Delineating the decadal expansion of Lake Basaka (Ethiopia) using various image interpretation techniques

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Abstract. Lake Basaka is expanding at a significant rate. Before the establishment of Matahara Sugar Plantation, the lake was like a small surface pond created during rainy season and used as grazing area. The lake expansion has certain negative consequences to the region. Thus, appropriate method of quantification of the Lake expansion is extremely important. In this particular study, the areal expansion of the Lake Basaka and sugarcane plantation was analysed. Four LandSat images (1973, 1986, 2000 and 2008) were taken for the cloud-free period and processed in ERDAS Imagine and ArcGIS softwares. Three techniques were employed in the delineation of the areas of the lake and plantation: visual interpretation of FCC in GIS, enhancements and advanced classification in ERDAS Imagine. The study result shows that Lake Basaka expansion is very significant and the increment is geometric rather than linear. Overall, the finding indicates that visual image interpretation gives a fast and accurate indication of the Lake Basaka expansion compared to image enhancement and classification techniques.

1. Introduction
Lake Basaka is expanding at a significant rate [1-2] as opposed to the other Ethiopian rift valley lakes, which are shrinking [3-4]. The total surface area of the lake is estimated to be about 50 km² in the year 2015 [5], which was about 3 km² in the 1960’s [3-6]. Before the establishment of the Matahara Sugar Estate (MSE) in the 1970s, according to the information from elders of the indigenous (Karayayuu) people, the Lake was like a small surface pond created during the rainy season and used as grazing area and watering for their livestock during the dry season.

The lake expansion has certain negative consequences to the region. The lake expansion affects the surface- and ground-water dynamics and soil properties of the region and the condition is specifically dangerous for the sustainability of MSE and Matahara town in particular and the Awash basin irrigation development in general [2]. An appropriate method of quantification of the Lake expansion is extremely important.

This study was initiated with the objective to determine the expansion extent (spatio-temporal) of Lake Basaka in the past about 40 years using different image interpretation techniques. Four LandSat images (1973, 1986, 2000 and 2008) were taken and processed in ERDAS Imagine and ArcGIS softwares. Satellite image processing is a digital techniques consisting of a number of operations and modules as expedients to elucidate the information contents of images to the utmost [4]. Various satellite image interpretation methods and techniques have been in use. The three most widely used image interpretation techniques are visual interpretation, enhancement and image classification. Visual
satellite image classification techniques are robust, effective and efficient methods, but time consuming [7].

2. Methodology

2.1. Brief Description of the Study Area
Lake Basaka is located in the Middle Awash Basin, central rift-valley of Ethiopia at about 200 km SE of the capital city, Addis Ababa. Matahara area is situated on a nearly levelled plain (slope < 3%) surrounded by mountain chains of variable elevation in the south, south east, south west and north west (Figure 1). The area is situated in the central rift valley region and hence vulnerable to the occurrences of different tectonic and volcanic activities. As a result, the area is characterized with features of past & recent volcanic events [1-2, 4, 8]. Matahara area is characterized by bimodal rainfall distribution pattern with mean annual rainfall of about 543.7 mm. The long-term mean maximum and minimum temperatures are 32.9 and 17.5 °C, respectively. The climate of the area, in general, is classified to be semi-arid.

![Figure 1. The Study Area: (a) Location; (b) TIN view of the study area and the surrounding escarpments as created from the DEM](image)

2.2. Satellite Image Acquisition, Processing and Interpretation
Four series of Landsat images (1973-MSS, 1986-TM, 2000-ETM+ & 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 covered both Matahara & Wonji Sugar Estates. The Digital Elevation Model (DEM) 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/extracted in ArcGIS (9.2) [9] for the study area and the surrounding features.

