ERDAS Imagine. The 2000 ETM+ image was selected for accuracy assessment because of the availability of detailed LUC maps only for this particular period, which was produced by the WWDSE (1999) by detailed field investigations. Certain pixel-wise true data were obtained from actual field observations and the WWDSE (1999) map randomly, and subsequently compared with the classified images. The class values for reference pixels were assigned as per the available ground control points.

Finally, the error (confusion) matrix was generated in ERDAS Imagine, which included all three 'accuracies' (*user accuracy, UA; producer accuracy, PA; overall accuracy, OA*) and kappa coefficient (*conditional, K′; overall, K*). Moreover, the relative error of area (REA) was calculated from the error matrix, using the index derived by Shao *et al.* (2003) and adopted by Shao and Wu (2008), as follows:

$$\mathrm{REA}_k = \left(\frac{1}{UA_k} - \frac{1}{PA_k}\right) * 100 \tag{1}$$

where UA and PA = user and producer accuracy for class k, respectively.

Postprocessing and change analysis

Postprocessing, such as clump, sieve and filtering (majority) operations was applied to eliminate local variability and to improve the appearance and reliability of the products. The classified image was further smoothened, using majority filtering (3*3 for the 1973 image and 5*5 for the TM and ETM+ images). The subsetting of the classified and smoothened image for the delineated lake catchment was then made. The followed procedures are generally illustrated in Fig. 4.

The areal coverage, annual rate of change, change rate and relative change were tabulated for each LUC type. The annual deforestation (change) rates were calculated on the basis of the following formula (Etter *et al.* 2006b):

$$\mathrm{Rate} = \frac{1}{(t_2 - t_1)} \ln\left(\frac{A_2}{A_1}\right) \tag{2}$$

where A_1 and A_2 = forest cover at initial (t_1) and next time step (t_2), respectively.

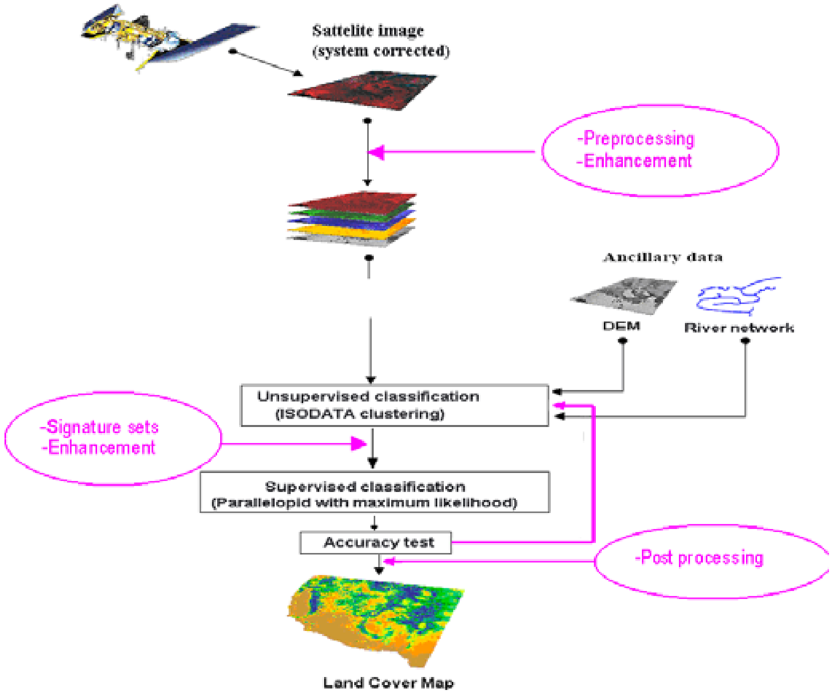

Fig. 4. Flow chart of land use/land cover classification analysis.

