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Analyzing the Decadal Land Use/Cover Dynamics of Basaka Lake Catchment (Main Ethiopian Rift) Using LANDSAT Imagery and GIS.

Megersa Olumana Dinka

Assis. Prof. (PhD). Institute of Technology (School of Natural Resources and Environmental Engineering), Haramaya University, P.O.Box 138, Dire Dawa, Ethiopia. E-mail: **magarsol@yahoo.com**

Abstract

The development of accurate classification methods in rapidly changing catchments like Lake Basaka is fundamental to understand the catchment dynamics, as it was not addressed by the previous studies. Thus, the aim of the current study was to map the decadal land use/cover (LUC) regimes of Lake Basaka catchment from time-series of LANDSAT images and then analyze the changes occurred in different times. Both unsupervised and supervised image classification systems were utilized in ERDAS Imagine (9.1). Moreover, appropriate pre- and post-processing were applied. Seven major LUC classes were identified in the final land cover maps produced after supervised (Maximum Likelihood) classification exercise. The analysis result showed that Lake Basaka catchment had experienced/undergone a drastic change in the LUC in the last 4-5 decades due to the rapid increase in human settlement, deforestation, establishment of irrigation schemes and Awash National Park. From 1973 to 2008, approximately 18924 ha of forest and 4730 ha of grazing lands were devastated. At the same time, there was a shift of land cover from forest/woodland to open woodland, shrub and grazing lands. Generally, the land cover classifications were achieved at very high overall accuracy (84.34%) and overall kappa statistics (0.802), indicating the use of the classified LUC in this study as an input into hydrologic models. This provides opportunity to understand and quantify the regimes of hydrologic responses of the lake catchment due to the changing LUC in different hydrologic periods and the resulting dynamics of lake's water balance.

Key words: accuracy, Basaka Lake, change analysis, image classification, LANDSAT

1. INTRODUCTION

Land use-land cover (LUC) changes by human interventions (direct and indirect) are the main factors responsible for the ecological change at local, regional and global scale (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 proved that the destruction of natural vegetation cover has been one of the major causes for the deterioration of regional climate and environment (Fu 2003). The appraisal of the LUC change in Africa by Basset and Bi Zueli (2000) indicated that environmental degradation (loss of forest and soil erosion) increased linearly with population density (Mapedza et al. 2003). That means land use pressure will not slow down, especially in developing countries like Africa, in the near future under a fast growing human population and a fluctuating (progressive/recession) global economy.

Change in LUC has impacts on the atmospheric- and subsurface-components of the hydrologic cycle (Scanlon et al. 2005). It alters the balance between rainfall, evaporation, and infiltration and consequently the runoff response of the area (Marcos et al. 2003, cit. Jiang et al. 2008). The destruction of tropical forests is the major concern since it has a cumulative impact on biodiversity, regional and global climate and soil productivity (Laurance 1999; Geist and Lambin 2001; Lambin et al. 2003). The underlying simple assumption is that land under little vegetation cover is subjected to high surface runoff amounts, low infiltration rate and reduced groundwater recharge. The reduced infiltration and groundwater recharge, eventually, lead to lowering of water tables and intermittence of once-perennial streams (Bewekt and Sterk 2005). The in-depth review regarding the influence of a good forest cover (presence or absence) on rainfall, streamflow totals and their seasonal distribution, erosion and sediment yields in the humid tropics was presented by Bruijnzeel (2004).

Comprehensive knowledge of LUC dynamics may be useful to reconstruct the past and predict the future changes (Hietel et al. 2004). Understanding the impact of LUC on hydrologic processes (e.g. runoff, erosion, soil loss, water yield) is needed for optimum management of natural resources (Scanlon et al. 2007) and hence, helpful in elaborating the sustainable management practices to preserve essential landscape functions (Hietel et al. 2004). There is a strong need for hydrologic modelling tools that can be used to assess the likely effects of the LUC change on the hydrologic processes at catchment scale (Legesse et al. 2003). However, understanding and predicting the processes, causes, and consequences of LUC are very essential to landscape ecology and to regional land use planning and biodiversity conservation, which rely heavily on improved LUC change data and models (Lambin et al. 2003; DeFries and Eshleman 2004; Etter et al. 2006b; Manandhar et al. 2009).

Lake Basaka is expanding at a fast rate. Its advancement is causing certain economic, social and environmental problems. It is already inundated more than 41 km^2 of grazing land (Olumana 2010) thereby seriously affecting the indigenous Karrayyuu people (Pastouralists and Semi-Pastoralists) in terms of displacement, and loss of human and animal life; and hence challenging pastoralism in the area (Gebre 2004, 2009; Elias 2008; Olumana 2010). The lake expansion already started affecting the production and productivity of the nearby sugar estate (Olumana et al. 2009; Olumana 2010). It is also interfering with the structures in the major highway and railway line forcing the government to change 3 times so far. Prior to the introduction of irrigated agriculture in to the region (as per information obtained from the elders of the locality), Matahara plains and the surrounding escarpments (including Basaka Lake catchment) were covered by relatively thick forests and woods, with different plant and animal species. The ecosystem was more or less protected and well balanced. Currently, however, all the surrounding escarpments were seriously degraded because of significant human intervention in the area. Therefore, identifying the type and amount of land cover in the area at different decades is extremely important to understand the regimes of hydrologic processes in the catchment and the resulting dynamics of lake water balance. None of the studies conducted on the lake expansion so far considered the decadal LUC change occurred in its catchment since 1970s while analyzing the changes in regimes of hydrologic processes of the area and dynamics of the lake water balance. Although the detail LUC mapping for Basaka Lake catchment was done recently by WWDCE (1999), the map indicates the LUC condition during the year 2000s only.

Therefore, the aim of the current study was to map the spatio-temporal LUC dynamics of Lake Basaka catchment from time-series LANDSAT images and then analyze the changes occurred in different periods. The study built on the premise that Remote Sensing and GIS, assisted with ancillary data, provides a powerful tool for extracting the various land cover features from the satellites images.