Then the satellite images with good resolution (panchromatic) was georeferenced with the base map (topomap and plantation map) of the project area to the required accuracy (<30m) in GIS and then the other images were registered with the already georeferenced image (image-to image registration) in ERDAS Imagine by matching some of the easily identifiable features (like crossing of roads, rivers, railways, irrigation/drainage canals, bridges, etc) on both the map and images. The images were imported to ERDAS Imagine [10] and ILWIS softwares for identification of important features using the different image interpretation techniques. The image geometric and radiometric corrections were carried out in ERDAS Imagine. Then the images were converted to false colour images (FCC) in ERDAS and imported to GIS for delineation based on the different interpretation (visual) elements such as tone, shape, hue and association/pattern in addition to colour.
After testing the different image enhancement techniques, the filtration, histogram equalization, brightness inversion, stretching and indices were adopted depending upon the Landsat type. High pass filtering (high frequency kernel) with user defined Laplacian (non-directional) edge filter, which has the effect of increasing spatial frequency [11] was used in order to bring edge between homogeneous groups of pixels. This technique is especially useful for some areas of the image where the agricultural plots and some line features such as roads are not clearly visible. A stretch (histogram equalization) and brightness inversion operations were carried out as a radiometric enhancement after making a haze and noise reduction for the TM images. Spectral enhancement techniques using the application of specific band ratios (indices) such as Normalised Difference Vegetation Index (NDVI), Time Composited Normalised Difference Vegetation Index (TNDVI), Salinity Index (SI), Normalised Difference Salinity Index (NDSI), Normalised Difference Water Index (NDWI) were employed for the different Landsat types following standard algorithms [1, 4, 12-14].

Furthermore, image classifications (supervised and unsupervised) were done for each the images in ERDAS. First the unsupervised classification was carried out, which are useful for selecting training areas for the supervised classification system. The training samples for the supervised classification (maximum likelihood) were identified using user-defined polygon in the area of interest (AOI). The class from a thematic data layer of the results of the unsupervised classification was used to select the parametric signature for each class. These training samples were used to create the parametric signature of each class based on field observations and image data file values.

3. Results and Discussion
The shapes and areas of Lake and sugarcane plantation were delineated by the three image interpretation techniques and the results are summarized in Figure 2. Based on average values, the surface area of the lake increased from 1028 ha in 1973 to 4337 ha in 2008. Similarly, the sugarcane plantation area increased from 6105 ha to 13151 ha in the same period. The average of the three image interpretation indicates that Lake Basaka expanded by about 2017 ha from 1973–1986, which is about 150 ha/year considering linear increment. From 1986–2000, the expansion is about 875 ha, which is 63 ha/yr. In the period 2000–2008 the total expansion is about 417 ha, which is 52 ha/yr.

As evident from Figure 2, the expansion extent of the lake is very terrible and creates a great developmental challenge in the Awash basin. The lake has a potential to join Awash River in the near future [1-2, 4]. The expansion of the lake has negative socio-economic and environmental impacts in the region, especially the nearby sugarcane farm and villages.

![Figure 2. Area of Lake Basak: comparison of the three image interpretation techniques. Note that the fitted equation is the 2nd degree polynomial.](image_url)
3.1. Visual Interpretation Techniques

Satellite Images can be interpreted using the different visual interpretation elements such as structure, tone, texture or shape variations in individual bands. However, the precise identification of some features is very difficult from a single band. The use of false colour composite images provides an aid for better and faster visual interpretation. Thus, the images for the different periods were converted to FCC (RGB) (where the red (R) indicates vegetation, the green (G) indicates the bare soil and the blue (B) represents the presence of water) so that it is easily interpretable to human naked eye.

Different band combinations were adopted depending upon the sensor type: 4-3-2 for MSS images and 6-4-1 for TM and ETM+ images. Monoscopic visual interpretation of the standard FCC were carried out using the combination of different visual interpretation elements such as tone, shape, hue, pattern, texture and association. The colour of Lake Basaka is not blue, rather deep dark to dark blue and observed to be black in the FCC (see Fig. 2). Since the vertisols (volcanic soils with inverting property) near the lake are also showing almost similar colour, the texture was used an important visual element to differentiate the tonnage. At the interface between the two (Lake and soil), the DN (Digital Number) values are changing abruptly and used as demarcation.

The 1973 MSS image, even after FCC, is difficult to identify the shape of the lake by naked eye and makes the visual interpretation difficult and unrealistic. Agricultural plots are easily identified and visually observe as the area is in semi-arid climatic zone and the images were taken during dry period (Dec-Feb). In the area, only sugar farms are available during these periods and hence, the hue, size, shape, and texture of the plantation areas are identifiable, which can also be easily delineated from the base map of the area.

