

# ASSESSMENT OF SURFACE WATER DYNAMICS USING MULTIPLE WATER INDICES AROUND ADAMA WOREDA, ETHIOPIA

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**KEY WORDS:** NDWI, WRI, MNDWI, Surface water

## ABSTRACT:

Rapid change of Adama wereda during the last three decades has posed a serious threat to the existence of ecological systems, specifically water bodies which play a crucial part in supporting life. Role of Satellite images in Remote Sensing could be more important in investigation, monitoring dynamically and planning of natural surface water resources. Landsat-5(TM) & Landsat 8 (OLI) has high spatial, temporal and multispectral resolution and therefore provides consistent and perfect data to detect changes in surface changes of water bodies. In this paper, a study was conducted to detect the changes in water body extent during the period of 1984,2000 &2017 using various water indices such as namely Water Ratio Index (WRI), Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), supervised classification and wetness component of K-T transformation and the results are Presented. NDWI has been adopted for this study as compared with other indices through ground survey. The results showed an intense decreasing trend in the lakes of chelekleka ,kiroftu ,lake 1 and lake 3 of surface area in the period 1984–2017, especially between 2000 and 2017 when the lake lost about 1.309 km<sup>2</sup> (one third) of its surface area compared to the year 2000, which is equivalent to 76%,18% ,0.03% and 96%. Interestingly koka lake has shown very erratic changes in its area coverage by losing almost 3.5 sq.km between 1984 and 2000 and then climbing back up by 14.8 sq.km in 2017. Percentage of increment was observed that 10.6 % as compared with previous year.

## 1. INTRODUCTION

Assessment and monitoring the changes in environment using remote sensing technology is extensively used in various applications, such as land use/cover change (Salmon et al.,2013; Demir et al.,2013), disaster monitoring (Volpi et al.,2013; Brisco et al.,2013), forest and vegetation change (Kaliraj et al., 2012; Markogianni et al.,2013), urban sprawl (Bagan et al.,2012; Raja et al.,2013), and hydrology (Dronova et al.,2011; Zhu et al.,2011). surface water will play an important role in human survival and social development Ridd and Liu (1998). It is most needful for humans, food crops, and ecosystems (Lu et al.,2011). Collecting information about the spatial distribution of open surface water is most important in various scientific disciplines, such as the assessment of present and future water resources, river dynamics, wetland inventory, climate models watershed analysis, surface water survey and management, agriculture suitability, flood mapping, and environment monitoring (Desmet and Govers,1996; Zhou and Wu,2008; Du et al.,2012; Sun et al.,2012). Recently developed remote sensing satellites with different spatial, spectral and temporal resolution provide an abundant data that become primary sources and being used for detecting and extracting surface water and its changes in recent decades (Xu,2006; Zhou et al.,2011; Tang et al.,2013; Li et al.,2013; McFeeters,2013). Images from Landsat series was one of the most widely used remote sensing data that adopted for water body detection as well as changes over the periods (Moradi et al.,2017). Landsat series satellite has different sensor such as multispectral scanner (MSS) for Landsat -1 to Landsat -3, Thematic mapper (TM)for Landsat -4 and Landsat-5 and Enhanced Thematic mapper plus(ETM+) have been used for many environmental applications specifically for water body

dynamics studies (moradi et al.,2017, Mcfeeters,1996; Xu,2006). Latest era on Landsat series has begun with Operational Land Imager(OLI) on board Landsat 8 has 12-bit pixel instead of 8-bit pixel of ETM+ that gives higher quality and better signal to noise ratio than ETM+ (Irons et al.,2012).

Several algorithm has been adopted for change detection studies on water body especially on Landsat data that categorized in to four main groups:1- classification and pattern recognition methods it includes supervised (Tulbure et al.,2013) and unsupervised methods (Ko et al.,2015).2-spectral un-mixing (sethre et al.,2005).3-single band threshold (Klein et al.,2014) and 4-spectral water index (Ji et al.,2009). Errors are more common when single band methods chosen to extract water features along with different cover types because of defined threshold values are needed to extract water features(Du et al.,2012).index based methods are more accurate than classification methods it does not require any basic knowledge (Li et al.,2013).Multi band methods comprises two or more different reflective bands for improved surface water extraction (Du et al.,2012).For instance, Normalized difference water index(NDWI) has developed for extracting water feature from satellite imagery.

