Study of Fluctuations in Surface Area of Lake Haramaya using NDWI and MNDWI Methods

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ABSTRACT

Lakes are of great value to human beings and important for various reasons like regulating the flow of river water, to maintain the eco-system and storage of water during the dry seasons. Lake Haramaya, which is situated at 14 km Northwest of Harer town (UNESCO Site) is one of the famous and beautiful lakes of Ethiopia. It acts as a source of life for human beings and animals. The over exploitation of the lake haramaya for water supply and agricultural purposes has led to its extinction in the last two decades. This study attempts to identify the fluctuations in surface area of Lake Haramaya between 1995 to 2020 by using multi-temporal satellite data. The Landsat 5TM images of 1995, 2000 and 2010, Landsat 7ETM+ image of 2005 and Landsat 8 OLI TIRS images of 2015 and 2020 are analyzed using the Normalized Difference Water Index (NDWI) and Modified Normalized Difference Water Index (MNDWI) methods. These methods are used to quantify the changes in surface area and compared to each other for identifying the suitable method for detecting water bodies. The present study shows that, between 1995 to 2010 the lake lost up to 2.3238 sq.km and almost dried. But, during 2011 to 2020 the lake surface area increased by 2.6946 sq.km. The study states that the lake surface area is fluctuating and MNDWI method is highly reliable in extracting water bodies.

Keywords: *Lake Haramaya, NDWI, MNDWI, Landsat, Dynamic Degree*

1. Introduction

Land surface water plays a vital part in the water cycle. The most accessible inland water resources such as lakes and rivers accounts for only 0.007% of the Earth's water budget which is being utilized by ecosystems and human consumption (Zhu et al., 2014). During 1970 to 2015, "global megatrends" like population increase, urbanization and climate change have contributed to the declination of inland and marine wetlands by 35%(Ramsar Convention on Wetlands, 2018). Over the past three decades, the global permanent water area including the artificially increased area of reservoir has decreased by 90,000 km^2 because of the human activities and climate change (Pekel et al., 2016). So, monitoring the surface water dynamics is necessary for national as well as regional development and it is being focused by the United Nations Sustainable Development Goals framework.

The primacy of remote sensing over other conventional techniques in mapping and inventory of earth resources are large ground coverage of satellite images, affordability of multiple spectral information, the temporal resolution and digital format of the satellite images(Moghaddam et al., 2015). All over the world, researchers are using remote sensing for environmental change detection studies. Any change in land cover and land use results in a change in the radiance of the object and it will be detected by the satellite sensors (Lu et al., 2013; Mas, 2010). Different methods were employed to identify open water bodies from remote sensing data. Open water bodies can be identified or extracted from bands in various ways like supervised classification method, unsupervised classification method, single-band threshold method, water body index method, knowledge decision tree classification method, spectral matching based on discrete particle swarm optimization (SMDPSO) and improved spectral matching method based on discrete particle swarm optimization with linear feature enhancement (Wei et al., 2020). Water bodies can be easily identified compared to other land cover types due to the

lower spectral reflectance property than those of other land surface materials (Deus & Gloaguen, 2013; Gowen et al., 2014). Therefore, many studies have suggested water indices can be used for classifying water and non-water features in multi-temporal satellite images.

Water Indices can be defined as a mathematical model which are used for enhancing the water signals for a given pixel at images obtained from visible and near-infrared scanning sensors (El-Asmar & Hereher, 2011). Visible (Green) and near-infrared portions of the spectrum are being used for the calculation of these models. They use various algebraic operations by combining two or more spectral bands to enhance the difference between water and non-water features (Ali et al., 2019). Land surface water information can be extracted more accurately, quickly and easily by water indices compared to image classification methods which are highly dependent on human expertise (Du et al., 2014). The most commonly used water indices are the Normalized Difference Water Index (NDWI) and the Modified Normalized Difference Water Index (MNDWI)(Xu, 2006). Both of these methods were applied in the previous studies (Dinka, 2012; Donia, 2019; Nair & Babu, 2016; Zheng et al., 2019). Therefore, NDWI and MNDWI were used as the primary methods in this study. This paper deals with the study of fluctuations in surface area of Lake Haramaya by using the NDWI and MNDWI methods along with their comparisons on detecting the water bodies between 1995 to 2020.

2. Materials and Methods

2.1. Study Area

Lake Haramaya is located in the eastern highlands of Ethiopia, which is administratively bounded with the Haramaya Woreda of Eastern Harerghe Zone in the regional state of Oromia, at the coordinates of 9º22' – 9º26' North of Latitude and 41º56' – 42º44' East of Longitude as shown in Figure 1. It is situated at a distance of 505 kms from Addis Ababa, the Capital city of Ethiopia and 14km northwest of Harar town. It was the only source of drinking water for the towns of Harar, Awedy and residents of haramaya. It is located at an altitude of 2047 metres above sea level. Normally, it experiences three types of seasons namely: Belg, short rainy season between February to May, Kiremt, the long rainy season between June and September and the Bega, dry season from October to January.

