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Assessment of Spatial Expansion of Rift Valley Lakes Using Satellite Data

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Abstract

The present work assessed the expansion and fluctuation of Lake Nakuru in Kenya by using satellite data and information. Surface water magnitude was measured from optical sensors, such as Landsat. ENVI software was used to process and analyze data from the satellite images. The data was then used to create shapefile to get the area of the lake only. The shapefiles were classified using both Supervised and Unsupervised classification, and the area of the lake was obtained in hectares. The obtained area in hectares was recorded in a table and graphs were plotted to show the trend of the lake in the years 1972-2019. Furthermore, correlation was done by assuming the area of the shapefile before any classification is more accurate, therefore it was compared with the other results obtained by using different methods. Maximum likelihood gave the best correlation values. For R^2 it gave 0.8627 and R was 0.9312.

Keywords

Remote Sensing, Landsat, Soil Erosion, Supervised Classification

1. Introduction

Numerous natural and man-made variables are now having an impact on water resource systems all around the world [1] Depletion of groundwater supplies, increased water demand from a growing human population, and changes in climate and land-use conditions continue to be major concerns for water managers [2] Water resource systems are crucial to local economies in sub-Saharan Africa because they provide water for home and agricultural utilities, fisheries, recreation, and the promotion of local tourism [3]. The Rift Valley Lakes in Eastern Africa are among the Global 200 Freshwater Ecoregions of today because they support ecoregions with significant biodiversity. However, the Rift Valley Lakes have seen increases in their lake water levels, areas, and volumes, impacting not just the area's unique biodiversity but also the local populations' infrastructure and way of life. Given the prolonged above-average rainfall during the extended rainy season, the situation has worsened more recently [4].

Lake Nakuru is positioned at the base of the Kenyan Rift Valley. The lake is within Lake Nakuru national park and is served by five main rivers Njoro, Makalia, Nderit, Larmudia and Ngosur, Ngosur being a permanent river and the other four being seasonal rivers. The lake is at an altitude of 1754 m (5755 ft) above sea level with it having no outlets. It has a surface area of about 45 km^2 within latitude −0.3562˚N and longitude 36.1002˚E. Being in the Rift Valley where volcanic activities as well as climatic changes have been very notable, the lake experienced radical changes, the lake's water level dropped vividly in the early 1990's but has since generally recovered. In 2013, the lake established a startling upsurge in the water levels which led to the relocation of flamingoes [5].

The water levels in Lake Nakuru have been rising progressively since 2012 at an average of three meters [6]. The changes in Lake Nakuru have been documented by S.M. Onywere, as 31.8 Km^2 in January 2010 to a high of 54.7 Km in Sept 2013, an increase of 22.9 Km^2 (71.9%) [7]. The rise in water levels has caused diverse effects to the neighboring community and Nakuru County at large. The neighboring community in Mwariki has been displaced and the farms in Barut submerged. The wild animals in Lake Nakuru National Park have also been displaced from their habitats causing human-wildlife conflict which leads to the destruction of farms. Economically the County government has been affected with the drop in tourism as the floods have caused the flamingoes to migrate to other regions. The submerged offices of the Kenya Wildlife Services have also posed huge losses. The floods have also affected the sewage and in turn lead to the decrease in the quality of the water in Nakuru County, due to the mixing of the sewage and sediments the pH of the water has been altered leading to the death of fish.

Recent years have seen some scientific considerations of the rising water levels in the lakes of Kenya's Rift Valley. The phenomenon of rising lake levels was initially described by [7], who also provided thorough descriptions of the affected lake attributes. Using these findings as a foundation, [8] demonstrated the profoundly detrimental effects of flooding brought on by water level rises on the local people residing in riparian zones. Similar to [9] concentrated their analysis on the patterns of Lake Nakuru water surface fluctuations between 1984 and 2013, coming to the conclusion that there was no discernible relationship between rainfall and changes in the lake surface area, [9] from the Jomo Kenyatta University of Agriculture and Technology (JKUAT) did a study where they tried to link the water level increase to rainfall changes; he however established that there was no correlation between the two. Other hypotheses that have been formulated include tectonic plate's movement, Mau Forest degradation, sedimentation and siltation. However, little work has been done to prove these hypotheses.