2. 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 Oromiya Region, at approximately 200 km southeast of Addis Ababa (Fig. 1). It is volcanically dammed, endoheric, and terminal lake situated in the northern part of the Main Ethiopian Rift (MER) at the near distance to the Afar triangle-a triple junction where three sub-plates (*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 Matahara Sugar Estate (MSE) in the south and southeast side and Awash National Park (ANP) to the east (Fig. 1). The lake catchment has variable altitude ranging from 950 m at Basaka Lake to over 1700 m at Fentalle Crater (volcanic mountain). Owing to the location of Matahara area in the central rift valley region (upper part of Main Ethiopian Rift, MER), it is vulnerable to the occurrences of different tectonic and volcanic activities. This is evident from the observation of vast lava extrusions at the foot slope of mountain Fentalle (volcanic crater), dots of extensive scoriceous hills in the locality (Mohr, 1971), lava flows produced by the eruption in the northern part of the Lake in the 1980s (Halcrow 1978) and availability of a number of hot springs supplying Basaka Lake (Olumana 2010). The salinity/alkalinity level very high, not tolerable by most plants and animals. The lake catchment is about 500 km^2 and receiving an annual rainfall of approximately 0.28 billion m^3.

Analysis of the long-term (1966-2009) weather data of the area indicates that the Matahara plain is characterized by bimodal and erratic rainfall distribution pattern. The major rainy season occurs from July to September and the minor, occasional rain occurring between

February and May (Fig. 2). The potential evapotranspiration and temperature are always above rainfall except July and August. That means irrigation is necessary in the area for about 9-10 months as the rainfall is not sufficient in both amount and distribution. The long-term mean annual rainfall is about 543.7 mm and the mean maximum and minimum temperatures are 32.9 °C and 17.5 °C, respectively. The climate of the area, in general, is classified to be semi-arid (Olumana 2010).

According to the detail characterization of the soil and LUC units for Lake Basaka catchment by WWDSE (1999), there are nine soil types in the catchment (Fig. 3a), listed according to their decreasing areal coverage: Lepthosols (33%), TMP_L (17%), Cambisols (13%), Podzoluvisols (6%), Luvisols (5%), Podzol (5%), Fluvisols (4%) and Solnchaks (2%) (Olumana 2010). The remaining proportion (≈15%) is covered by Lake, island and lava flow. Lepthosols, the predominate soil type in the catchment, are characterised as course textured, shallow soil with weakly developed soil structure, occupying the western part of the catchment and mainly covered by open bushy woodlands (Fig. 3b). Cambisols is a well-drained, deep and medium- to coarse-textured soil unit mainly occupyied northern part of the watershed (west part of the lake) and is mainly covered by open grassland and bushland. TMP_L are mountain soils mainly found on Fantalle Crater in the northern part of the catchment, occupied by forestlands and dense woodlands. Podzoluvisols are a well drained, medium to coarse textured soil, very deep with moderately developed structures. It is mainly found in the southeastern part of the catchment. The southern part of the lake (Abadir side) is occupied by Luvisols and the immediate northern part is occupied by Lava flow (WWDSE 1999; Belay 2009; Olumana 2010).

3. METHODS

3.1. Landsat and Ancillary Data

In the current study, an attempt was made to use LANDSAT imagery, which started observation in the early 1970s. Four series 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 surrounding. The times of image acquisition were during non-rainy season (Table 1).

Ancillary data such as Digital Elevation Model (DEM), digital plantation's (base) map and topographic maps were collected from different sources. The DEM (90m 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 the surrounding features. The digital plantation base maps (CAD format) showing all the roads, irrigation and drainage networks, field plots, and Awash River were collected from MSE. The 1975 Matahara topo-sheet (scale 1:50,000) was purchased from the Ethiopian Mapping Authority (EMA). Meteorological data was collected from the database of the sugar estate and friends Furthermore, other secondary data such as soil map and LUC information were obtained from other reports (e.g. WWDSE 1999; Ayenew 1998, 2007; etc), FAO Soils (FAO, 1990) and EthioGIS. Oral information regarding the lake condition since its formation was also gathered from the indigenous Karrayyuu people, management body of Middle Awash Control Authority, MSE professionals. The condition of lake and its catchment was also observed by the author during field work (2007-2010).

3.2. Pre-processing

An intensive pre-processing such as geoferencing, layer-stacking, resolution merge, sub-setting were carried out in order to orthorectify the satellite images into UTM coordinates (WGS 1984, Adindan) and in order to remove disturbances such as haze, noise, steep slope effect, radiometric variation between acquisition dates. The satellite images were registered with the available topographic map of the project area and digital plantation's base map in ArcGIS by matching some of the identifiable features like crossing of roads, railways, river, irrigation canals, bridges etc on both the base map as well as on the satellite image. All the images were referenced to the required accuracy (RMSE<5m) by selecting ten representative points with good distribution. The images were then processed in ERDAS Imagine 9.1 (ERDAS 2006) The raw multiple satellite images were imported and stored in *.img format in the ERDAS Imagine 9.1.

3.3. Satellite Image Processing

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

3.3.1. Unsupervised classification

Unsupervised classification was done for the enhanced images. First ISODATA (Iterative Self-Organizing Data Analysis Technique) clustering technique was performed in order to group the similar pixels into clusters by setting 50 spectral classes with maximum iteration of 15 and convergence threshold of 0.95. False color composite (FCC) or pseudocolor of the mask file was created for each satellite image using appropriate band combinations since all the images were taken during dry seasons (December to February) (Table 1) and was used as indicator for the different land cover categorization based on the visual elements. That means visual interpretability of the color composite (FCC/TCC) is pre-requisite for image classification and plays significant role for the success of land cover classification.

The signatures from unsupervised classification were aggregated into LUC categories according to the description given in (Table 2). Then, the easily identifiable classes were categorized into LUC units to create appropriate signatures for the supervised classification. Those classes hardly possible to separate were retained without assigning into land-cover category. Some of the unidentified similar classes were cluster busted into the other identified classes by user-defined training identification technique.