RESULTS AND DISCUSSION

Preprocessed colour composite images

Figure 5 illustrates the True Colour Composite (TCC) of the raw Landsat TM 1986 image. TCC indicates the true colour of LUC conditions in an electromagnetic (EM) spectrum, whereby bareland/rock, vegetation and water are represented by red (R), green (G) and blue (B) MS bands, respectively, allowing the different LUC conditions to be visually interpreted. Sugarcane farms (WSSE and MSE), lakes (Koka Dam, Basaka and Ziway), forests (evergreen), etc., can be identified. A deep green TCC colour indicates matured crops or dense evergreen forests. Riverine forests also are identified along the course of Awash River. The three lakes have different reflectance colours on the TCC images. Koka Dam (originally named Gallila Lake) is represented by a blue colour (i.e. true water colour), whereas Ziway and Basaka Lakes are represented by dark blue and blue black colours, respectively. The colour differences might be due to the ionic concentrations (especially bromide) in the respective lakes. Visual interpretability of the colour composite provides valuable information for identifying different LUC classes and, therefore, are the basic for LUC classification.

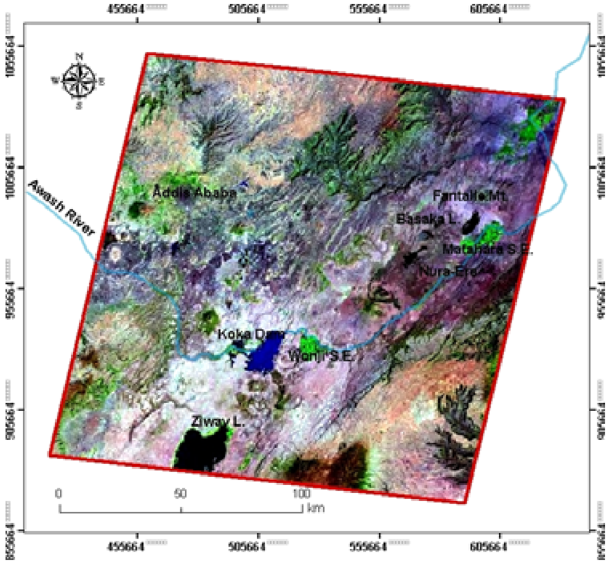

Fig. 5. True color composite of raw LANDSAT TM (1986) image.

Land cover mapping

The spatiotemporal land cover condition of the Lake Basaka catchment was mapped from time-series LANDSAT images, using image classification in ERDAS Imagine. The final land cover maps, produced after a supervised (ML) classification exercise for the different considered periods (1973, 1986 and 2000), are illustrated in Fig. 6. As it is almost the same as for the year 2000, the data for 2008 were not included in the LUC map. Seven major LUC classes were identified on the basis of this analysis; namely: forestlands; bushy woodlands (open); shrublands; grasslands; water (lake); farmlands; and wetlands/lava flow (Fig. 6).