Location Map of Lake Haramaya
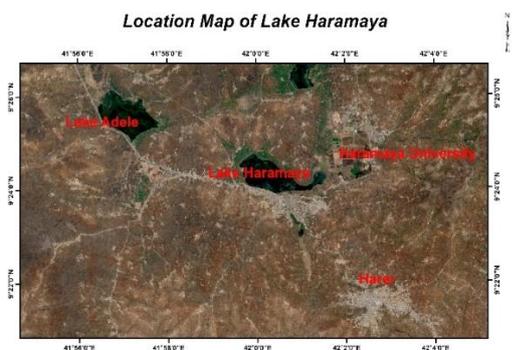
(a)

(b)

Figure 1. Location Map of the Study Area

2.2. Data used

Landsat satellite data were downloaded from the United States Geological Survey (USGS) Earth Explorer archives. Satellite images pertaining to the years 1995, 2000, 2005, 2010, 2015 and 2020 during the dry seasons of November and December were used for this study. The details of the satellite data are given in the Table 1.

Table 1 Satellite data used for the present study

Satellite	Sensor	Acquisition Date	Resolution (m)	Path/Row	Processing Level
Landsat5	TM	16.11.1995	30	166/54	L2SP
Landsat5	TM	29.11.2000	30	166/54	L2SP
Landsat7	ETM+	03.11.2005	30	166/53	L1TP
Landsat5	TM	11.12.2010	30	166/54	L2SP
Landsat8	OLI	23.11.2015	30	166/54	L1TP
Landsat8	OLI	20.11.2020	30	166/54	L1TP

2.3. Image Pre-processing

All the images were warped to a specific map projection, namely the Adindan UTM zone 38N using a first order polynomial transform algorithm in order to assure that each permanent feature is exactly at the same location in all images. A total of 16 prominent ground control points (GCP) were examined and matched in all images. After rectification, the root mean square error (RMSE) does not exceed 0.5 pixels showing a high geometric accuracy of the images. The images were then corrected for any atmospheric interference caused by haze, dust, smoke, etc. using the dark-object subtraction method. Then the layer stacking and Subsetting have been done for extracting the study area. The methodology is shown in Figure 2. ArcGIS 10.3 and ENVI 5.3 softwares have been employed in these corrections.

2.4. Water Indices

Figure 2 Flowchart showing the methodology of the study

The spectral water indices have been used to extract the water bodies from the remotely sensed images by computing the difference between two bands and appropriate threshold has been applied to differentiate the results into two classes namely water and non-water features. Among 7 bands, in Landsat5 TM three bands such as Band 2 (visible green, 0.52-0.60), Band 4 (NIR, 0.76-0.90) and Band 5 (SWIR 1, 1.55-1.75) have been used. In Landsat7 ETM+, out of 8 bands, Bands 2,4 and 5 have been used. In Landsat8 OLI TIRS, Band 3 (Green, 0.53-0.59), Band 5 (NIR, 0.85-0.88) and Band 6 (SWIR 1, 1.57-1.65) were utilized.

In the present study, NDWI and MNDWI were employed to extract the water body information. These two indices have been expressed as follows:

$$NDWI = (Green - NIR)/(Green + NIR) \quad (1)$$
$$MNDWI = (Green - SWIR\ 1)/(Green + SWIR\ 1)- \quad (2)$$

The equation (1) of Normalized Difference Water Index (NDWI) was proposed by McFeeters (McFeeters, 1996) to identify the surface waters in wetland environments and to allow for the measurement of surface water extension. By using this index, water features will be seen enhanced and the adjoining vegetation and soil will be suppressed. However, the NDWI application in water body areas which have built-up background is mixed with noises and the area of extracted water body is over estimated. So, NDWI is not able to extract shallow water surface. To overcome this limitation in identifying water surface, a Modified

Normalized Difference Water Index (MNDWI) expressed in equation (2) has been proposed by Xu (Xu, 2006). It uses the SWIR 1 band instead of NIR band as in NDWI because water absorbs more SWIR compared to NIR, so that the built-up land, soil and vegetation will be seen suppressed.

In this study, both of the above-mentioned indices have been used to study the fluctuations in surface area of Lake Haramaya and the results obtained were compared. First, NDWI and MNDWI have been calculated for the data of the corresponding years using ArcGIS 10.3 band math function. Then, a threshold value of greater than or equal to "zero" has been applied for visualizing the water bodies. As a result, water features have the positive values and the built-up, vegetation have the negative values in the derived indices. After applying thresholding, the data is reclassified into a single class of water body for extracting the required lake boundary. Finally, the surface area of the lake has been calculated.