3.3.2. Supervised classification

To evaluate the above-mentioned classes before performing supervised classification, 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 were interpreted as per Jensen's (1996) general rule: the classes can be separated very well above 1900; the separation is fairly good between 1700 and 1900; and the separation is poor below 1700.

User-defined training sites (pixel-wise) were defined on an area of interest (AOI) for known cover types in addition to the training samples obtained from unsupervised classification. These training sites were necessary to define classes that did not get classified uniquely during the unsupervised classification (Shetty et al. 2005). Especially, the 1973 MSS image classified the lake and wetland/lava flow into the same cluster and these were re-clustered into different land-cover categories by user defined clustering set. Appropriate band combinations were obtained and adopted (by trial and error procedure) while 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) parameteric decision rule. ML classifiers are the conventional image classification algorithms widely employed in most of the LUC change monitoring studies (Rogen and Chen 2004).

3.3.3. Accuracy assessment

Accuracy assessment of the classification was done for the LANDSAT ETM+ 2000 image 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 map for this particular period only, which was produced by WWDSE (1999) by detailed field investigation. Certain pixel-wise true data were obtained from the actual field observation and WWDCE (1999) map randomly, and then 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 the three accuracies (*user's accuracy, UA, producer's accuracy, PA and overall accuracy, OA*) and kappa coefficient (*conditional, K' and 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):

$$REA_k = \left(\frac{1}{UA_k} - \frac{1}{PA_k} \right) * 100 \quad (1)$$

where, UA and PA are the user's and producer's accuracy for class k, respectively.

3.3.4. Post processing and change analysis

*Post-processing su*ch as clump, sieve, filtering (majority) operations were applied in order to eliminate local variability, 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). Then, sub-setting of the classified and smoothened image for the delineated lake catchment was made. In general, the followed procedures are illustrated in flow chart (Fig. 4).

The areal coverage, annual rate of change, change rate and relative change were tabulated for each LUC types. The annual deforestation (change) rates were calculated using the following formula (Puyravaud 2003, cit. Etter et al. 2006b):

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

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

4. RESULTS AND DISCUSSION

4.1. Pre-processed Colour Composite Images

Fig. 5 illustrates the True Colour Composite (TCC) of the raw Landsat TM 1986 image. TCC indicates the true color of LUC condition in electromagnetic (EM) spectrum, whereby bareland/rock, vegetation, and water are represented by red (R), green (G) and blue (B) MS bands, respectively. Accordingly, the different LUC condition can be visually interpreted.

Sugarcane farms (WSSE and MSE), Lakes (Koka Dam, Basaka and Ziway), forests (evergreen), etc can be identified. Deep green in TCC indicates matured crops or dense evergreen forests. Riverine forests also identified along the course of Awash River. The three lake waters have different reflectance colour on the TCC image. Koka Dam (*originally named Gallila Lake*) is represented by blue colour (i.e true colour of water); whereas Ziway and Basaka Lakes are represented by dark blue and blue black colours, respectively. The difference in colour may be due to the ionic concentration (especially Bromide content) of the respective lakes. Visual interpretability of the colour composite provides valuable information for identification of different LUC classes and hence, the basic for LUC classification.

4.2. Land Cover Mapping

The spatio-temporal 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 supervised (ML) classification exercise for the different considered periods (1973, 1986 and 2000) are shown in Fig. 6. Be note that the year 2008 was not included in LUC map since it is almost the same as that of 2000. From the analysis seven major LUC classes were identified: forestlands, bushy woodlands (open), shrubland, grassland, water (lake), farmlands, and wetlands/Lava flow (Fig. 6).

Classification Accuracy Assessment

The confusion matrix (classification accuracy) assessment report is summarized in Table 3. Note that swamps/lava flows are not included in accuracy assessment report owing to their size (smaller) compared to the other LUC type. Only seventeen total errors were found from the total 135 classified samples. Two samples of farms were labeled 'change' on the classified map, but were 'not changed' on the reference data (commission error). Moreover five samples (i.e. 2 forests, 1 shrub, 2 bare land with open shrubby woods) were labeled 'no change' on the classified map, but actually did change (omission error). These indicate 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).

However, reliable and acceptable OA and K vales were obtained, with PA and UA values very close to each other for this classification analysis (Table 3). These indicates the good image classification at the reasonable accuracy as well as the very high reliability of landscape matrices of spatial configuration (Shao and Wu 2008). K varies between '+1.0' for perfect agreement down to '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. The highest value was 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 and close to zero for each LUC unit. REA<5% is acceptable and even the classification was achieved within REA<1% (Table 3). Forest land detection in the area, as revealed by its relatively lower PA and UA, was relatively difficult since its reflectance is similar to matured sugarcane and citrus crops. In addition to that, the reflectance from 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 degree of spatial resolution to be classified accurately because their reflectance is almost different from other LUC units in the area.

4.3. Change Analysis

The areal statistics (area, net change, rate of change and relative change) for different LUC units are summarized in Table 4. The lake catchment experienced a rapid change in LUC in the past 4-5 decades. However, the individual LUC units did not experienced the same trends and relative changes in 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. Forest and grazing lands had fallen noticeably by about 18,924 ha (86%) and 4,730 ha (50%), respectively, in the period 1973 to 2008. Shrub land showed almost stable coverage throughout the periods. Around 4300 ha of grazing land was lost due to the expansion of lake and the remaining (430 ha) due to formation of lava and land degradation (mostly erosion).

Furthermore, the relative loss and gain of forest and open bushy woodland (i.e., 18,924 ha (36.2%) and 18,006 ha (34.6%), respectively) in the past 35 years (1973-2008) was almost comparable. That means forest lands were mostly changed to bushy wood lands, which are open and sparse in coverage. The decrement of grazing land (4,730 ha) and expansion of lake water (3,831 ha) were approximately equal, indicating the expansions of the lake and wetland were almost at the expense of the grass land. Since 1980s (Table 4) the expansion of the lake was also 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 the lake water since the mid of 1990s. Grass and farm lands were susceptible to the expansion of the lake due to their location at lower elevation and at a very close proximity to the lake.