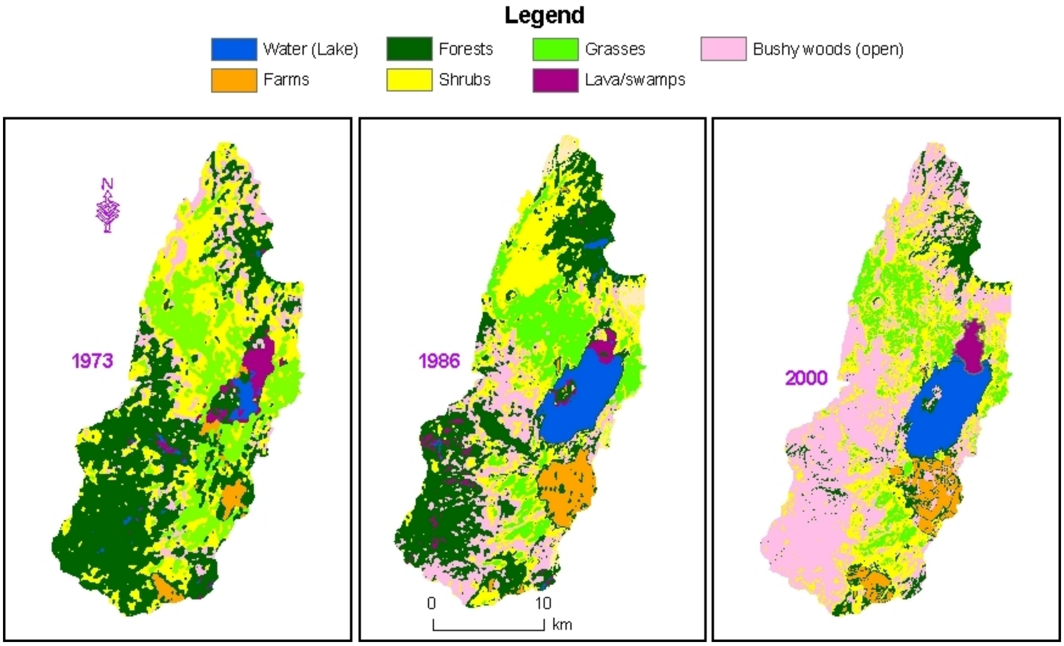

Fig. 6. Land cover maps for Lake Basaka catchment, 1973, 1986 and 2000.

Classification accuracy assessment

The confusion matrix (classification accuracy) assessment report is summarized in Table 3. Swamps/lava flows are not included in the accuracy assessment report because of their smaller size, compared with the other LUC types. Only seventeen total errors were found from the total 135 classified samples. Two farm samples were labelled 'change' on the classified map, but were 'not changed' on the reference data (commission error). Moreover, although five samples (2 forests; 1 shrub lands; 2 bare lands with open shrubby woods) were labelled 'no change' on the classified map, they actually did change (omission error), illustrating the difficulty in separating forests from farms (sugarcane + citrus) and open bushy woods from shrubs or forests. Water and grassland were relatively assigned to the required category (i.e. with no commission or omission error).

Reliable and acceptable OA and K vales were obtained, however, with PA and UA values very close to each other for this classification analysis (Table 3). This indicates the good image classification at a reasonable accuracy, as well as the high reliability of landscape matrices of spatial configuration (Shao & Wu 2008). The value of K varies between '+1.0' for perfect agreement, down to a value of '0.0.' The high value of *K* further indicates a strong agreement between the remotely sensed classification and the reference data. The obtained *conditional Kappa* (*K'*) for the individual class is different for different land cover units, with the highest value obtained for farms, followed by open bushy woods, water (lake), grasses, forests and shrubs. The PA and UA obtained for the individual land cover classes were very high, ranging from 75% (forests) to 93% (farms) and from 80% (forest) to 91% (bushy woods), respectively. Higher PA and OA indicate low errors of omission and commission, respectively. Moreover, the REA is very small, being close to zero for each LUC unit. A value of REA<5% is acceptable, and this classification was achieved within a value of REA<1% (Table 3). Detection of forest lands in the area, revealed by its relatively lower PA and UA, was relatively difficult, as its reflectance is similar to matured sugarcane and citrus crops. Further, the reflectance from a deep green tree was similar to that of Basaka Lake water. It is evident from the classical kappa coefficient that the lake water (*K'* = 0.87) and farmland (particularly sugarcane, (*K'* = 0.93) do not require high degrees of spatial resolution to be classified accurately, mainly because their reflectance is different from other LUC units in the area.

Change analysis

The areal statistics (area; net change; rate of change; relative change) for different LUC units are summarized in Table 4. The lake catchment experienced a rapid change in LUC over the past 4–5 decades. The individual LUC units, however, did not experience the same trends and relative changes during the different courses of time (Fig. 7). The highest changes occurred in the forests, followed by bushy woods (open), grasses and lake water. Swamps/lava, farms and shrubs also had undergone slight changes. Forests and grazing lands had decreased noticeably by about 18 924 ha (86%) and 4730 ha (50%), respectively, during the period of 1973 to 2008. Shrub

Table 3. Confusion matrix summarized for Landsat ETM+ 2000 image

					Accuracy (%)		
Land cover class	Classified totals	Number totals	Number correct	*K'*	PA	UA	REA
Water	16	16	14	0.867	87.5	87.5	0.00
Farms	28	30	26	0.931	92.7	86.7	0.07
Forests	32	30	24	0.793	75.0	80.0	−0.08
Shrubs	14	13	11	0.769	78.6	84.6	−0.09
Grasses	11	11	9	0.800	81.8	81.8	0.00
Bushy Woods	34	32	29	0.903	85.3	90.6	−0.07
Swamps/Lava	–	–	–	–	–	–	–
Total	135	132	113		81.6	83.5	−0.03

Overall classification accuracy (OA) = 84.34%

Overall Kappa statistics/coefficient (*K*) = 0.802

PA = producer's classification accuracy (%); UA = user's classification accuracy (%); *K'* = classical kappa;

REA = relative error of area (Shao *et al.* 2003; cit Shao and Wal, 2008).

