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Sustainability of Water Bodies of Edku Lake, Northwest of Nile Delta, Egypt: RS/GIS Approach

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Abstract

In this paper, Edku Lake was selected as a case study to apply the RS/GIS techniques to investigate the water body sustainability. It is one of the northern coastal lakes in Egypt, located at the northwestern part of the Nile Delta. Edku Lake is an important fishing area in Egypt and receives its water from two sources. One of sources is the drainage water of Kom Belag and Bersik drains and second is the sea water. Remote sensing and GIS software are used in this study for processing of the images and managing the database of each image. The different techniques of classification were tested, the results showed that the maximum likelihood supervised classification technique was more accurate to monitor changes in the water bodies of the Lake. The technique was applied to subsets of the Landsat TM, ETM+ and OLI/TIRS images acquired on 1984, 1990, 1998, 2003 and 2015, respectively to monitor changes in the Lake. The results showed that the water bodies of the lake decreased during the period from 1984 to 2015. The extracted data from the images have been used to develop statistical models for the different classes to predict the future situation of each class. The results of prediction indicated that the water body of the lake will be more decrease in 2030. The results indicate that the water body of the lake is not sustainable. The results of this study will act as warning for the decision makers to take the necessary actions/policy to reduce the environmental risk and maintain the healthy environment of the lake.

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Keywords: Edku Lake; land use and land cover; Sustainability; Water bodies; Remote sensing; ERDAS and ArcGIS software.

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1. Introduction

Sustainability can be defined as the ability to continue a defined behavior indefinitely. In ecology, sustainability is how biological systems remain diverse and productive indefinitely. This study provides a practical method to assess the sustainability of the surface water body by computing the sustainability of water body indicator (area of the water body at particular year/area of the water body at the reference year). High concentrations of nutrients from agricultural and urban runoff are the main cause of algal blooms in many estuaries and coastal waters [1]. Edku Lake is an example of the wetland in Egypt. Edku Lake is the smallest in area comparing with Manzala Lake or Burullus Lake. Bughaz El-Meadia connects the lake to the Mediterranean Sea. Edku Lake is a typical delta edge lagoon, with a history of steady contraction from 200 km^2 before the 1940 to some 150 km^2 in the 1950 to some 70 km^2 in the 2008. It is estimated that a reduction of some 30% of the lake area has occurred in the last 20 years by the development of drainage and irrigation schemes in the eastern portion [2]. The water chemistry and productivity of this lake is generally controlled by the drainage water reaching it through the two main drains namely Kom Belag and Bersik [3]. Edku Lake changed due to the discharge of agriculture wastes and municipal wastes into the lake without appropriate treatment. Discharging the agriculture wastes and the municipal wastes into the lake without proper treatment causes an increase in the floating vegetation and decrease in water bodies. This increase of floating vegetation effects the functioning and biodiversity of Lake ecosystem negatively and consequently threaten the lake sustainability. Conditions of darkness and anoxic under floating vegetation leave little opportunity for animal or plant life. Remote sensing is considered a cost-effective way to detect change detection in LULC over wide geographic areas [4]. Also, the use of RS/GIS techniques can provide useful information on spatial and temporal changes in aquatic vegetation in the lakes [5]. Satellite images are suitable for wetland mapping and monitoring in developing countries where funds are limited and information on wetland areas, and wetland losses over time are not available [6].

Wetland management encompasses mapping and monitoring so that public managers and decision makers can be provided with credible and relevant information [7]. Change detection of LU/LC leads to the impact on the socio-economic, biological, climatic and hydrological systems [8]. Change in LU/LC is one of the most important indicators for global and regional environmental change [9]. To guarantee the sustainable management of natural resources, it is important to monitor and control the processes of change in LULC [10]. Change detection in LULC across spatial and temporal scales is indispensable to achieve sustainable environmental management [11]. Providing sufficient information on what kind of changes occur and where/when they occur, in addition to the rate of occurrence is essential in planning process. Also, the physical and social forces that drive these changes to understand the effects of LU/LC on the ecosystems [12]. Classification and mapping the types of LULC by high accuracy is an important issue to support the sustainable management of natural resources. To find the changes in LU/LC with a proper accuracy, the suitable classification system should be used. Also, division of all objects into different classes according to the requirements of the study should be adopted [13]. This study aims to provide an accurate estimate of the LU/LC in Edku Lake and assessment the sustainability of water bodies of the lake using remote sensing and GIS approach.