The knowledge of the dynamics of LUC changes may be useful to construct the past and predict the future possible changes (Hietel et al. 2004). Therefore, the temporal changes of cover types could be identified and forecasted. The pre-change cover type could be observed from the land cover classified for the 1973 Landsat MSS image and the post-change cover type (predicted for future) could be observed from the trends of the LUC change in the catchment in the past 4-5 decades. The 1973 image clearly indicates that the area had a very rich vegetation cover before 1970s, which was evident from the 85% areal coverage by forest, shrubs and grasses and also witnessed by the indigenous peoples of the locality. Before introduction of irrigated agriculture (end of 1960s), according to local witness, the lake catchment area was covered by thick forests and occupied by different animal species. Since 1970s, the lake catchment had undergone a significant change in LUC. For example, the total areal coverage of forests, shrubs and grasses in the year 2000 was about 41.7%, indicating the total loss of 43.3% within 3 decades. This was due to the rapid increment in deforestation, cultivation, settlement, lake expansion, wetlands, etc (Olumana 2010). A similar LUC trend could be expected in the future, and hence the land cover condition may deteriorate even further. Deforestation in the area had a negative impact on the catchment; may result in the change of hydrologic condition of the catchment and change the regimes of water balance of the lake. These, in turn, had an impact on the livestock balance in the catchment and sustainability of irrigated agriculture in the region, which ultimately brings both social and economic instability.

4.4. Demographic Pressure on LUC Change

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

The intensification and diversification of agricultural land use in the lake catchment as well as the establishment of Awash National Park and the availability of highways has brought various pressures on the lake catchment's LUC condition. Commercial agriculture was introduced to the area at the expense of forestland, woodlands, shrubland and grassland. Settlement and in-migration into the area increased due to the relatively good job opportunity in the commercial farms. And the good transport facilities in the region enhanced business activities. For example, the establishment of MSE alone has added more than 28,000 people to the area (Fig. 8), almost all of them are in-migrants. Furthermore, the indigenous people (pastoralists and semi-pastoralists) were confined in the catchment due to the loss of their land by agriculture, lake, settlements and the land demarcated for ANP. The population pressure on the catchment comes mostly from outside the catchment: Matahara, MSE, Fantalle, Wolanchiti, Awash, etc.

Eventhough there is no clear justification for Lake Basaka catchment, the link between population, LUC change, land degradation and water quality deterioration have been suggested for Lake Nakuru catchment in Kenya (Yillia, 2008) in the rift valley basin. However; there are certain indicators for the link of these variables for Lake Basaka catchment too. The population growth has increased the demands for food, water, fuel woods, charcoal and housing. The wood/forest lands are mostly destroyed due to the need for house construction as well as for charcoal production, which is the source of income for some of people dwelling in the catchment and nearby area. The people are competing on scarce natural resources for survival and sometimes conflicts between communities are the result (e.g. Karayyuu and Isa) (see Gebre 2004; Elias 2008).

4.5. Effects of Rainfall Variability and LUC Change on Lake Fluctuation

The annual fluctuations of rainfall (as Standard Precipitation Index, SPI) and lake level are illustrated in Fig. 9. It should be noted that the period between 1976 to 1999 is used for comparison since the lake stage measured data collected from different sources is limited to that period only and most of the reported evidences (e.g. WWDSE 1999; Ayenew 2004, 2007; Belay 2009) considered the same period. SPI value <-1.5 are considered to be severe drought. On the other hand, the SPI vale >1.5 are considered to be extremely wet (McKee et al. 1993, cit. Khan et al. 2008). Accordingly, the years 1973, 1984 and 2002 are extremely dry (strong El Nino) years and the years 1967, 1983 and 2008 are extremely wet (strong La Nino) years. Even, 1984 is always remembered in Ethiopians by the severe drought and the associated famine, which resulted in significant losses of life and property.

The effect of the extreme climatic (rainfall) events on the lake level records and the stochastic behaviour of the extremes (maximum and minimum) on the lake regimes can be realized from 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 is extremely wet period (strong La Nina) in the recorded history in the region (1966-

2007). Wet years correspond to an increase in the lake stage; wheras dry years exhibit a decline in lake stage.

The lake level is highly variable, mostly following the patterns of rainfall distribution. However, the monthly and annual lake level fluctuations is reduced post-1990s and are almost following the same general trend (gain of about 0.18 m $year^{-1}$), though the rainfall pattern is slightly reduced. As discussed earlier, this period (post-1990s) is characterized by significant LUC change in the lake catchment (Table 4). These characteristics of the lake level fluctuation can be an evidence for the responsibility of other factors, other than rainfall variability, for the expansion of lake in recent years (post-1990s), depending upon the balance between the inflow and outflow components of the lake.

The effects of LUC change on hydrologic processes can be clearly realized from Table 5. Eventhough the rainfall in the area is relatively stable; the hydrologic processes (runoff, erosion rate and sediment delivery rate) showed increment at different periods considered. The sensitivity analysis made by Olumana (2010), in his comprehensive water balance analysis, confirmed that about 80% of the increment in hydrologic processes (surface runoff and soil erosion) in the lake catchment post-1990s are due to LUC change and the remaining proportion (20%) is due to rainfall variability.

4.6. Implications of LUC Change to the Environment

There is a significant change in LUC, as explained above, due to various reasons, which could lead to different environmental effects such as land degradation (deforestation, erosion, sedimentation) and flooding (surface runoff). The catchment was rich in vegetation cover (highland forests) in early 1960s, but changed from 42.2% to 6% in 2008. Deforested lands are exposed to the impacts of raindrops, which may accelerate the detachment, removal and transport of soil particles and its associated consequences (Morgan 1986, cit. Olumana 2010). Conversion of native tropical forests to other land cover types may produce permanent changes in annual stream flow (Bruijnzeel 2004). The catchment received attention in recent periods mainly because of its environmental and socio-economic problems and related political decisions.