Table 4. Summary of areal change statistics (net change; rate of change; relative change) for different Land use–land cover (LUC) units in Lake Basaka catchment

Period	Year	Water (lake)	Farms	Forests	Shrubs	Grasses	Bushy woods	Swamp/Lava
I. Area (ha, %)								
	1973	753 (1.4)	1080 (2.1)	22 073 (42.2)	12 939 (24.7)	9555 (18.3)	5563 (10.63)	356 (0.7)
	1986	2943 (5.6)	4585 (8.8)	11 054 (21.1)	12 161 (23.2)	6568 (12.6)	14 261 (27.3)	748 (1.4)
	2000	4168 (8.0)	2500 (4.8)	3887 (7.4)	12 755 (24.4)	5188 (9.9)	22 312 (42.6)	1500 (2.9)
	2008	4585 (8.8)	2344 (4.5)	3152 (6.0)	12 075 (23.1)	4821 (9.2)	23 569 (45.0)	1655 (3.2)
II. Net change (ha)								
1	1973–1986	2190	3505	−11 019	−778	−2987	8698	392
2	1986–2000	1225	−2085	−7167	594	−1380	8051	752
3	2000–2008	417	−156	−735	−680	−367	1257	155
Total	1973–2008	3832	1264	−18 921	−864	−4734	18 006	1299
III. Annual change rate (%)								
1	1973–1986	9.7	10.4	−4.9	−0.5	−2.7	6.7	5.2
2	1986–2000	2.5	−4.3	−7.5	0.4	−1.7	3.2	5.2
3	2000–2008	1.1	−0.7	−2.3	−0.6	−0.8	0.6	1.1
Average	1973–2008	5.0	2.2	−5.4	−0.2	−1.9	4.0	4.3
IV. Relative change (%)								
1	1973–1986	4.2	6.7	−21.1	−1.5	−5.7	16.7	0.7
2	1986–2000	2.4	−4	−13.7	1.2	−2.7	15.3	1.5
3	2000–2008	0.8	−0.3	−1.4	−1.3	−0.7	2.6	0.3
Total	1973–2008	7.4	2.4	−36.2	−1.6	−9.1	34.6	2.5

Value in parenthesis = percentage areal coverage.

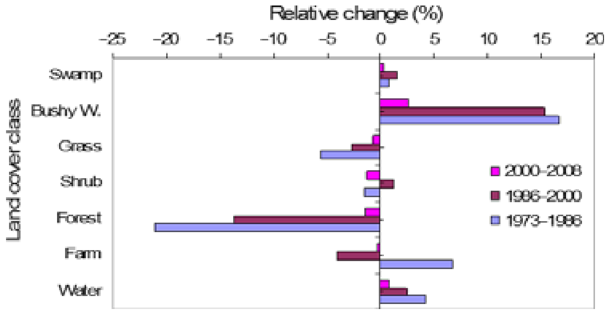

Fig. 7. Relative LUC changes in Lake Basaka catchment during different periods.

lands illustrated an almost stable coverage throughout the study periods. About 4300 ha of grazing land was lost because of the expansion of the lake, with the remaining 430 ha related to the formation of lava and land degradation (mostly erosion).

The relative loss and gain of forests and open bushy woodlands (i.e. 18 924 ha (36.2%) and 18 006 ha (34.6%), respectively) over the past 35 years (1973–2008) were almost comparable. Thus, forest lands were mostly changed to bushy woodlands, which are open and sparse in coverage. The decrease in grazing land (4730 ha) and the expansion of the lake water area (3831 ha) were approximately equal, indicating the lake and wetland expansions were almost at the expense of the grass lands. Since the 1980s (Table 4), the lake expansion also was at the expense of the sugarcane farm (Abadir-E fields) in the area. About 400 ha of cultivated lands and 2000 ha of productive lands were inundated by lake water since the mid1990s. Grass and farmlands were susceptible to the lake expansion because of their location at a lower elevation and being in close proximity to the lake.