2. Study Area

Edku Lake is a brackish lake and located in the northwestern part of the Nile Delta to the west of Rosetta branch. Geographically, it is located between longitudes 30° 8′ 30″ and 30° 23′ E and latitudes 31° 10′ and 31° 18′ N (see Fig. 1). The lake is connected to the Mediterranean Sea through Bughaz El-Meadia, a 20 m wide, 100 m long and 2 m deep channel. The actual surface area of the lake has been decreased due to reclamation of a large area for cultivation purposes. Water depths in the lake are ranging between 10 to140 cm, the maximum depths being in the central and eastern parts [2]. Two main drains discharge their water into the lake. The first drain namely Kom Belag receives its water from three subdrains; Bosily, Edku and El-Khairy where they are connected at about 3 km to the east of the lake. The drainage water of kom Belag drain is discharged at the eastern part of the lake. The second main drain connected to the lake is Bersik drain which outlets its water at the southern central part of the lake. Lake water is mainly affected by the growth and creeping of floating vegetation on the water bodies.

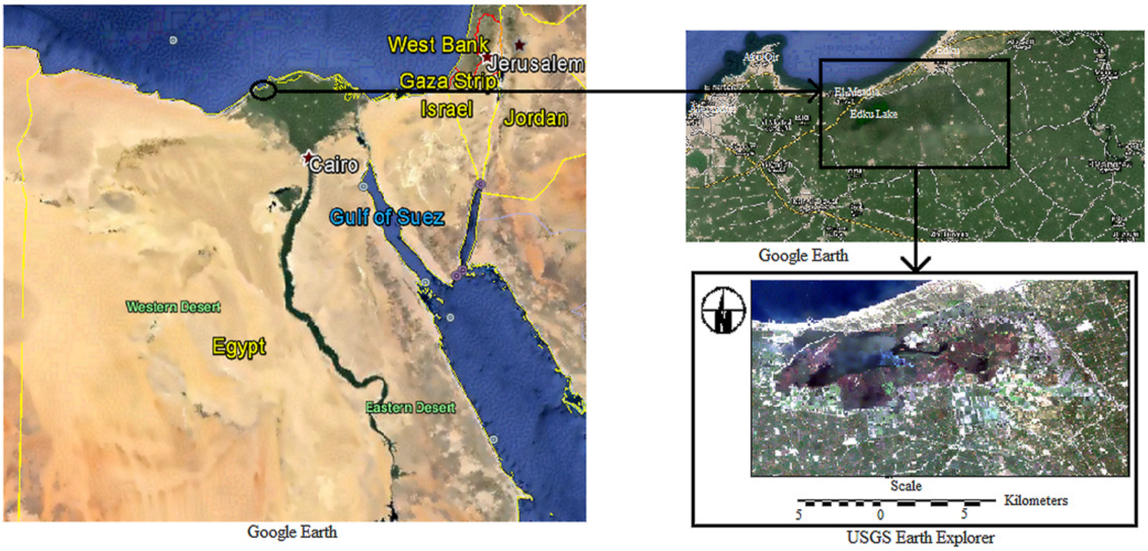

Fig. 1. Location of the study area of Edku Lake.

3. Methodology and Data Collection

Five satelite images were selected. Three belong to Landsat Thematic Mapper (TM), one belong to Enhanced Thematic Mapper Plus (ETM+) and one belong to Operational Land Imager and Thermal Infrared Sensor (OLI/TIRS). All are with 30 m ground resolution acquired on 1984, 1990, 1998, 2003 and 2015 respectively. These images are downloaded from United States Geological Survey [14]. ERDAS 9.1 and ArcGIS 9.3 software were used for Image processing and detecting the changes in LU/LC. Geometric correction of the images had been done using the first order polynomials [15]. All images are registered in the same projection system (UTM, WGS 84). Three different techniques are applied to detect the change of the lake water bodies using Maximum likelihood supervised classification, Minimum distance supervised classification, Mahalanobis distance supervised classification. The accuracy of the classification for the three methods were assessed based on the following four criteria (a) procedure accuracy, (b) user accuracy, (c) overall accuracy and (d) overall Kappa [16,17,18].