LUC change has crucial impact on the hydrology as well as the dynamics of lake water balance (both quantitatively and qualitatively). Consequently, the significant change in LUC is expected to result in increased surface runoff (or reduction of infiltration), ET (due to the rising temperature), erosion and sediment yield. Furthermore, since the lake is the outlet/pour point for the catchment, an effect on the regimes of lake water balance is apparent. The increment of runoff and erosion rates in the lake catchment (Table 5) was already reported by Olumana (2010). As clearly indicated in the table, runoff coefficient, CN and erosion rates showed significant increment after mid 1980s. This condition coincides with the period of significant LUC change in the region.

Water erosion is a common problem in Ethiopia, which is, apart from other factors, governed by the patterns of land cover and types of conservation measures practiced, which is also true for the Basaka Lake catchment. The area is prone to the effects of runoff and erosion due to its topographic, soil and climatic conditions. Hence, the LUC change occurred in the catchment, as revealed in Table 5, could be one of the main factors for the expansion of the lake level and brings great environmental hazards to catchment. The recent LUC, its history and spatio-temporal dynamics is very important in order to understand the complex interactions between environmental and socio-economic factors occurring in the lake catchment.

5. SYNTHESIS AND CONCLUSION

The satellite image analysis showed that Lake Basaka catchment had undergone a drastic change in the LUC in the last 4-5 decades due to the rapid increase in human settlement, deforestation, establishment of irrigation schemes (MSE and Nura-Era) and Awash National Park. Population pressure in the area had brought competition on scarce resources for survival and sometimes resulted in conflicts between different societies. It seems that the demographic pressure may continue similarly or it may be accelerated. The significant change in LUC may have adverse effects on the environment (e.g. land degradation, drought and/or flooding) as well as socio-economics. Forestland and grassland sharply decreased in the study area while lake size and open bushy woodland increased both spatially and temporally. Shrubland and lava flow stayed relatively stable. From 1973 to 2008 approximately 18924 ha of forest and 4730 ha of grazing lands were devastated. The majority of the lost grassland area was overtaken by the lake water.

Generally, the increment in lake water and bare lands were at the expense of forest and grazing lands destruction. Grasslands and farmlands were susceptible to the expansion of the lake due to their close vicinity to the water. More than 400 ha of cultivated lands and 2000 ha of productive lands were flooded by the lake water since the mid-1990s. At the same time, there was a shift of land cover from forest/woodland to open woodland, shrub lands and grazing land. The relative decrement in forest coverage (18921 ha) and increment in open bushy woods (18006 ha) were approximately equal. This reveals that most of the forest land was converted into bushy woodlands. Farmland showed a significant increment in the first period (1973-1986) due to the establishment of Abadir sugarcane farm at full scale, which slightly decreased since then. This may be due to the inundation of parts of Abadir-E land by the lake and/or due to the difficulty in separating farmland from grassland or bare land during dry periods. Generally, the lake water, wetlands/lava, open bushy woodlands and farmlands showed an increment of about 5-fold, 4-fold, 3-fold and 1-fold respectively.

The study result also revealed that the level fluctuation is generally flowed the patterns of rainfall variability until the end of 1980s. The lake level continued increasing post 1990s irrespective of the rainfall fluctuations and slight decrement in average values. This period coincides with the significant LUC change occurred in the region. Hence, it is logical to suggest that rainfall variability and LUC change had contributed for the lake level fluctuation. However, LUC change is found to be mostly responsible for the change in regimes of hydrologic processes within the lake catchment.

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Table 1. Details of satellite data used in the study

Sensor	Path/Row	Cloud Cover (%)	Resolution (Pixel size)	Acquisition Time
Landsat – MSS	180/54	0	57m * 57m	Jan, 1973
Landsat – TM	168/54	0	30m * 30m	Jan, 1986
Landsat – ETM+	168/54	0	28.5m * 28.5m	Dec, 2000
Landsat – ETM+	168/54	0	28.5m * 28.5m	Feb, 2008

Table 2. Characteristics of the land covers classes identified in Lake watershed

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

- *Note that water is not described.*

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

Land Cover Class	Classified Totals	Number Totals	Number Correct	K'	Accuracy (%)		
					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 and relative change) for different 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)	22073 (42.2)	12939 (24.7)	9555 (18.3)	5563 (10.63)	356 (0.7)
	1986	2943 (5.6)	4585 (8.8)	11054 (21.1)	12161 (23.2)	6568 (12.6)	14261 (27.3)	748 (1.4)
	2000	4168 (8.0)	2500 (4.8)	3887 (7.4)	12755 (24.4)	5188 (9.9)	22312 (42.6)	1500 (2.9)
	2008	4585 (8.8)	2344 (4.5)	3152 (6.0)	12075 (23.1)	4821(9.2)	23569 (45.0)	1655 (3.2)

* value in parenthesis are the percentage areal coverage.

Period	Year	Water (Lake)	Farms	Forests	Shrubs	Grasses	Bushy woods	Swamp/ Lava
II. Net change (ha)								
1	1973-1986	2190	3505	-11019	-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	-18921	-864	-4734	18006	1299
IV. 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
V. 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

Table 5. Estimated values of rainfall, CN, runoff, 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
Runoff (mm)	37.2	79.3	108.3	119.80
Erosion rate (tons ha^{-1} yr^{-1})	45.1	87.2	107.3	107.0
Sediment rate (tons ha^{-1} yr^{-1})	5.4 (very low)	17.0 (low)	26.8 (moderate)	27.8 (moderate)