Knowledge of the dynamics of LUC changes might be useful to reconstruct past conditions and predict the future possible changes (Hietel *et al.* 2004). Thus, temporal changes of land cover types can be identified and forecasted. The prechange cover type could be observed from the land cover classified for the 1973 Landsat MSS image, and the postchange cover type (predicted for the future) could be observed from the LUC change trends in the catchment over the past 4–5 decades. The 1973 image clearly indicates the area had a very rich vegetation cover before 1970s, as evidenced by the 85% areal coverage by forest, shrubs and grasses, as well as accounts from the indigenous peoples of the locality. According to local witnesses, the lake catchment area was covered by thick forests and occupied by different animal species before the introduction of irrigated agriculture at the end of the 1960s. Since the 1970s, the lake catchment had undergone a significant change in its LUC conditions. The total areal coverage of forests, shrubs and grasses in the year 2000, for example, was about 41.7%, indicating a total loss of 43.3% over the course of 3 decades. This loss was attributable to the rapid increment in deforestation, cultivation, settlement, lake expansion, wetlands, etc (Olumana 2010). A similar LUC trend can be expected in the future, resulting in even further deterioration of land cover conditions. Deforestation had a negative impact on the catchment and might result in changed hydrological conditions in the catchment, as well as changing the lake water balance regime. These changes, in turn, can have an impact on the livestock balance and the sustainability of irrigated agriculture in the region, ultimately resulting in both social and economic instability.

Demographical pressure on LUC change

According to the Central Statistics Authority (CSA, 2005) reports, the population of the town of Matahara increased by 5.4% between 1994 and 2005 (Fig. 8), a very high figure, compared with the national average (~3.1%). Further, the population in rural areas of Fantalle Woreda illustrated an annual growth rate of about 3.5%, being slightly higher than the national growth rate. The Matahara area experienced rapid population growth, especially after the establishment of MSE, and construction of the Addis Ababa-Djibouti railways and Addis Ababa-Harar-Dire Dawa-Jigjiga highways. Further, expansion of irrigation in middle and lower valleys contributed to the population growth in the area, which is a centre for people coming from the Hararghe zone, parts of East Shoa zone, most parts of the Somali region, parts of Afar region, and the Harari and Dire Dawa administrative regions.

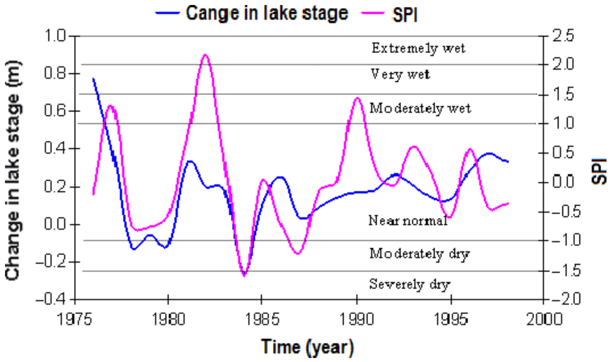

Fig. 8. Changes in lake stage and standard precipitation index (characteristics of SPI adopted from McKee *et al.* 1993; Khan *et al.* 2008).

Intensification and diversification of agricultural land use in the lake catchment, as well as establishment of ANP, and the availability of highways, has resulted in various pressures on the lake catchment's LUC condition. Commercial agriculture was introduced to the area at the expense of forestland, woodlands, shrublands and grasslands. Settlement and immigration into the area increased because of the relatively good job opportunities at the commercial farms. And good regional transport facilities also enhanced business activities. The establishment of MSE alone, for example, added more than 28 000 people to the area (Fig. 8), almost all being immigrants. Further, the indigenous people (pastoralists and semi-pastoralists) were confined in the catchment because of the loss of their land to agriculture, the expanding lake, increased settlements and land demarcated for ANP. The population pressures on the catchment come mostly from outside the catchment, including Matahara, MSE, Fantalle, Wolanchiti, Awash, etc.

Although the Lake Basaka catchment situation is not necessarily similar, the link between population, LUC changes, land degradation and water quality deterioration has been suggested for the Lake Nakuru catchment in Kenya in the Rift Valley basin (Yillia 2008). Nevertheless, there are certain indicators for linking these variables to the Lake Basaka catchment as well. The population growth has increased demands for food, water, fuel woods, charcoal and housing. The wood/forest lands are mostly destroyed because of the need for wood for house construction, as well as charcoal production, which is the source of income for some people dwelling in the catchment and nearby areas. The people are competing for scarce natural resources, sometimes resulting in conflicts between communities (e.g. Karayyuu and Isa) (Gebre 2004; Elias 2008).