4. Results and Discussion

4.1. Assessment of Classification accuracy

The results of classification of the 2015 image using the three techniques indicate the superiority of that maximum likelihood supervised classification technique with the highest accuracy based on the above mentioned criteria. The overall accuracy for maximum likelihood supervised classification is 96.89% while it is 80.22% and 91.33% for Minimum distance supervised classification and Mahalanobis distance supervised classification respectively. Based on results, the maximum likelihood supervised classification technique had been used to subsets of the Landsat images acquired on 1984, 1990, 1998, 2003 and 2015, respectively to monitor changes in Edku Lake to assess the water body sustainability of the lake. The overall accuracy of the classification of the captured images using the maximum likelihood classification technique in 1984, 1990, 1998, 2003 and 2015 are 80.44%, 86.67%, 92.44%, 96.00% and 96.89% respectively. Figures (2) and (3) show the example of classified images for the years 1984 and 2015 using the maximum likelihood classification method.

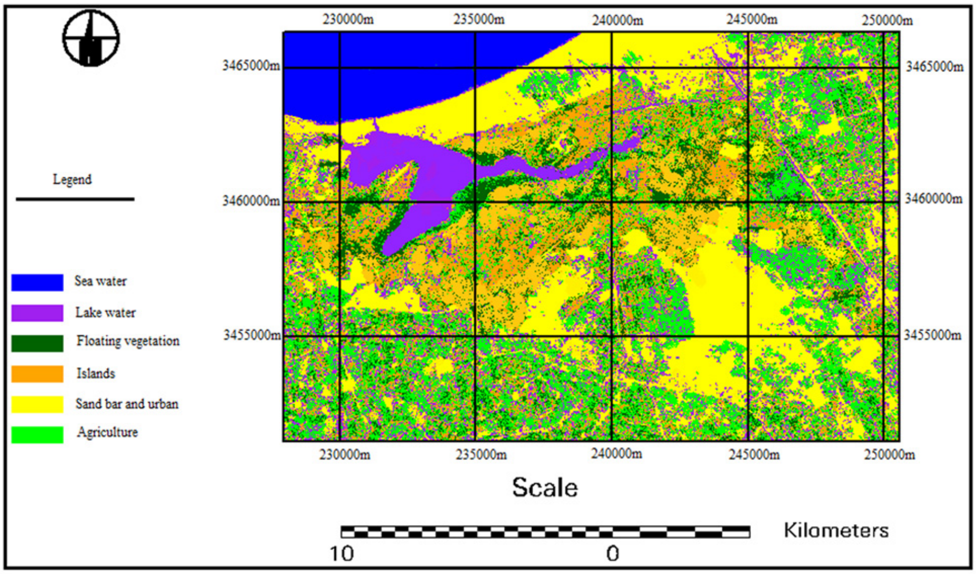

Fig. 2. The 1984 image maximum likelihood classification.

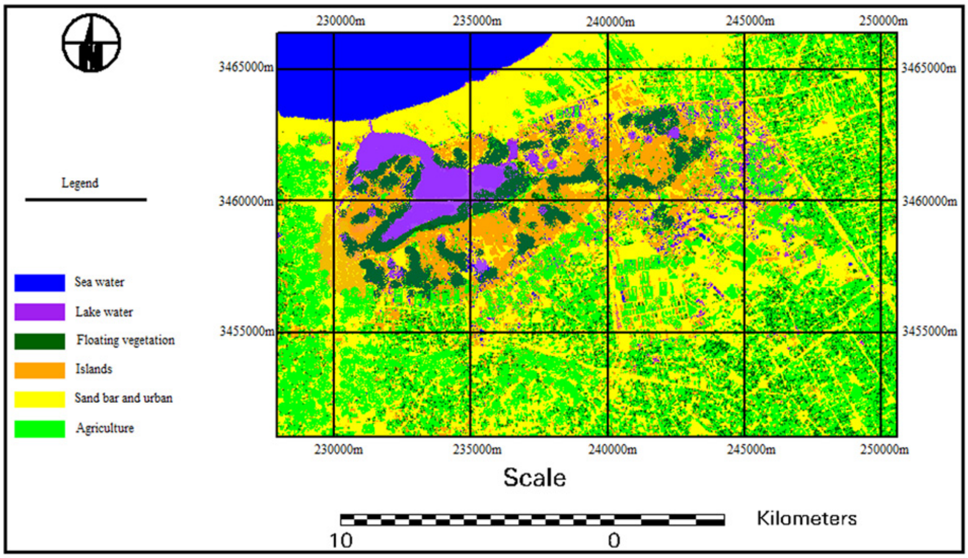

Fig. 3. The 2015 image maximum likelihood classification.