In this paper, we examined siltation as a factor affecting the rise in the water level of the Rift Valley Lakes. This was achieved through the selected epoch of 1990, 2000, 2010 and 2020. The investigation employed remote sensing techniques through Google Earth Engine Cloud Platform. Landsat Images were acquired, and Land classification carried out for the four epochs using a suitable classification algorithm, four classes (vegetation, water, bare land and built-up areas) were used, and the corresponding areas computed to enable the determination of a correlation. NDVI analysis was also carried out and this information together with the DEM, Rainfall data and Soil data were used to model the risk of soil erosion risk in the study area.

2. Materials and Methods

2.1. Description of the Study Area

Lake Nakuru is positioned at the base of the Kenyan Rift Valley. It is within Lake Nakuru national park and is served by five main rivers Njoro, Makalia, Enderit Larmudiac and Ngosur (KWS, 2002) (**Figure 1**). River Njoro is a permanent river feeding the lake and the other four being seasonal rivers, it is an enclosed catchment area as the lake has no outflows. It is at an altitude of 1754 m (5755 ft) above sea level. It has a surface area of about 45 km^2 within latitude −0.3562˚N

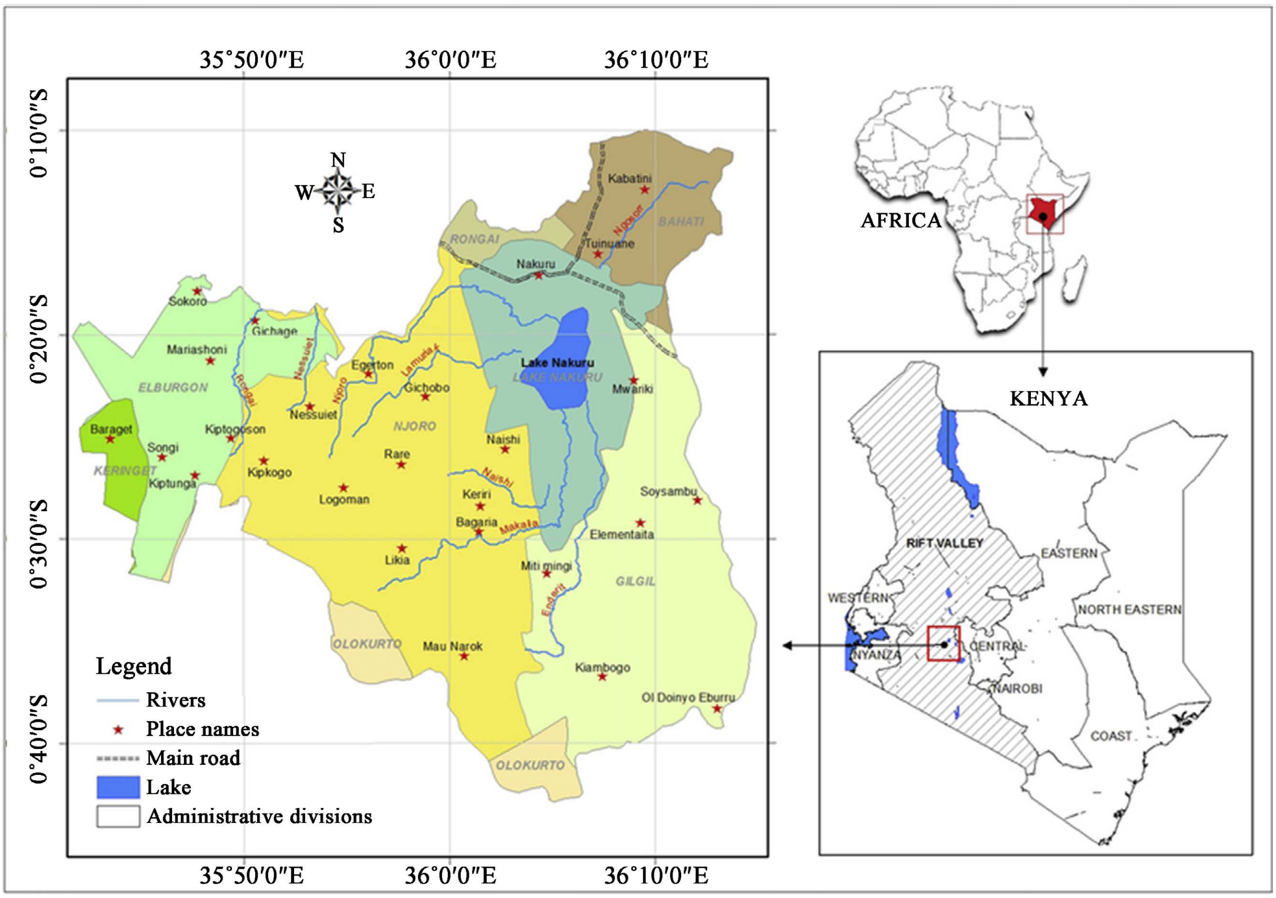

Figure 1. Geographical location of the study area modified from [10].

and longitude 36.1002˚E. The catchment area is in the surrounding vegetation, Mau Forest, Eburu forest and Dundori forest. The Mau Forest covers an area of 650 km^2. Eburu covers an area of 87.38 km^2 to the South of the lake while Dundori forest covers an area of 69.56 km^2 to the East of the lake as observed by [11].

2.2. Data and Processing Tools

This study was carried out in Lake Nakuru area in Nakuru County using two methods. In the first method, data was obtained from the USGS website whereby Landsat 7 and 8 images were used, though images collected after May 31, 2003, had data gaps when the SLC failed, the images had about 78% of their pixels missing. In the second method shapefiles were used, to find out how the lake surface area had changed, it was done by using different methods.