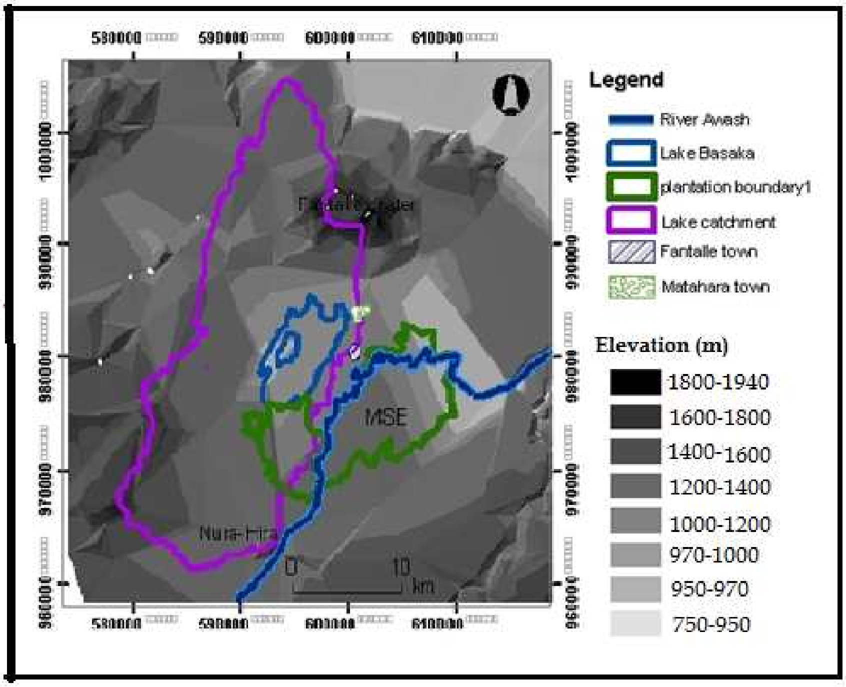


Fig.1 Matahara plain and the surrounding: topographic view from DEM

124x95mm (120 x 120 DPI)

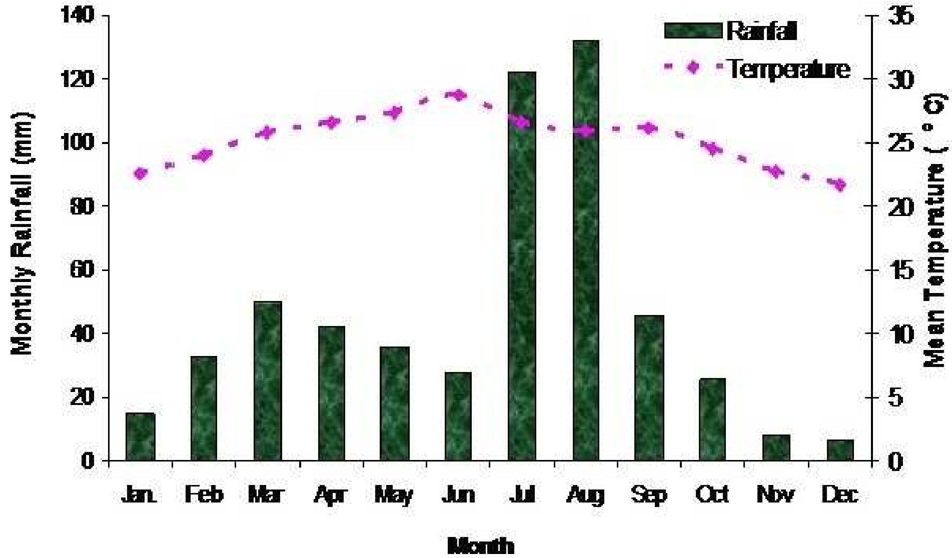


Fig. 2 Mean annual seasonal variability of rainfall and temperature in Matahara Area (1966-2010)

167x122mm (96 x 96 DPI)

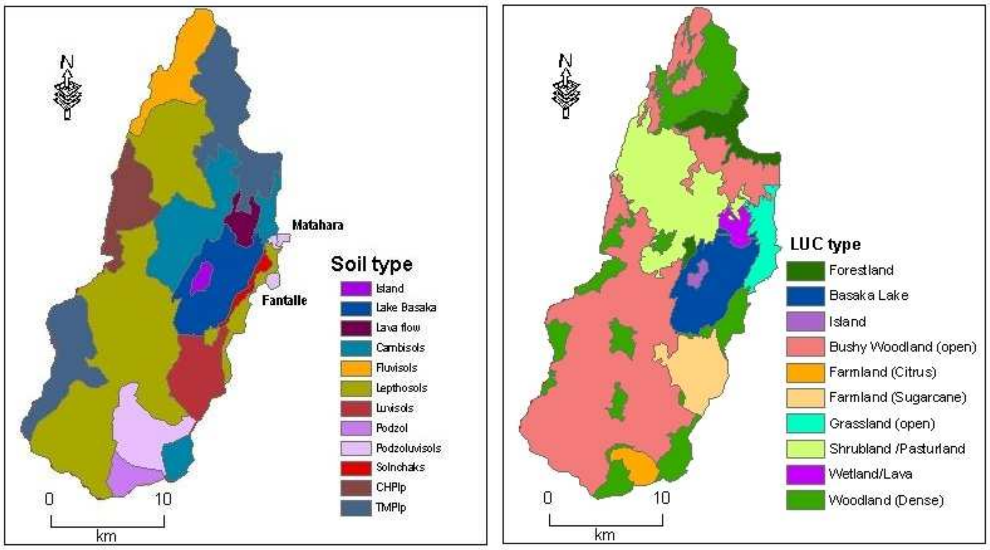


Fig. 3 Pedogenic (left) and land cover (right) characteristics of Basaka Lake Catchment. Note that LUC is for the year 2000 (modified from WWDSE)

168x113mm (120 x 120 DPI)