In the past decade there are Different indices has lined up for extracting water surface.one of the popular water index is normalized difference water index(NDWI)(Mcfeeters,1996). Modified normalized difference water index has been developed to overcome the problem of water pixel mixed with buildup features(Xu,2006). Automated water extraction index (AWEI) was introduced to get better result which Landsat image has shadow and dark surface. Water Ratio Index (WRI) is another widely used water index by Shen, L and C. Li (2010). This study

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has, therefore, implemented NDWI among others to extract and quantify the water surface area changes of ADAMA wereda and its surrounding. In doing so, Landsat images of 1984 (TM) 2000(TM) & 2017(OLI) has been used. The main objective of this project is to detect the surface water change detection patterns (1984-2017) of Landsat multispectral images using different water indices in Adama woreda and its surrounding.

## 2. STUDY AREA

The study area, Adama wereda have 100145.61-hectare area coverage. It comprises Adama city, Wonji sugar factory and town, Koka Lake, and other rural Kebeles. Adama wereda is located in Oromia region, east Shoa zone and it bounds a geographic coordinates ranging from 39°27'E to 39°30' E and 8°21'N and 8°46'30" and the altitude of Adama Woreda ranges from 1500 to 2300 meters above Mean Sea Level (MSL). The population is moderately dense and annual rainfall is 500-800 mm. It is bounded by beset wereda in the east, Lome wereda in the North West, Duga bora in south west, Dodo tana sire wereda in south and Shenkora and minjar in north. The varied topography which includes hills, plains and undulating landscapes with lakes and the rift valley escarpment. The major types of vegetation are bush scrub, grasslands. Only few places are covered by little forest. location of lakes in study area has given below.

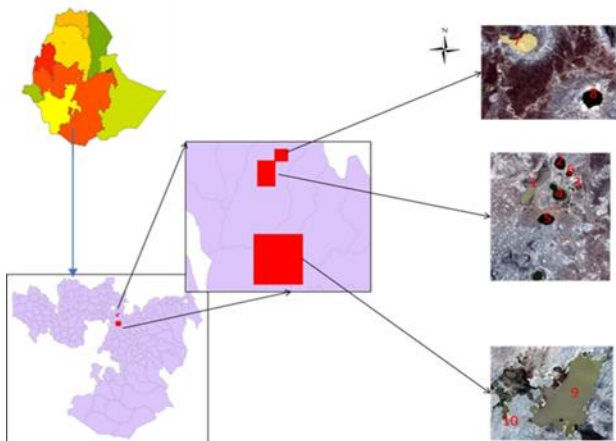


Figure 1. Location of Lakes in Adama Woreda

## 3. METHODOLOGY

The procedure performed in this project will derive the change in Adama wereda and its surrounding over a different period of time, the change detection in Adama wereda is carried out in the three satellite images over different period of time (1984, 2000 & 2017). Figure 2 below explains about the entire flow of work.

### 3.1 Water Surface Extraction

In order to detect the changes in surface water area of Adama woreda and its surrounding in the period 1984–2015, to analyze the performance of different satellite derived indices including Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), Modified Water Ratio Index (WRI), KT Transform and Supervised classification has been examined for extraction of surface water from individual temporal Landsat data.

S.No	Lake name	Latitude	Longitude
1	Chelekleka	8°45'39.64"N	38°58'8.58"E
2	BishoftuGuda	8°47'15.13"N	38°59'35.03"E
3	Kiroftu	8°46'45.63"N	39° 0'1.69"E
4	Hora	8°45'44.59"N	38°59'30.70"E
5	Bishoftu	8°44'36.03"N	38°59'2.62"E
6	Lake 1	8°46'45.81"N	39° 1'12.46"E
7	K'oftu	8°49'50.15"N	39° 2'55.37"E
8	Lake 2	8°48'12.13"N	39° 4'59.15"E
9	Koka	8°24'53.15"N	39° 6'30.51"E
10	Lake 3	8°21'37.51"N	38°57'16.34"E