2.3. Data Pre-Processing

Once the images were downloaded from the earth explorer website, shapefiles were created for every image in each year. Since the images are already georeferenced, NDVI was performed on the images and the different ranges for different classes on the images were saved and thereafter used to calculate statistics for all the classes. The second method was to perform supervised classification whereby maximum likelihood was used and thereafter the statistics of the area was calculated, which was given in hectares.

2.3.1. Normalized Difference Vegetation Index

It evaluates vegetation by calculating the dissimilarity between Near-Infrared (which vegetation intensely reflects) and Red (which vegetation engages).

$$\text{NDVI} = \left(\text{NIR} - \text{Red}\right) / \left(\text{NIR} + \text{Red}\right) \tag{1}$$

In this case study NDVI was used to be able to identify the different things in water and be able to distinguish what is making the lake area expand, therefore Density slice was performed in order to use different ranges for water, vegetation and soil. For water the range −1 to 0 and Cyan for the color, for vegetation range 0.3 to 0.9, Green for its color and for soil range 0.0 to 0.3. Finally, the statistics for the classes got in hectares and recorded.

2.3.2. Unsupervised Classification

In this classification method, there is no training data provided. Pixels are characterized into clusters based on their resemblances, which can be done using two methods K-MEANS and ISODATA. Under supervised classification K-MEANS was performed on the images, this was done by setting a number of classes, in this case the number of classes was set to 3, to avoid many classes in the water because the main interest was to assess the spatial change of the lake area not its constituents. After giving an output result the image was used to get statistics for the lake area in hectares.