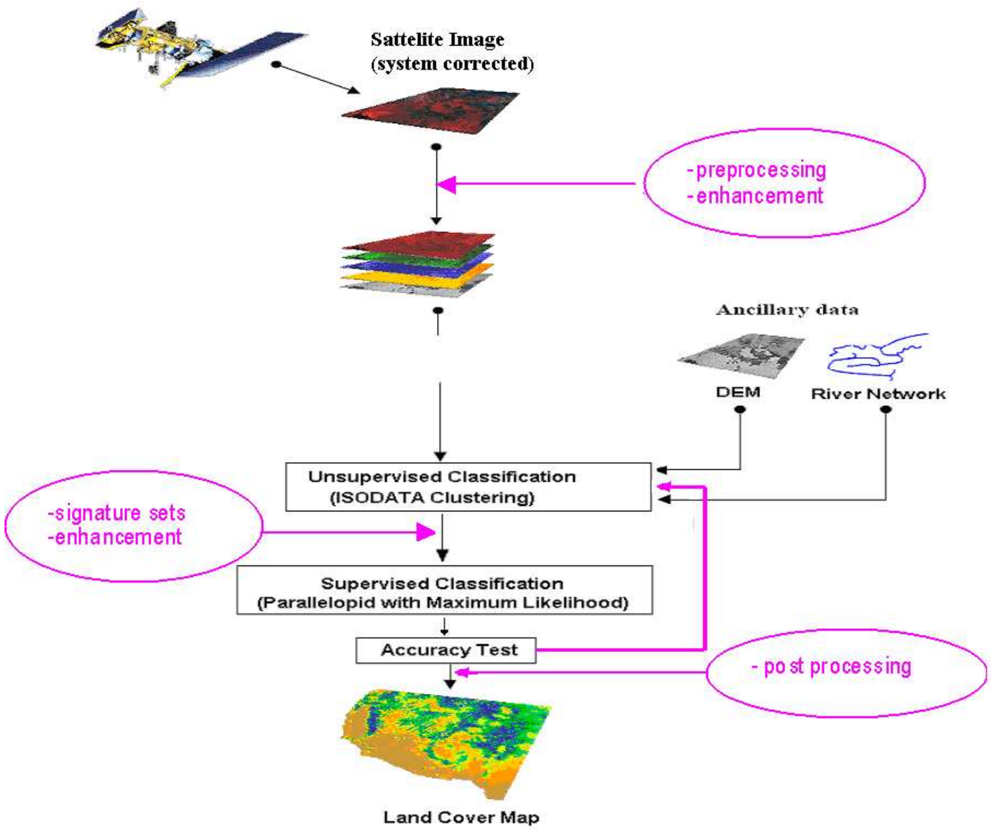


Fig. 4 Flow chart used for land use/cover classification

193x175mm (120 x 120 DPI)

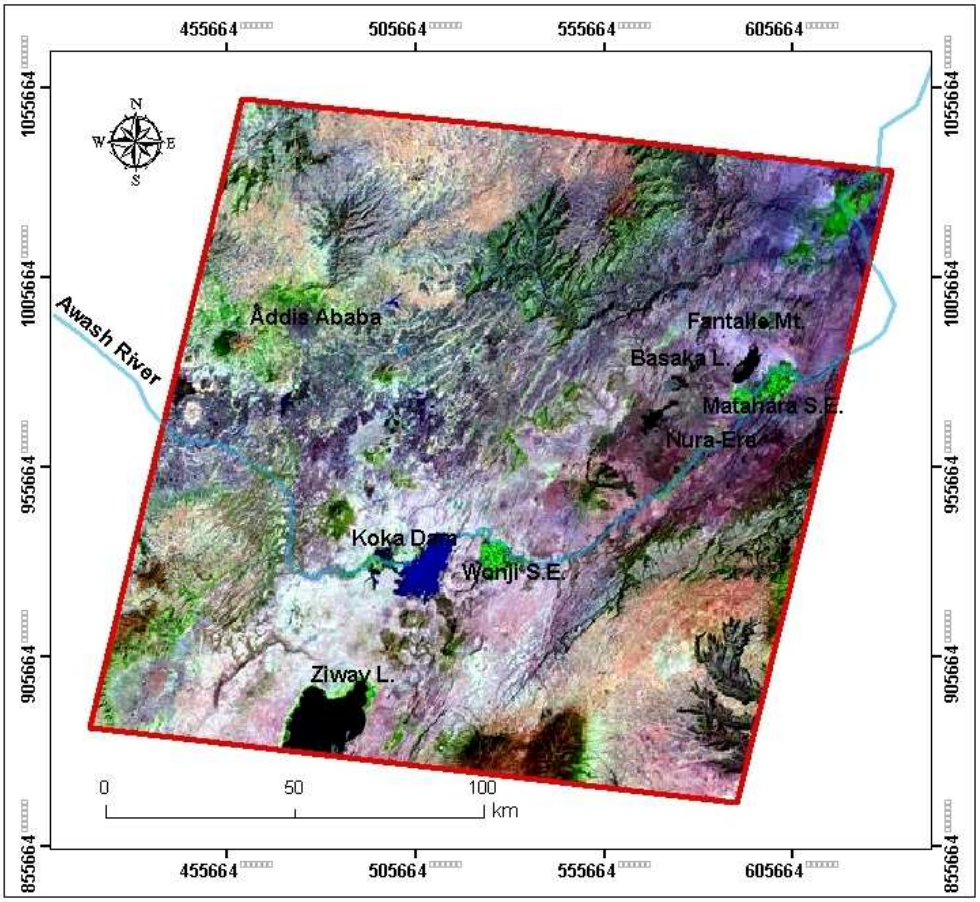


Fig. 5 True Colour Composite of raw Landsat TM (1986) image

155x151mm (120 x 120 DPI)

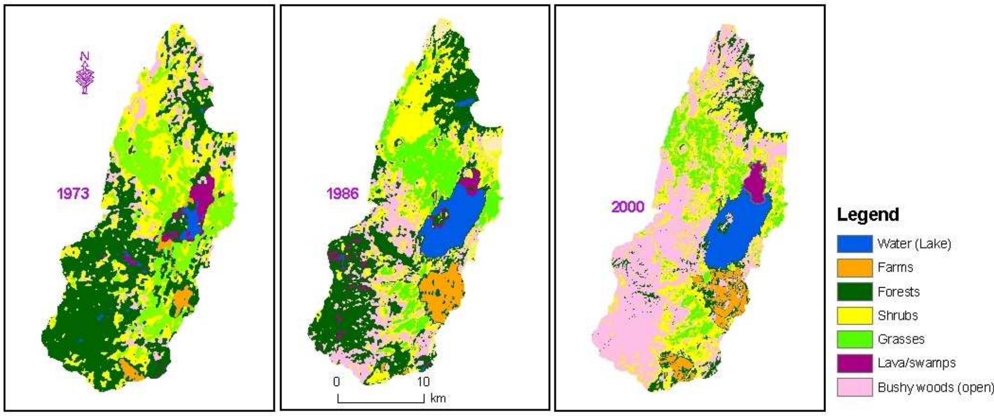


Fig. 6 Land-cover maps in Lake Basaka Catchment (1973, 1986 and 2000)