The dynamic degree of the lake area of different study periods was also found out using the following equation (Li et al., 2009; Wang et al., 2011).

$$K = \frac{(Ub - Ua)}{Ua} * \frac{1}{T} * 100 \quad (3)$$

In equation (3), K is the dynamic indicator for lake area, Ua and Ub are the areas of the lake at start date and end date. T is the time scale under consideration.

3. Results and Discussion

The changes in the Lake Haramaya's surface area using NDWI and MNDWI are shown in the Figures 3 and Figure 4 respectively, which reveals that there occurred a significant fluctuations and shrinkage during the study. The results of the NDWI as shown in figures 3.3a – 3.3f reveals that the lake almost dried up between 1995 to 2010 and after 2015 the lake re-emerged to its full extent. In 1995, the lake had 2.3283 sq.km area and in 2000 the area was reduced to 2.1375 sq.km. The lake continued to shrink to 0.2853 sq.km in 2005 and reaches 0.3456 sq.km in 2015. In 2020, the lake area is increased to 2.5569sq.km in contrary to the shrinkage in the previous years. But, the NDWI was incapable to extract the water body in the year 2010.

The results of the MNDWI as shown in Figure 4 reveals the same pattern in the changes in lake surface area like NDWI but it can able to identify the water body in 2010. The lake had an area of 2.4723 sq.km in 1995 and shrunk to 2.2005 sq.km in 2000. The shrinkage continued to 2005 and 2010 with an area of 0.7749 and 0.1485 respectively. In 2015, the lake started to reclaim its surface area by having an area of 0.9198 sq.km. In 2020, the surface area of the Lake Haramaya is 2.8431 sq.km. MNDWI extracted the water body for the year 2010 unlike NDWI. The lake surface area during the study period by NDWI and MNDWI are shown in the figures 5 and Figure 6 respectively.
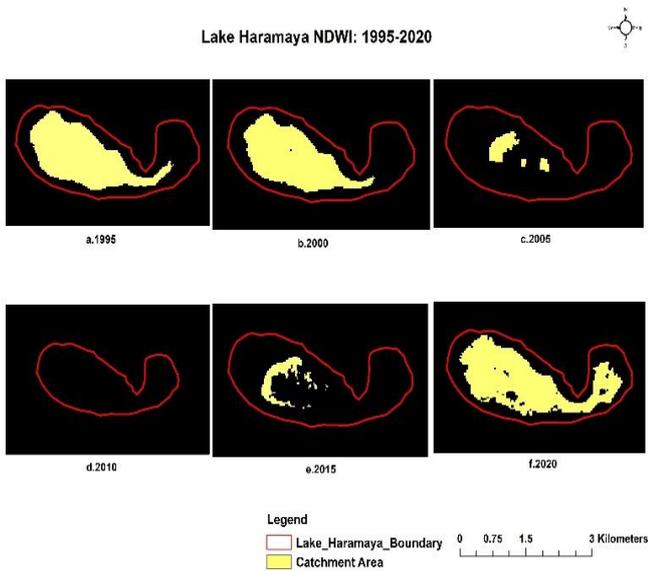
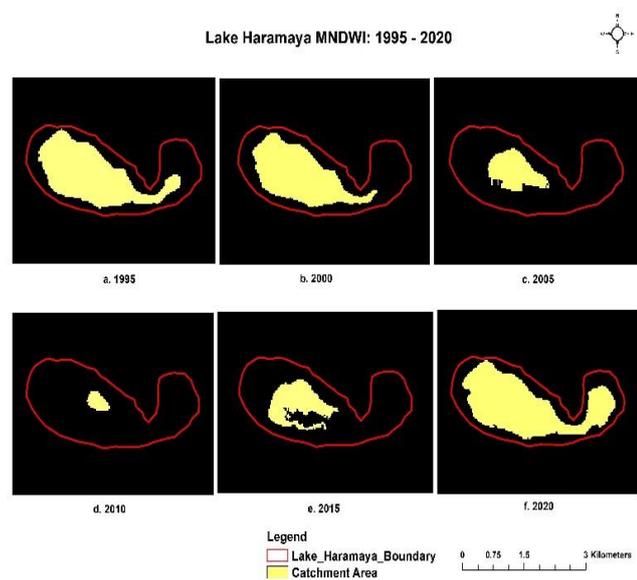Figure 3 Water Surface Area using NDWI