2.3.3. Supervised Classification

Training data is present in supervised classification, the user detects different land covers classes and then the computer uses the training data and applies them on the image which results into a thematic map, the computer software determines the different classes by using what is similar to the classes in the training data. In supervised classification both maximum likelihood and spectral angle mapper were performed. First, before performing maximum likelihood, Region Of interests (ROI) were created from the output image of NDVI, in order to get the different regions and later the ROI'S were saved. In maximum likelihood the saved ROI'S were used to select the classes, no threshold was used. Statistics were gotten from the output image. The second classification Spectral Angle Mapper was used to further classify the image by using the region of interests and later getting the statistics of the region of interests in hectares.

3. Results and Discussions

In this case study, results on how Lake Nakuru was changing during the past years, were obtained. This was done by finding the area of the lake in hectares for different years using different classification methods, namely, NDVI, Supervised classification both Maximum likelihood and Spectral Angle Mapper, lastly Unsupervised classification under K-Means. By getting the data from the graphs which were plotted for the different years against the area in hectares, furthermore correlation between the area of the lake using the shapefiles and the area of the lake under different classification methods was performed, assuming the area of the lake using the shapefile is more accurate, in order to get the correlation coefficient. With that the results were able to show the spatial change of the lake area.

3.1. Area of Lake Nakuru Using Different Classification Methods

The area of the lake was obtained and recorded in form of tables, by indicating the years and the area under the different methods of classification performed on the images. Under different classification methods different areas were found showing how the lake area is changing, both increase and decrease of the lake size was seen as it is observed in the table below (**Tables 1-3**).

Table 1. Showing area of Lake Nakuru in different methods of classification used in different years. Year (1987-2006).

YEARS	1987	1989	1995	2000	2001	2002	2003	2004	2005	2006
Area of shapefile	3493.44	4019.4	4008.24	4775.51	3626.19	3588.48	3681.72	3825.36	3695.76	3544.47
Area using NDVI	3297.87	3552.57	3287.52	4594.41	2244.87	2045.34	3608.64	3075.84	3005.1	2889.09
Area using K-means	3201.3	3571.56	2966.49	4126.86	3081.33	2665.8	3205.17	2752.74	2057.67	2439.54
Area using M.L.C	3089.61	3358.8	3036.42	4417.2	2504.3	2307.33	3556.44	3000.96	3001.14	2895.39
Area using SAM	3194.1	3525.3	3210.66	4056.84	2325.24	2227.23	3496.23	2595.24	2551.95	2455.11

3.2. Analysis

From the tables on the findings of the lake area, using the results, line graphs (Figure 2) were drawn to make it visible to see the changes of the lake area over the years. From figure it is evident that the area was expanding steadily from the year 2010 to 2019.

Correlation between the Lakes Area Using Its Shapefile and the Area of the Lake in Different Methods

The When the line graph was plotted to show the change of the lake area, Ms

Table 2. Showing area of Lake Nakuru in different methods of classification used in different years. Year (2007-2015).

YEARS	2007	2008	2009	2010	2011	2012	2013	2014	2015
Area of shapefile	3716.1	4060.17	3809.61	3723.57	4206.15	4587.54	5087.07	5688.09	5569.56
Area using NDVI	2913.93	3219.39	3183.03	2784.42	3502.26	3737.79	4200.3	5404.05	5445.36
Area using K-means	1567.71	3149.91	2426.76	1742.04	3362.31	3609.81	4092.66	4010.4	4211.37
Area using M.L.C	2783.7	3081.15	3201.75	2590.83	3505.86	3769.56	4102.2	5076.99	5205.15
Area using SAM	2375.01	2600.01	2964.87	2442.15	3348.72	3600.18	3736.89	5097.24	5126.04

Table 3. Showing area of Lake Nakuru in different methods of classification used in different years. Year (2016-2019).