4.2. Change detection analysis

Change detection in the Edku Lake in the period from 1984 to 2015 indicate that there is a deterioration in the water bodies of the lake due to increased area of the floating vegetation and reclamation of a large area for cultivation purposes. The increase in floating vegetation is due to the discharge of agriculture wastes and municipal wastes into the lake without adequate treatment. Table (1) shows the change in each category during the five periods. Figure (4) shows the temporal variation of areas for the detected 6 classes as % of the total area.

Table 1. The lands cover changes in (Hectare) in 1984, 1990, 1998, 2003 and 2015 (see Fig. 4)

Class	Area in 1984 (ha)	Area in 1990 (ha)	Area in 1998 (ha)	Area in 2003 (ha)	Area in 2015 (ha)
Sea water (SW)	2183.31	2177.23	2106.54	2225.61	2219.65
Lake water (LW)	3126.72	2804.21	2600.73	2522.74	2334.68
Floating vegetation (FV)	532.38	686.46	832.75	944.93	1110.83
Islands (IS)	5731.04	5126.96	4203.59	4117.84	3640.05
Sand bar and urban (SU)	7042.95	6550.16	6210.54	6141.4	5643.24
Agriculture (AG)	16334.25	17605.63	18996.5	18998.13	20002.2
Total area	34950.65	34950.65	34950.65	34950.65	34950.65

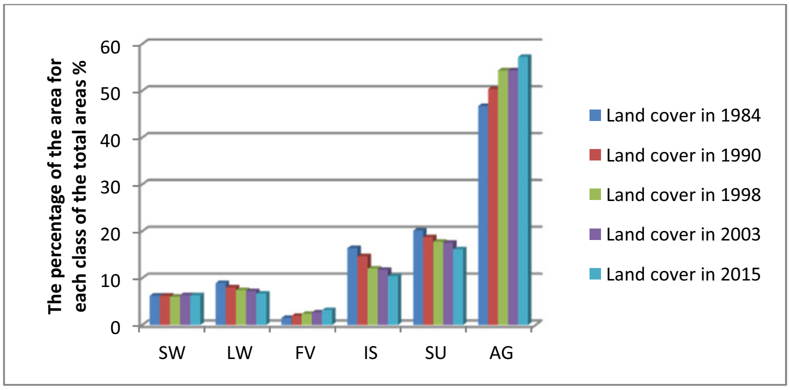

Fig. 4. Temporal variation of areas for the detected 6 classes as % of the total area.

As for the period from 1984 to 2015, water bodies of the lake were decreased by 792.04 ha (25.33%), while floating vegetation were increased by 578.45 ha (108.65%) (see Table 2). The main reason for overgrowth of floating vegetation in surface water is the discharge of wastewater into the lake without appropriate treatment, because the wastewater has plant nutrients, e.g., nitrates (NO3) and phosphate (PO4). The results showed that the agriculture area increased by 3,667.95 ha (22.46%) while urban and islands area decreased by 1,399.71 ha (19.87%), 2,091 ha (36.49%), respectively in the period from 1984 to 2015 (see Table 2). The sea water has minor changes during the period of study. Fig. 5 shows the spatial variation for the 6 detected classes for the period from 1984 to 2015.

Table 2. The lands cover changes in Hectare (ha) in 1984 and 2015 and the average of change per year (see Fig. 5)

Class	Area in 1984 (ha)	Area in 2015 (ha)	Change in area (ha)	% Change in area to 1984	% Change in area to the total area	Change/year (ha/year)
Sea water	2183.31	2219.65	36.34	1.66%	0.10%	1.17
Lake water	3126.72	2334.68	-792.04	-25.33%	-2.27%	-25.55
Floating vegetation	532.38	1110.83	578.45	108.65%	1.66%	18.66
Islands	5731.04	3640.05	-2090.99	-36.49%	-5.98%	-67.45
Sand bar and urban	7042.95	5643.24	-1399.71	-19.87%	-4.00%	-45.15
Agriculture	16334.25	20002.2	3667.95	22.46%	10.49%	118.32
Total area	34950.65	34950.65	-------	-------	-------	-------