3.2. Image Enhancement Techniques

The three image enhancement techniques (spatial, radiometric and spectral) were applied depending upon the sensor type. After checking the different spatial enhancement techniques, the textural analysis and non-directional edge filter were used. Figure shows the results of the texture analysis of layer-stacked image for the 1986 image. The left image is the texture analysis for layer combination 6-4-2 and the right image indicates the 4-3-2 combination. From the two images, the boundaries of the two images can be delineated easily.

Figure 4 (left) illustrates the results of user defined Laplacian (non-directional) edge filtering operation and Fig. 3 (right) shows the brightness inversion as radiometric enhancement technique for the 2000 ETM+ image. It can be clearly observed from the Figure 3 that the brightness inversion is better than the non-directional edge filtering since it gives a clear demarcation between the Lake and
the vertisol (volcanic soil) in the north side of the lake. Also it gives a clear distinction between soil (bare/ploughed) and vegetation cover.

The use of spectral enhancement (using indices) is more useful in extracting features as compared to the other spatial and radiometric enhancement techniques. After checking the different spectral enhancement techniques, the indices including NDWI, NDSI and TNDVI were used. Therefore, the different indices were selected for the different images and used for the preparation of the map of the lake. For the 1973 MSS image, NDSI gave satisfactory results and for the 1986 TM image, TNDVI was adopted. For the 2000 and 2008 ETM+ images, NDWI was adopted to produce the final map (shape and expansion) of the lake.

Figure 5 indicates the results of spectral enhancement using TNDVI and NDWI. The results of NDWI (Figure 5, right) indicate that the sugarcane (matured) has the highest value and water has the lowest value and therefore, the Lake and the plantation area can easily be delineated. Therefore, the salinity index (SI) of the Lake Basaka is as high as \((1/0.42=2.38)\). The SI of some of the crop field is as low as \((1/2.17=0.46)\). This value indicates that the Lake Basaka has at least SI as high as five times that of the plantation soil, which is also confirmed from their measured EC values.
3.3. Image Classification
Image classification forms an important tool for examination of the digital images produces a map like image as the final product of the analysis [14]. Here the Landsat images were classified in ERDAS Imagine [9] in order to delineate the Lake and plantation areas. The accuracy values were checked and found to be within the acceptable range. The good accuracy obtained was due to the fact that the classification signatures used were obtained from unsupervised classification followed by training samples. The results of supervised classification (maximum likelihood) are shown in Figure 2.

3.4. Quantitative Evaluation of the three Methods
As observed in Figure 2, the results obtained from the three image interpretation techniques are almost similar and follows the same general pattern. The lake increment is geometric rather than linear. In general, the visual interpretation gives an accurate result almost comparable with the image enhancement and classification techniques. Thus, it is possible to suggest that the visual satellite image classification techniques are relatively fast and effective methods for the delineation of the surface area of the lake and plantation. Moreover, it overestimates the surface area of the lake. In general, the average of the three techniques gives a relatively better estimation for the area of the lake and plantation. The average value is fitted with a 2nd degree polynomial function as shown in Figure 2.

4. Conclusion and Recommendation
The surface area of Lake Basaka and sugarcane plantation has been delineated using three image interpretation techniques. The analysis result indicates that visual image interpretation gives a fast and efficient ways for the delineation of the Lake Basaka expansion compared to image enhancement and classification techniques. However, the average of the three image interpretation techniques usually gives a better result. The average of the three image interpretation techniques indicates that Lake Basaka expanded by about 2017 ha from 1973–1986, which is about 150 ha/year considering linear increment. In the period between 1986 to 2000, the expansion is about 875 ha, which is 63 ha/yr. In the period 2000 to 2008 the total expansion is about 417 ha, which is 52 ha/yr. The expansion of the lake has already started affecting Matahar Sugar Estate (MSE) in terms of groundwater dynamics, soil salinization, yield decline, etc and it should be considered seriously before it brings total devastation. If the past expansion trend continues, the sustainability of the plantation itself is under great risk. The expansion extent of the lake is very terrible and creates a great developmental challenge in the Awash basin. The lake has a potential to join Awash River in the near future, thereby impacting all downstream irrigation developments in the Awash Basin, and affecting the livelihood of the people depending on the water resources of this basin. All the beneficiaries of the basin, concerned institutions and the decision-makers of the country should consider the condition seriously and adopt mitigation measures before it brings irreversible damage to the region.

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