YEARS	2016	2017	2018	2019
Area of shapefile	5495.76	5678.28	6186.51	6249.42
Area using NDVI	5411.16	5538.06	5433.84	5909.58
Area using K-means	5354.37	5470.19	5453.46	4951.44
Area using M.L.C	5195.07	5301.09	5173.2	5645.61
Area using SAM	5072.85	5287.86	5501.52	5847.03

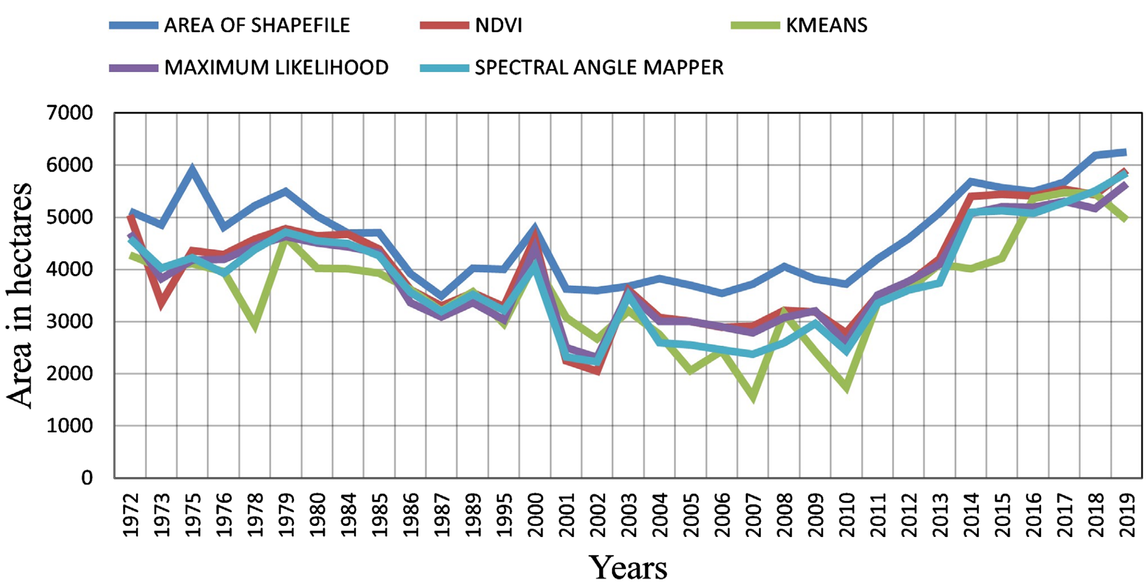

Figure 2. Variation of the lake area size in hectares using different classification methods over the years.

Excel was used to obtain correlation. In order to show the accuracy of using the shapefile to obtain the area of the lake in each classification method used. The correlation coefficient is 1, from the graphs below it is seen that they were able to produce a coefficient of 0.82 - 0.93, thus a good correlation (**Figures 3-6**).

3.3. Discussions

Since different classification methods were used, the change of the lake area is seen to be reducing in the years 1976-1987 and suddenly expanding in the years 2011-2018. The most appropriate line graph is Area of the shapefile, because it shows clearly how the lake reduced, then expanded, even though during year