Table 1. Location of lakes around Adama woreda and its surrounding

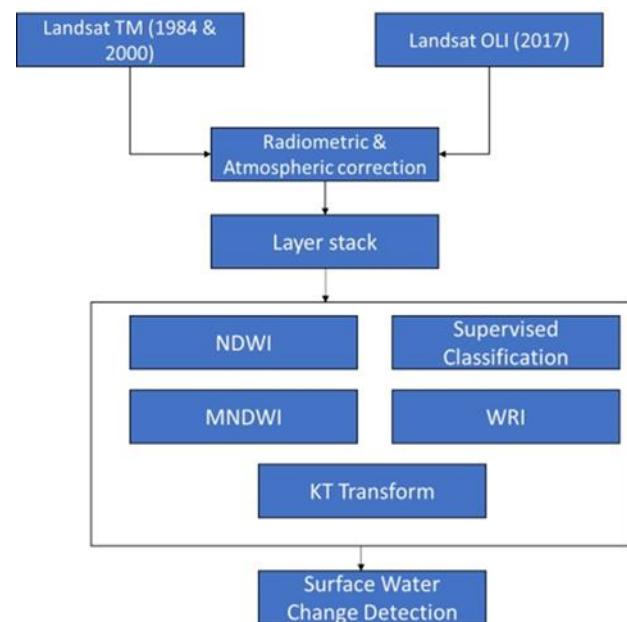


Figure 2. Methodology adopted for Study

NDWI, MNDWI, WRI, KT Transform and supervised classification were needed to calculate from Landsat 1984 TM, 2000 TM & 2017 OLI images to assess their performances for the extraction of surface water. Threshold value for land-water for each index has been given manually to classify the image into two categories, water and non-water. (Komeil et al., 2014). Suitable threshold value has been identified by doing trial and error and comparison to reference map generated using visual interpretation. Near infrared (NIR) band is usually preferred for visual interpretation of water bodies. Because NIR is strongly absorbed by water and its reflected by vegetation and dry soil.

Index	Equation	Remark
Normalized Difference in Water Index	$NDWI = \frac{(Green - NIR)}{(Green + NIR)}$	Water has positive value.
Wetness component of K-T transformation	$0.1509 * Blue + 0.1793 * Green + 0.3279 * Red + 0.3406 * NIR + 0.7112 * MIR + 0.4572 * SWIR$	Water has positive value
Modified Normalized Difference Water Index	$MNDWI = \frac{(Green - MIR)}{(Green + MIR)}$	Water has positive value
Water Ratio Index	$WRI = \frac{(Green + Red)}{(NIR + MIR)}$	Value of water body is greater than 1

Table 2. Satellite-derived indexes used for water features extraction in Landsat imagery

### 3.2 Water Ratio Index (WRI)

Since prevailing spectral reflectance of water in green (band-2) and red (Band3) bands as compared to Near Infra-red (Band 4) and Medium Infra-red (Band 5). Values of Water Ratio Index(WRI) shows that greater than 1 for water (Shen L and Li C,2010; Fang et al.,2011). where WRI is defined as

$$WRI = \frac{Green + Red}{NIR + MIR}$$

Fig 3 shows a Convincing result for water has been noticed in the year of 2000 and 2017. But in 1984, Surface water falls under the value ranges less than 1.

### 3.3 Normalized Difference Water Index (NDWI)

NDWI was introduced by Mcfeeters S.K. (1996) to extract surface water from Landsat images depends on strong absorption of water and strong reflection of vegetation in the portion of Near infra-red regions.

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

Index value ranges from -1 to +1 with water body has high values (very close to positive 1). Result proved that NDWI has ability to separate water body and vegetation but it has some sort of limitation on soil and built up area.

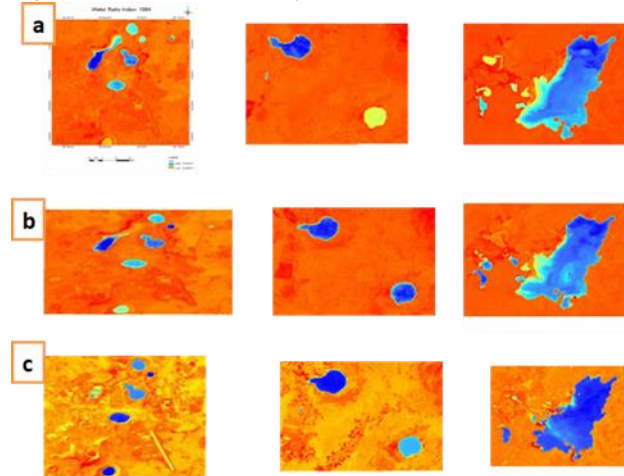
### 3.4 Modified Normalized Difference Water Index (MNDWI)