Effects of rainfall variability and LUC change on lake fluctuation

The annual rainfall (as Standard Precipitation Index, SPI) and lake-level fluctuations are illustrated in Fig. 9. It is noted that the period from 1976 to 1999 is used for comparison purposes, as the lake stage-measured data collected from different sources are limited only to that period, with most reported activities (e.g. WWDSE 1999; Ayenew 2004, 2007; Belay 2009) considering the same time period. SPI values <−1.5 are considered to illustrate severe drought conditions. However, a SPI value >1.5 is considered to be extremely wet (McKee *et al.* 1993; Khan *et al.* 2008). Accordingly, the years 1973, 1984 and 2002

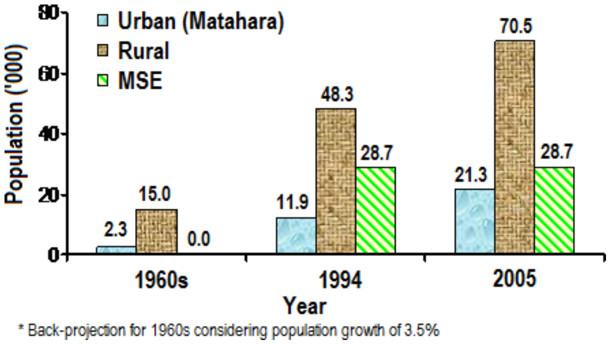

Fig. 9. Population dynamics in Fantalle Woreda (data from CSA, 2005).

are extremely dry (strong El Nino) years, while 1967, 1983 and 2008 are extremely wet (strong La Nino) years. In fact, the year 1984 is remembered by most Ethiopians as the severe drought year, and the associated famine resulted in significant losses of life and property.

The effects of extreme climatic (rainfall) events on the lake-level records and the stochastic behaviour of the extremes (maximum and minimum) on the lake regimes are illustrated in Fig. 9. The lowest lake-level change in the history of the lake stage records coincides with the 1984 severe drought, whereas the highest fluctuation occurred in 1982, which was an extremely wet period (strong La Nina) in the recorded history of the region (1966–2007). Wet years correspond to an increased lake stage, whereas dry years exhibited a lake stage decline.

The lake level is highly variable, mostly following rainfall distribution patterns. The monthly and annual lake-level fluctuations, however, were reduced in the post-1990s, almost always following the same general trend (gain of about 0.18 m year^{-1}), even though the rainfall pattern is slightly reduced. As previously discussed, this period (post-1990s) is characterized by significant LUC changes in the lake catchment (Table 4). These characteristics of lake-level fluctuations are evidence of the responsibility of other factors, other than rainfall variability, for the lake expansion in recent years (post-1990s), being dependent on the balance between the lake's inflow and outflow water components.

The effects of LUC changes on hydrological processes are illustrated in Table 5. Although the rainfall in the area is relatively stable, the hydrological processes (runoff; erosion rate; sediment delivery rate) exhibited increments at different periods. The sensitivity analysis of Olumana (2010), in his comprehensive water balance analysis, confirmed that about 80% of the increment in hydrological processes (surface runoff and soil erosion) in the post-1990s in the lake catchment are attributable to LUC changes, with the remaining proportion (20%) being attributed to rainfall variability.

Implications of LUC changes to the environment

As previously discussed, there are significant LUC changes attributable to various reasons, which could lead to different environmental effects such as land degradation (deforestation; erosion; sedimentation) and flooding (surface run-off). The catchment was rich in vegetation cover (highland forests) in the early 1960s, but changed from 42.2% to 6% in 2008. Deforested lands are exposed to the impacts of raindrops, which might accelerate the detachment, removal and transport of soil particles and the associated consequences (Morgan 1986; Olumana 2010). Conversion of native tropical forests to other land cover types might produce permanent changes in the annual stream flows (Bruijnzeel 2004). The catchment received attention in recent periods mainly because of its increasing environmental and socioeconomic problems and related political decisions.