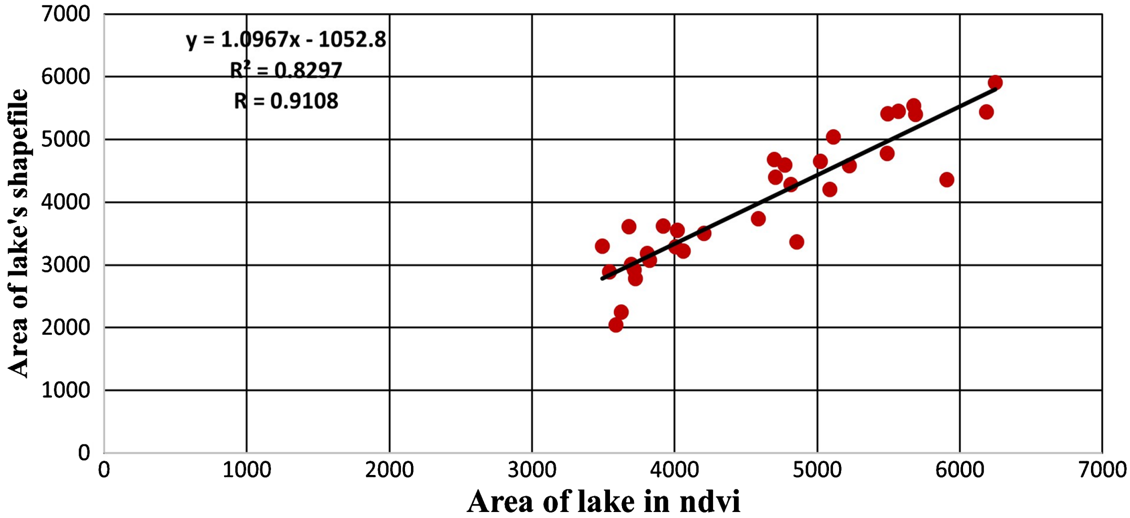

Figure 3. Correlation of the lake's shapefile and area using NDVI method.

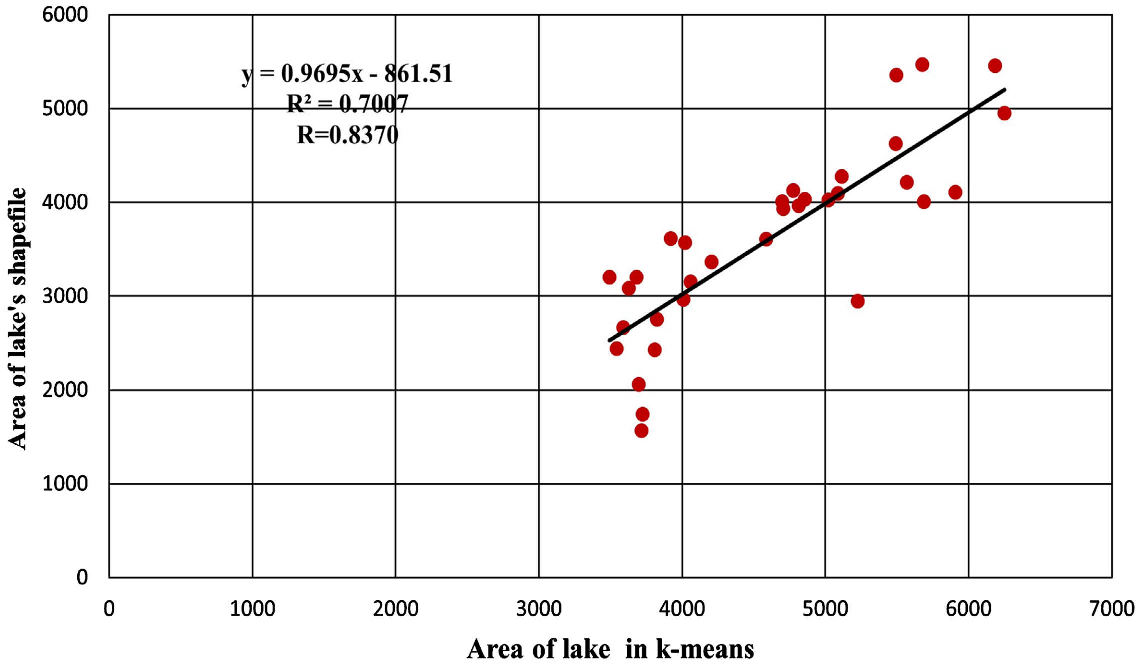

Figure 4. Correlation of the lake's shapefile and area using K-means method.