In order to overcome the limitations of NDWI on urban areas, Xu (2006) proposed new approach MNDWI which was found to be more efficient in distinguishing water and urban areas. MNDWI can be achieved with replacing infrared by shortwave Infrared wavelength of 1.57-1.65 micro meters.

$$MNDWI = \frac{Green - MIR}{GREEN + MIR}$$

Some of the results has been observed while computing Modified Normalized Difference water index are, 1) water has higher positive values than in NDWI as it absorbs more MIR than NIR, 2). negative values indicate that built up land, 3). still vegetation and soil will have negative values as soil reflects MIR more than NIR (Jensen, 2004) and vegetation will reflect MIR

Figure 3. water ratio index of years 1984(a) ,2000(b) and 2017(c).



more than green.

Advantage of MNDWI is that more accurate in extraction of open surface water body as built up land, soil and vegetation all negative values and it was suppressed.

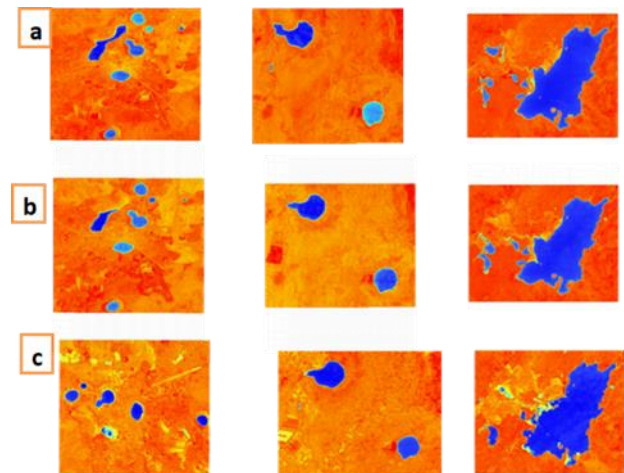


Figure 4. Modified Normalized difference in water indices of 1984(a) ,2000(b) and 2017(c).

### 3.5 Wetness component of K-T transformation

Tasseled cap transformation, also called K-T transformation, it provides coordinate axis point to the direction has close by association with features through rotating coordinate space. Once rotation has performed, pointing direction of coordinate axis was closely related to process of plant growth and soil (Yanan et al., 2013). It helps to analyze and interpret the crop characteristics and good practical significance. KT transform was introduced by Kauth and Thomas (1996) to distinguish between three special features as brightness, greenness and yellowness for MSS data. Afterwards, Crist and Cicone (1984) utilized the tasseled cap transformation for Thematic mapper data. The weights are different and the third component is taken to represent soil wetness rather than yellowness as in Kauth and Thomas' original formulation. The wetness component of K-T transform can be utilized to extract water information wherein a weighted sum of bands of ETM+ is taken according to the following formula (Vivek et al., 2015):

$$\text{Wetness} = 0.1509 * \text{Blue} + 0.1793 * \text{Green} + 0.3279 * \text{Red} + 0.3279 * \text{Red} + 0.3406 * \text{NIR}_{0.7112} * \text{MIR}_{0.4572} * \text{MIR}_{0.4572} * \text{SWIR}$$

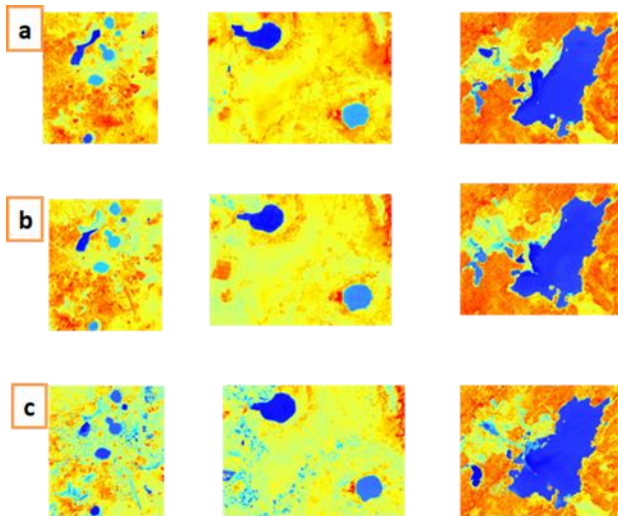


Figure 5. wetness KT Transform of 1984(a), 2000(b) and 2017(c).