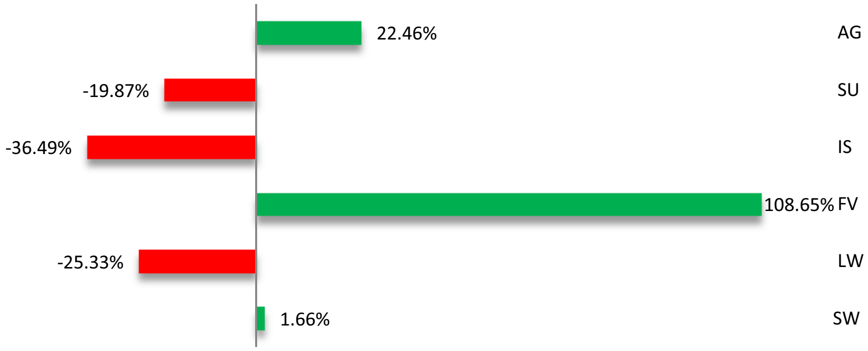

Fig. 5. Spatal variation for the 6 detected classes for the period from 1984 to 2015

The results of change detection were used to build statistical models to predict the future changes of the different detected classes. Fig. 6 shows the statistical models used to predict the change in the future for the lake.

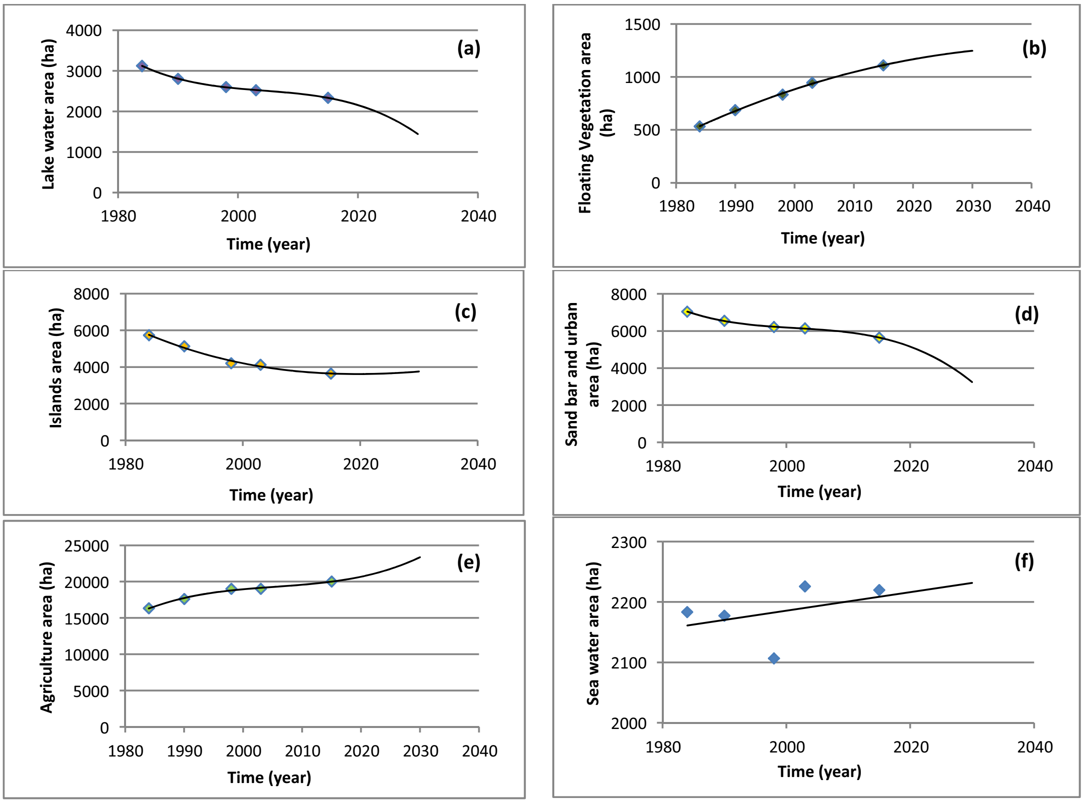

Fig. 6. Relationship between areas of different detected classes of the lake over the period from 1984 to 2015 with projection to 2030; (a) Lake water, (b) Floating vegetation, (c) Islands, (d) Sand bar and urban, (e) Agriculture, (f) Sea water

The coefficient of determination (R^2) is computed for the statistical models and found that the statistical models have the best values for the coefficient of determination (see Table 3). The statistical models had been used in prediction of sea water, lake water, floating vegetation, islands, sand bar and urban, and agriculture. Forecasting results indicate that the water bodies of the lake will decrease by 873.16 ha (37.4%) over the period from 2015 to 2030 (see Table 3) while floating vegetation area will increase by 89.75 ha (8.08%). Also, the agriculture area will increase by 3,476.87 ha (17.38%) over the period from 2015 to 2030 (see Table 3), while urban and islands area will decrease by 2,512.09 ha (44.52%), 61.75 ha (1.7%), respectively. Continual growth of floating vegetation result in more darkness of the hidden water body (under the vegetation) and lack of oxygen under the floating plants which negatively affects the ecosystems of Lake aquatic plant system. Floating vegetation also will negatively impact fisheries and navigation on the lakes. Fig. 7 shows the projected change in each class from 2015 to 2030.