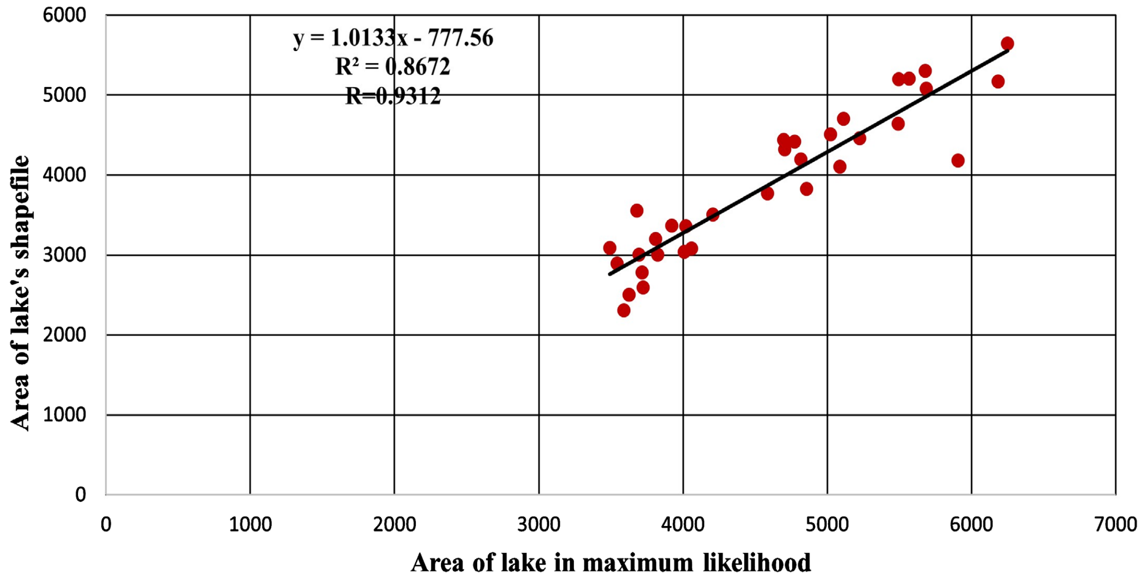

Figure 5. Correlation of the lake's shapefile and area using maximum likelihood method.