### 3.6 Supervised Classification

Supervised classification is the process of grouping pixels using a known identity of specific sites (i.e., pixels already assigned to informational classes) to classify pixels of unknown identity (i.e., to assign unclassified pixels to one of the several informational classes (Cambell, 2002). Knowledge of study area, aerial photography, and experience with remotely sensed data etc. are required before undergoing training samples. The training samples were provided over the image for known and unambiguous representatives for each class namely Water body and non-water. Maximum likelihood supervised classification was utilized over the image.

## 4. RESULT AND DISCUSSION

### 4.1 Surface water changes from 1984-2000

Surface water area for each of the 10 lakes were calculated by using Normalized Difference Water Index (NDWI) for 1984& 2000 (TM) and 2017 (OLI\_TIRS). Figure 2 shows that Lakes Chelekleka, BishoftuGuda, Kiroftu, Lake 1, K'oftu, Lake2, and Koka has shown very little change in their shape & spatial coverage for all years. Unlike lakes bishoftu, lake 2 and lake 3 has shown a very significant and discernible change in its surface area cover for each study year. The surface area change detection confirms that Lake BishoftuGuda, Kiroftu, Lake 1 and K'oftu has shown little change in their surface area over the study years. Lake koka has seen its maximum surface area reduction of 3.51sqkm between 1984 and 2000. Surface water area increment was evident in 2000 with Hora, Bishoftu, Lake 2 and Lake 3 were 0.041sqkm, 0.0087 sqkm, 0.280sqkm, 1.02sqkm respectively. The overall surface area changes for the study area between 1984 and 2000 was -3.94sqkms (negative sign indicating a decreasing trend). +1.359 sq.km (positive sign indicates that increase in trend).

### 4.2 Surface Water Changes from 2000-2017

Surface water area for each of the 10 lakes were calculated by using Normalized Difference Water Index (NDWI) for 2000 and

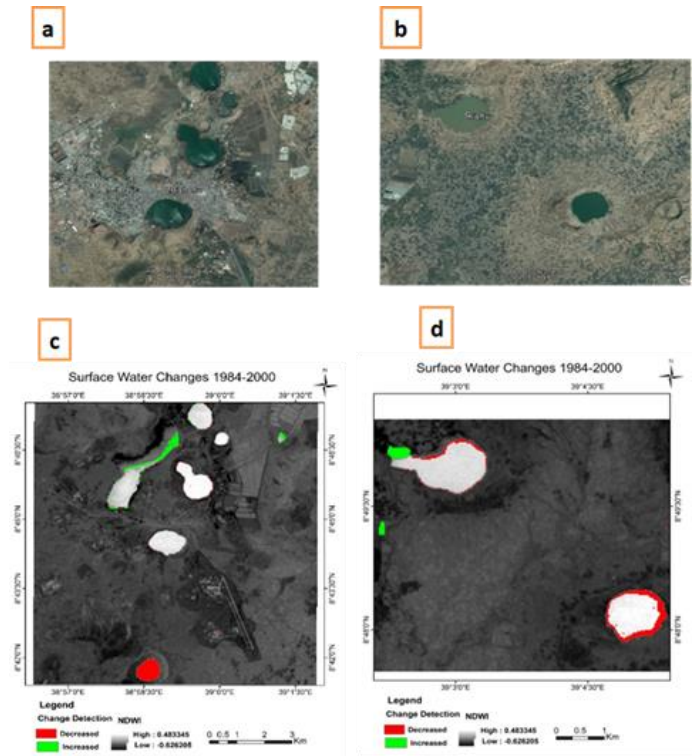


Figure 6, a& b shows that current scenario of lake and c& d shows changes from 2000-2017