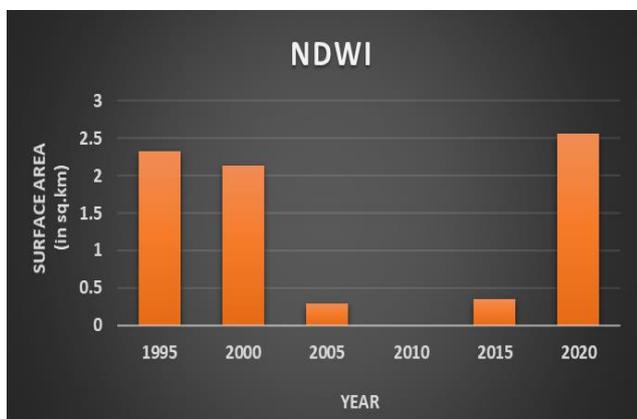Figure 4 Water Surface using MNDWI

Figure 5 Lake Surface Area between 1995 and 2020 using NDWI
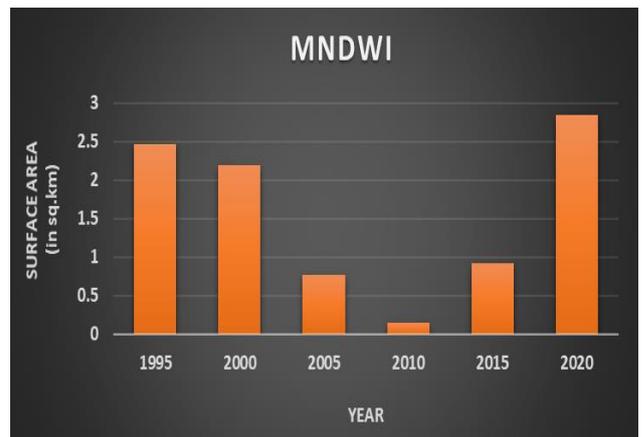

Figure 6 Lake Surface Area between 1995 and 2020 using MNDWI

As shown in Table 2, between the period of 1995-2000, the lake area almost decreased by 0.2718 sq.km and the dynamic degree of the lake is -0.1%; during 2000-2005 the lake area further declined by 1.4256 sq.km with the dynamic degree of -12.9% and it clearly shows the declining trend in water surface. During 2005-2010, the area fell by 0.6264 sq.km with the K value of -16.16. But, between 2010-2015, the lake again showed an increasing trend in surface area by 0.7713 sq.km and it further increased by 1.9233 sq.km in 2020.

Table 2 Changes in Surface Area of Lake Haramaya between 1995-2020 with Dynamic Degree (K)

Period	Lake Area (sq.km) (MNDWI)	Status	Dynamic Degree (K) %
1995-2000	0.2718	Decreased	-0.1
2000-2005	1.4256	Decreased	-12.9
2005-2010	0.6264	Decreased	-16.16
2010-2015	0.7713	Increased	103.87
2015-2020	1.9233	Increased	41.81

Both NDWI and MNDWI aimed to extract the water surface and quantify the surface area changes in the Lake Haramaya. Comparing the trends of haramaya lake in this paper with the results of other researchers, it is found that the changes have a high consistency pattern. In particular, (Gebrehiwot et al., 2019) have calculated the surface water area of Lake Haramaya from 1985, which verified the accuracy of the results from 1995 to 2005 in this study. Previous studies on surface extraction using Google Earth Engine Platforms (Jiang et al., 2021), perceptron model (Mishra & Prasad, 2015) provided a great details on dynamics of water surface extraction. The usage of multi temporal Landsat imageries helped to a wide extent in analysing the reflectance property of water as stated by (Rokni et al., 2014; Valeyev et al., 2019; Zhang et al., 2017). Also, MNDWI was the most effective method for enhancing

the water features compared to NDWI is verified as stated by (Dibs, 2018; Szabó et al., 2016)

4. Conclusion

Lake Haramaya has been suffering from severe exploitation by human beings for drinking water and agricultural activities. This study aimed to detect the changes of water surface area of Lake Haramaya by deriving the NDWI and MNDWI indices on multi-temporal Landsat images for 1995,2000,2005,2010,2015 and 2020. The statistical results showed a decreasing and heavy fluctuating trend in the lake surface area between 1995-2020. Between 2000-2010 the lake almost lost the area of 2 sq.km. But it reclaimed the lost area between 2015-2020. This makes the necessity for studying the reasons for the abrupt causes for the fluctuation. Furthermore, this study explained the efficiency of MNDWI over NDWI in extracting water surface accurately with the combinations of Green and SWIR bands. Overall, this method has been proven to be reliable in detecting the changes in surface area of Lake Haramaya. Accordingly, this study may be helpful in the future studies of change detection in the surface waters in the region.

5. References

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