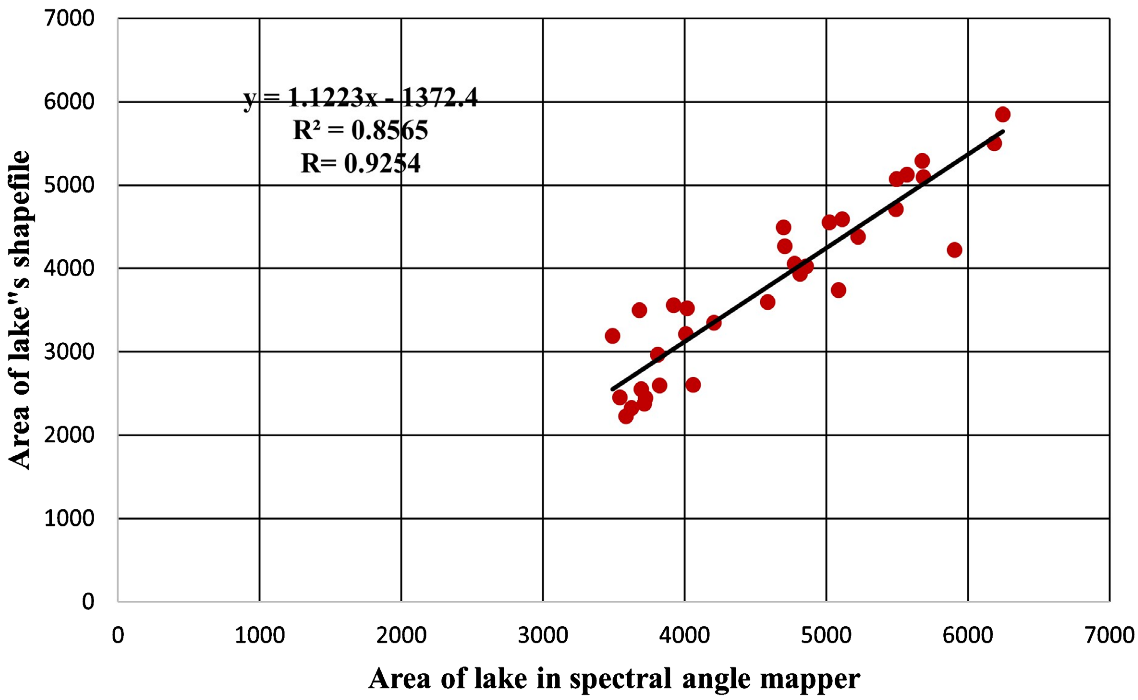

Figure 6. Correlation of the lake's shapefile and area using spectral angle mappermethod.

2005 and 2011 Landsat 7 its Scan Line Corrector in the ETM+ instrument failed, that's why on the satellite images it showed diagonal lines, it was still able to show the lake's area with a bit of reduction and still provided a good line graph.

Using NDVI the lake area reduced with about 1343.97 Ha which is about 29.2% decrease, then the area expanded with a 19.9% increase and finally from 2011 to 2018 it expanded again about 1535.4 Ha thus 39.35%.

With K-MEANS, from 1979 to 1995 the area reduced with about 1657.71 Ha that's a 35.84% reduction of the water area. Then increased in 2000 and had a "constant like" drop and rise in 2001 to 2010. From 2010 to 2019, the lake area then expanded by about 3209.4 Ha which is 64.81% increase.

Supervised classification was used and one method that was used is Maximum Likelihood whereby it showed from 1973 to 1984 the lake area abridged by about 610.76 Ha thus a 13.75% decrease. The following two years 1985 and 1987 the area decreased, then rose suddenly from 1995 to 2000 and later dropped till 2010. From 2010 to 2019 the lake area expanded by about 3054.78 Ha showing a 54.10% intensification.

The other supervised classification that's Spectral Angle Mapper showed a smoother graph than the other classification method, from the year 1979 to 1995 the lake area lessened with about 1503.6 Ha showing a 31.89% decrease. The lake area sustained an increase from 2004 to 2019 by about 3251.79 Ha which is a 55.61% showing a surge.

After getting the area of the lake in hectares and recording the results in a table, the area of the shapefile was considered to be more accurate therefore it was used for correlation with the other areas found from using different classification methods. The perfect correlation coefficient is 1, the graphs for correlation gave 0.91 for NDVI, 0.83 for K-MEANS, 0.93 for Maximum Likelihood and 0.92 for Spectral Angle Mapper.

4. Conclusion and Recommendations

By using different classification techniques, the results were able to provide a smooth line graph to show the change of Lake Nakuru area. Spatial distribution maps of the lake showed different images of the lake in each of the classification used, though the graph of the area of the shapefile is assumed to be more accurate because it's whereby the lake is calculated before any classification is performed on the image and is used to correlate the area of the lake with the other methods. Though the cause of the lake's change within the years isn't known. The change was seen using line graph and that the Lake Nakuru area is expanding from the years 2010 to 2018.

The land use practices of the region have been changing with the built-up area recording an increase of almost 400% over the past 30 years, the changes in these practices make a major contribution to the soil loss of the area as the vegetation and forest are destroyed leading to an increase in the susceptibility of the soil to erosion. The results of the classification also revealed the area of Lake Nakuru has increased by 50% from the year 1990 to 2018.The modeled factors despite assumptions being made on the soil erodibility factor and LS factor the results obtained.

To find better results, both data from satellite images and field survey data should be used to produce best results of the area of Lake Nakuru. The use of satellite data from Landsat images on the earth explorer website proved to be useful and successful in this case study and has proved to be appropriate in mapping and monitoring a lake area. Correlation graphs proved that Maximum Likelihood would be the best method to use to classify the image because it gave a coefficient of 0.93. Since the lake is showing an expansion from the results of the line graphs. It's prudent to monitor it which will help predict the future change of Lake Nakuru.

Data Availability

The data shall be available upon request from the corresponding author.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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