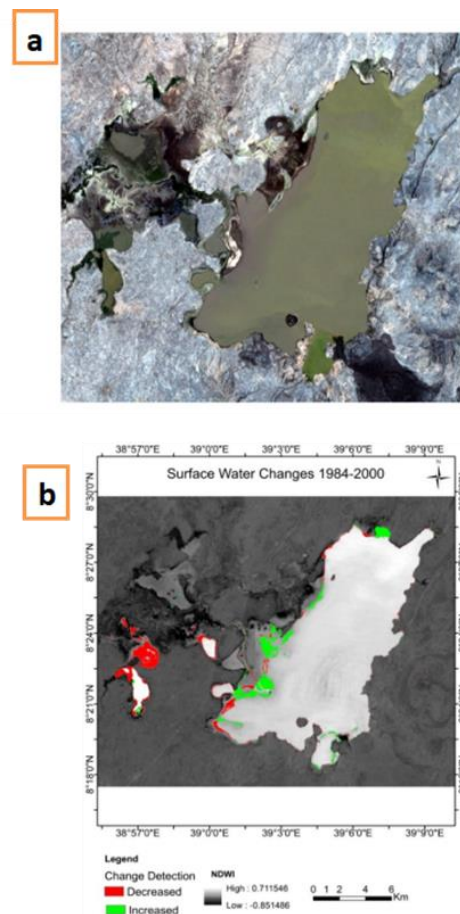
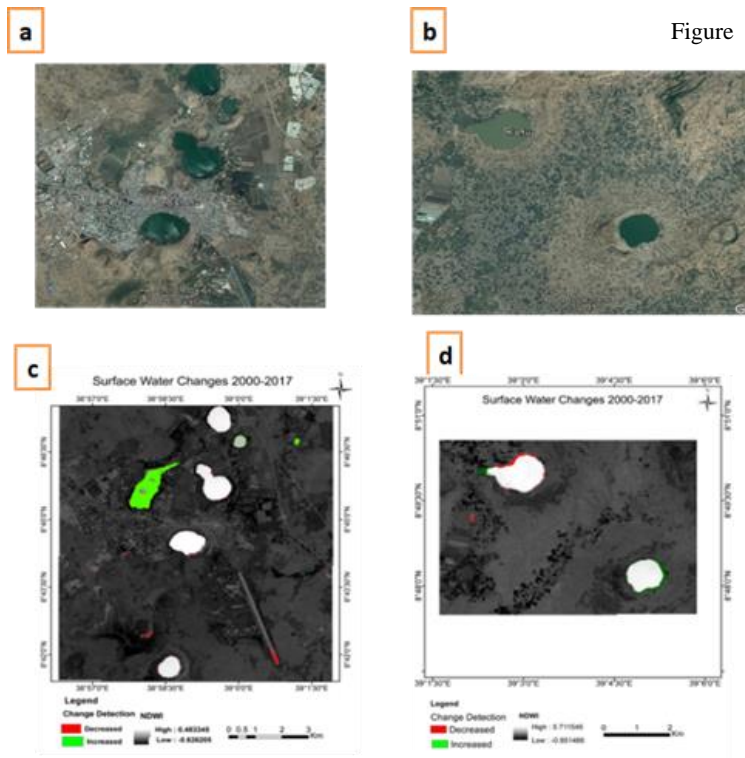


Figure 7, a & b shows that current scenario of lake from Google map and changes

2017 (OLI\_TIRS). Figure shows that Lakes Kiroftu, Lake 1 and Lake 2 has shown very little change in their shape & spatial coverage for all years. Unlike lakes chelekleka and lake 3 has shown a very significant and discernible change in its surface area cover for each study year. The surface area change detection confirms that Lake Bishoftu Guda Kiroftu, Hora, K'oftu, Koka has shown little change in their surface area over the study years. Lake koka has seen its maximum surface area increase of 14.88 sqkm between 2000 and 2017. apart from koka lake other lakes namely Bishoftu Guda Kiroftu, Hora, K'oftu has increased as compared with previous year in terms of area were 0.010sqkm, 0.0091 sq km, 0.020 sq km, 0.04 sq km. The overall surface area changes for the study area between 2000 and 2017 was -4.98sqkms (negative sign indicating a decreasing trend). +14.96401 sq km (positive sign indicates that increase in trend).



8, a & b shows that current scenario of lake and c & d shows changes from 2000-2017

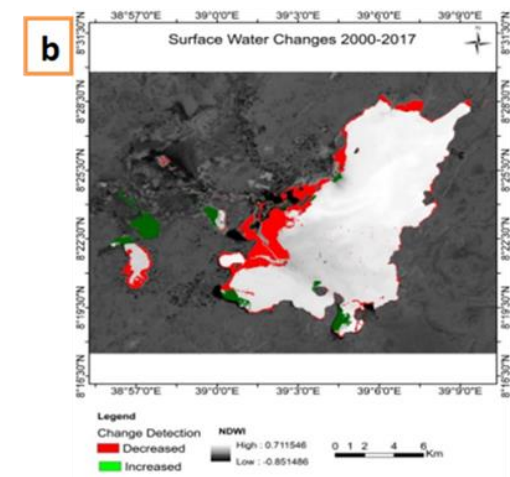


Figure 9, a & b shows current scenario of lakes and changes in koka lake from 2000-2017

year	chelekleka		Bishoftu Guda		Kiroftu	
	Estimated surface area (sq km)	surface area changes from previous year	Estimated surface area (sq km)	surface area changes from previous year	Estimated surface area (sq km)	surface area changes from previous year
1984	1.611		0.707		0.200	
2000	1.250	-0.361	0.704	-0.002	0.194	-0.006
2017	0.015	-1.235	0.715	0.010	0.158	-0.036