223x107mm (120 x 120 DPI)

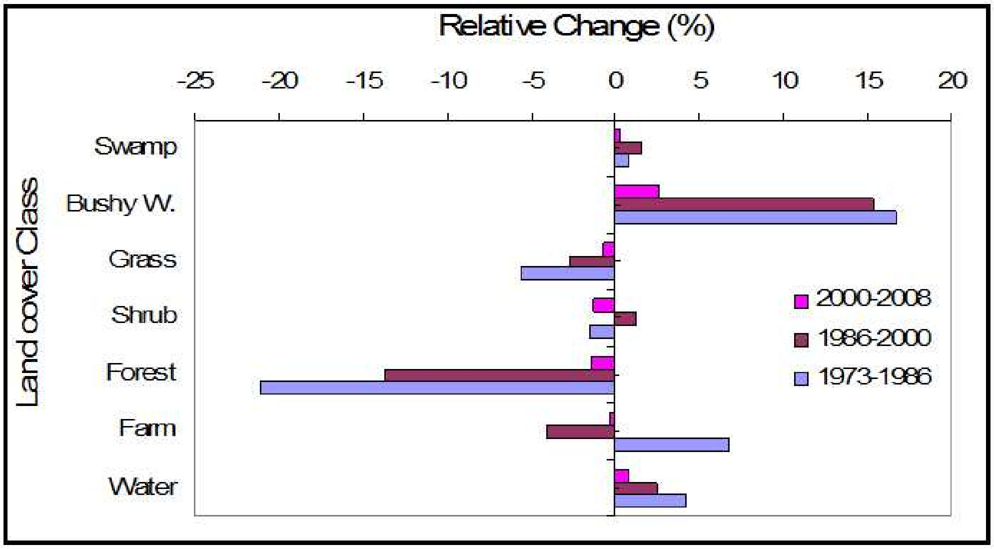
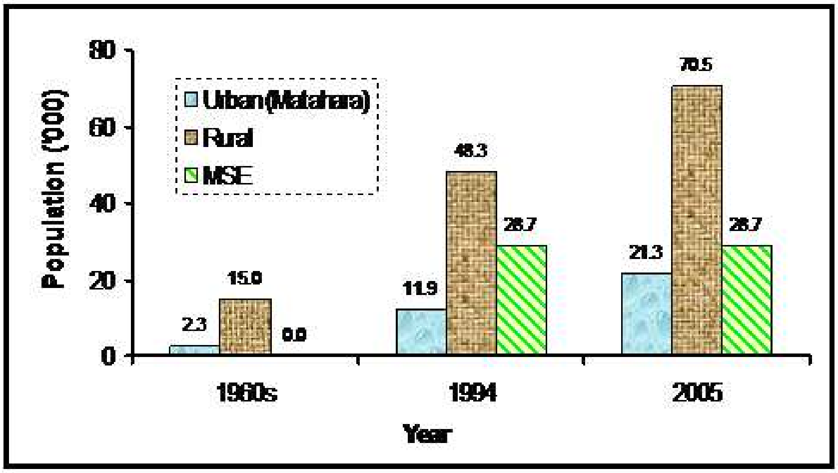


Fig. 7 Relative changes in LUC in Lake Basaka Catchment in different periods

147x97mm (120 x 120 DPI)



* Back-projection for 1960s considering annual population growth of 3.5%

Fig. 9 Population dynamics in Fantalle Woreda (data source: CSA 1994, 2005)

122x78mm (120 x 120 DPI)

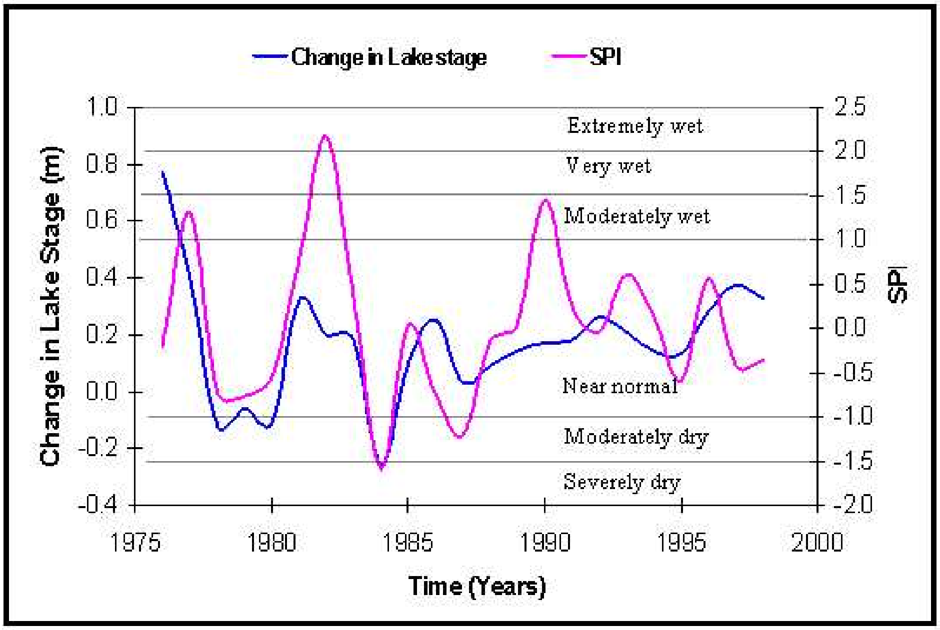


Fig. 8 Change in Lake stage and Standard Precipitation Index

The characteristics of SPI was adopted from Mckee et al. 1993 (Khan et al. 2008)

121x94mm (120 x 120 DPI)