Land use–land cover changes have crucial impacts on the hydrology, as well as the dynamics of the lake water balance (both quantitatively and qualitatively). Consequently, the significant changes in the LUC are expected to result in increased surface run-off (or reduction of infiltration), ET (because of the rising temperature), erosion and sediment yields. Further, an effect on the regimes of

Table 5. Estimated values of rainfall, CN, run-off, erosion and sediment rates (Olumana 2010)

Parameter	1973	1986	2000	2008
Annual rainfall (mm)	324.5	436.8	481.7	599.1
Curve number	61.2	68.2	73.7	74.2
Run-off (mm)	37.2	79.3	108.3	119.80
Erosion rate (tons ha^{-1} year^{-1})	45.1	87.2	107.3	107.0
Sediment rate (tons ha^{-1} year^{-1})	5.4 (very low)	17.0 (low)	26.8 (moderate)	27.8 (moderate)

the lake water balance also is apparent because the lake is the primary catchment water outlet. Olumana (2010) previously reported the run-off and erosion rate increments in the lake catchment (Table 5). As evident in the table, the run-off coefficient, curve number (CN) and erosion rates exhibited significant increments after the mid1980s, a period that coincides with the period of significant LUC changes in the region.

Water erosion is a common problem in Ethiopia, being governed by land cover patterns and types of conservation measures practiced, among other factors, a condition also true for the Basaka Lake catchment. The area is prone to the effects of run-off and erosion because of its topographical, soil and climatic conditions. Thus, the LUC changes in the catchment, as summarized in Table 5, could be a main factor for the expansion of the lake water level, resulting in significant environmental hazards to the lake catchment. The recent LUC, including its history and spatiotemporal dynamics, is very important to better understand the complex interactions between environmental and socioeconomic factors characterizing the lake catchment.

SYNTHESIS AND CONCLUSION

The satellite image analysis discussed in this study indicated the Lake Basaka catchment had experienced a drastic change in its LUC conditions over the last 4–5 decades because of the rapid increase in human settlement, deforestation, establishment of irrigation schemes (MSE; Nura-Era) and ANP. Population pressures in the area resulted in competition for scarce resources for survival, sometimes resulting in conflicts between different societies. These demographical pressures might continue similarly or might be accelerated. The significant LUC changes might have adverse effects on the environment (e.g. land degradation; drought and/or flooding), as well as socioeconomic conditions. Forestlands and grasslands sharply decreased in the study area, while the lake size and open bushy woodlands increased both spatially and temporally. Shrublands and lava flows remained relatively stable. Approximately 18 924 ha of forest and 4730 ha of grazing lands were devastated from 1973 to 2008, with the majority of loss grassland areas being overtaken by the lake water.

The increments in lake water level and bare lands were generally at the expense of forest and grazing land destruction. Grasslands and farmlands were susceptible to the expansion of the lake because of their close vicinity to the lake. More than 400 ha of cultivated lands and 2000 ha of productive lands have been flooded by the rising lake water since the mid1990s. At the same time, there was a land cover shift from forests/woodlands to open woodlands, shrublands and grazing lands. The relative decrement in forest coverage (18 921 ha) and increment in open bushy woods (18 006 ha) were approximately equal, indicating most of the forest land was converted into bushy woodlands. The farmland exhibited a significant increment during the first study period (1973–1986) because of the establishment of the Abadir sugarcane farm at a full scale, which has since slightly decreased. This might be due to the inundation of parts of the Abadir-E land by the lake water, and/or due to the difficulty in separating farmlands from grasslands or bare lands during the dry periods. The lake water, wetlands/lava, open bushy woodlands and farmlands generally exhibited an increment of about 5-fold, 4-fold, 3-fold and 1-fold, respectively.

The results of this study also revealed the lake water level fluctuations generally resembled the patterns of rainfall variability until the end of the 1980s. The lake water level continued increasing during the post-1990s, regardless of the rainfall fluctuations and the slight decrement in average values. This period coincides with significant LUC changes in the region. Thus, it is logical to suggest that rainfall variability and LUC changes contributed to the lake water–level fluctuations. However, the LUC change is thought to be mostly responsible, however, for the changing hydrological regime processes within the lake catchment.

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