Table 3. Surface water changes during the years 1984- 2017

year	Hora		Bishoftu		No Name 1	
	Estimated surface area (sq-km)	surface area changes from previous year	Estimated surface area (sq km)	surface area changes from previous year	Estimated surface area (sq km)	surface area changes from previous year
1984	1.067		0.933		0.083	
2000	1.109	0.042	0.942	0.009	0.038	-0.046
2017	1.118	0.009	0.963	0.021	0.000	-0.038

Table 4. Surface water changes during the years 1984- 2017

Year	K'oftu		No Name 2		Koka		No Name 3	
	Estimated surface area (sq km)	Surface area change from previous year	Estimated surface area (sq km)	Surface area change from previous year	Estimated surface area (sq km)	Surface area change from previous year	Estimated surface area (sq km)	Surface area change from previous year
1984	1.368		0.785		139.151		2.572	
2000	1.357	-0.010	1.065	0.281	135.636	-3.516	3.601	1.028
2017	1.400	0.043	0.876	-0.189	150.516	14.881	0.112	-3.489

Table 5. Surface water changes during the years 1984- 2017

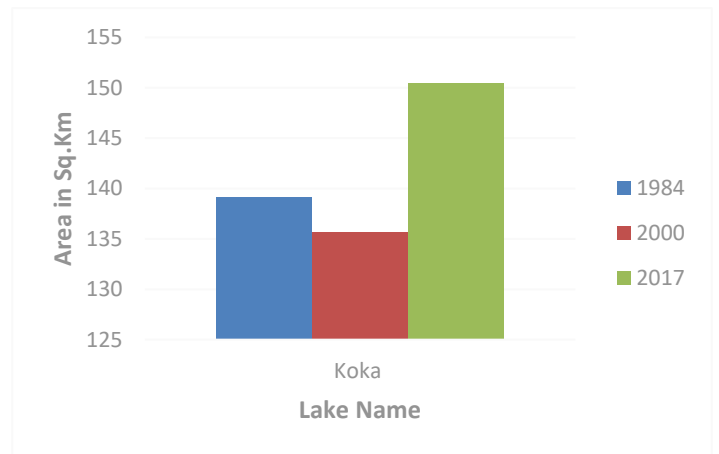


Figure 12. Area of surface water during 1984-2017

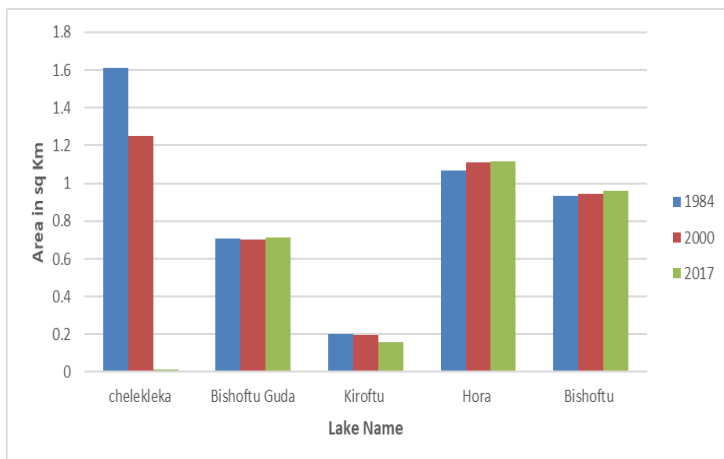


Figure 10. Area of surface water during 1984-2017

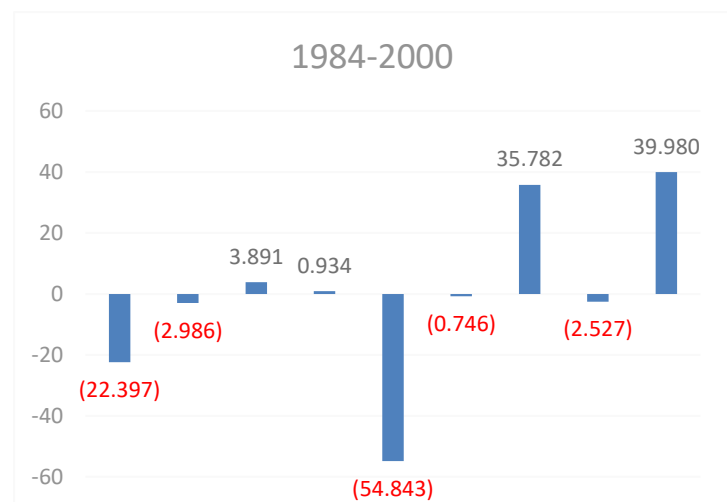


Figure 13. Area of surface water in percentage during (1984-2000).

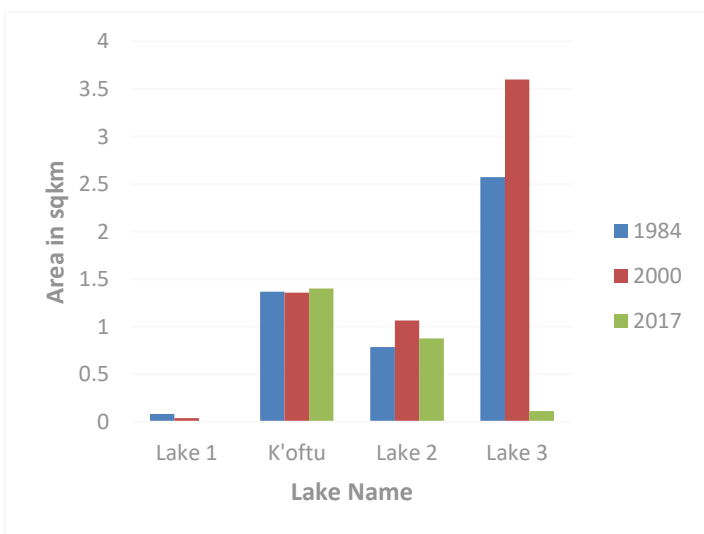