Table 3. Developed statistical models for the six classes and the predicted land cover area in the year 2030.

Class	The equation used to predict	R^2	Area in 2030 (ha)
Lake water	$Y= -0.0459x^3+276.03x^2-553334.206x+369750972$	0.9998	1461.52
Floating vegetation	$Y= 0.0001x^3-1.0789x^2+3138.163x-2759774$	0.9985	1200.58
Islands	$Y= -0.01x^3+61.803x^2-127281.48x+87355270$	0.9882	3578.3
Sand bar and urban	$Y= -0.102x^3+612.23x^2-1224937.195x+816960584$	0.9993	3131.15
Agriculture	$Y= 0.1789x^3-1076.5x^2+2159289.559x-1443760366$	0.9895	23479.07
Sea water	$Y= 1.5295x-873.43$	0.1486	2231..46

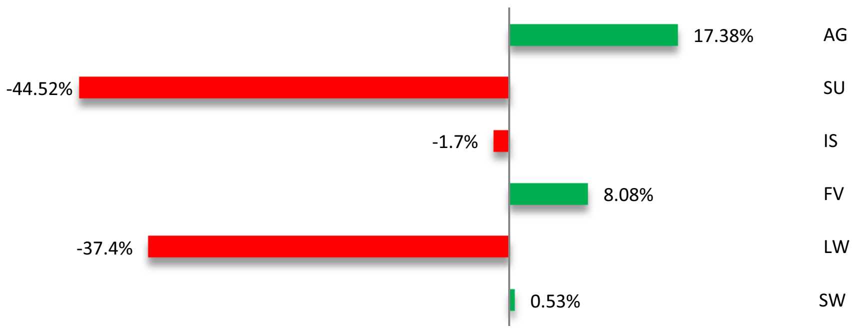

Fig. 7. Expected spatial variation for the 6 detected classes for the period from 2015 to 2030 based on the statistical models presented in Table 3.

5. Conclusion and Recommendations

The overall accuracy of the classification of the captured image in 2015 for minimum distance supervised classification, Mahalanobis distance supervised classification, maximum likelihood supervised classification was 80.22%, 91.33%, and 96.89% respectively. It is clear that the maximum likelihood supervised classification technique has the highest accuracy for classification for the study area and areas with similar conditions as the study area (heterogeneous area). maximum likelihood supervised classification was applied to subsets of the Landsat TM, ETM+, and OLI/TIRS images acquired on 1984, 1990, 1998, 2003 and 2015, respectively to monitor changes in Edku Lake to assess the water body sustainability of the lake. The overall accuracy of the classification of the captured images using the maximum likelihood classification technique in 1984, 1990, 1998, 2003 and 2015 was 80.44%, 86.67%, 92.44%, 96.00% and 96.89% respectively. This study provides a practical method to assess the sustainability of the surface water body by computing the area of the water body at particular year/area of the water body at the reference year. In the entire period from 1984 to 2015, water bodies of the lake declined by 792.04 ha (25.33%), while floating vegetation area increased by 578.45 ha (108.65%). It is concluded that the primary reason for the decline in water body of Edku Lake is the increase of the floating vegetation and reclamation of a large area for cultivation purposes. This increase in floating vegetation is mainly due to discharge the agriculture and municipal wastes into the lake without adequate treatment. Furthermore, the future prediction using the developed statistical models proved that the water bodies of the lake will be reduced by 873.16 ha (37.4%) over the period from 2015 to 2030. Based on these results, the author recommends that decision-maker must take suitable measures to achieve the water body sustainability of the lake through short and long term strategy otherwise, the ecosystem of the lake may be threatened and impacted negatively. Cleaning the lake from floating vegetation using the proper cleaning equipment at a rate 18.66 ha/year shall be sufficient for the short term while for long term adequate treatment for agriculture and municipal wastes before being discharged into the lake should be conducted. This shall reduce the environmental risk and maintain the lake to sustain the lake water area against further reduction by the successive growth of floating vegetation.

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