Figure 11. Area of surface water during 1984-2017

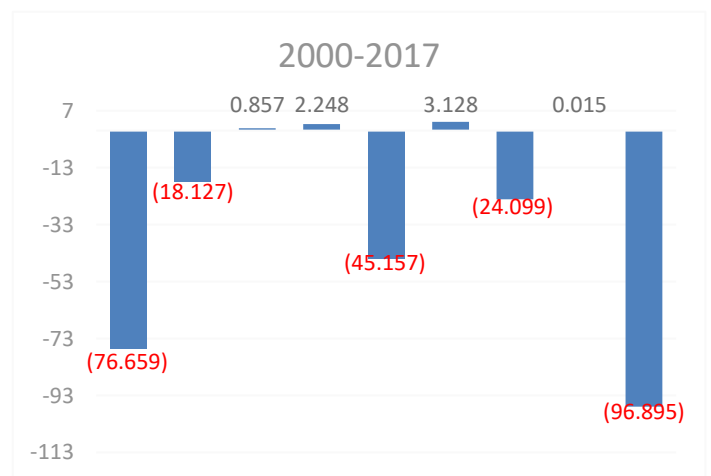


Figure 14. Area of surface water in percentage during (2000-2017)

## 5. CONCLUSION

This study aimed to model the spatio-temporal changes of Lakes in Adama woreda and its surrounding in the period 1984–2017. Through a comparative analysis, the NDWI was selected and employed for this purpose.

The results showed an intense decreasing trend in the lakes of chelekleka, kiroftu, lake 1 and lake 3 of surface area in the period 1984–2017, especially between 2000 and 2017 when the lake lost about 1.309 km<sup>2</sup> (one third) of its surface area compared to the year 2000, which is equivalent to 76%, 18%, 0.03% and 96%. Interestingly koka lake has shown very erratic changes in its area coverage by losing almost 3.5 sq.km between 1984 and 2000 and then climbing back up by 14.8 sq.km in 2017. Percentage of increment was observed that 10.6 % as compared with previous year. This, makes Lakes in Adama woreda and its surrounding with a very dramatic decline and rise history in about thirty-three years' period. If such a decreasing trend in Lakes in Adama woreda continues, it is very likely that the lake will lose its entire water surface in the near future

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