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Change detection in the water bodies of Burullus Lake, Northern Nile Delta, Egypt, using RS/GIS

Hickmat Hossen[a]* , Abdelazim Negm[b]

[a]*Ph.D. Student, Department of Environmental Engineering, Egypt-Japan University of Science and Technology E-JUST, P.O. Box 179, New Borg El-Arab, Alexandria, Egypt, E-mail: hickmat.abdullah@ejust.edu.eg*

[b]*Head of Natural Resources Lab., Department of Environmental Engineering, Egypt-Japan University of Science and Technology E- JUST, Alexandria, Egypt, (seconded from Faculty of Engineering, Zagazig University, amnegm@zu.edu.eg), E-mail: negm@ejust.edu.eg*

Abstract

The Egyptian coastal lakes have changes in the water bodies due to the severe anthropogenic activities. In this paper, the Burullus Lake was selected as a case study. It is the second largest of the Egyptian northern coastal lakes along the Mediterranean coast. It has economic and environmental impacts on the nearby society of Kafr El-Sheikh, Egypt. ERDAS IMAGINE and ArcGIS software are used in this study for processing of the images and managing the database of each image. Different classification techniques are 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 method is applied to subsets of the Landsat TM, ETM+ and OLI/TIRS images acquired on 1984, 1990, 1998, 2003 and 2015, respectively. Five classes are detected including sea water, lake water, floating vegetation, sand bar and urban, and agriculture land. The results showed that the water bodies of the lake decreased by 44.97% (14,503.68 ha), while floating vegetation area increased mostly by the same amount during the period from 1984 to 2015. This increase in floating vegetation is mainly due to discharging of agriculture wastes and municipal wastes in the lake without adequate treatment. The sea water has minor changes during the period of study. The agriculture area increased by 45.52% (10,529.02 ha), while the sand bar and urban area decreased mostly by the same amount during the period from 1984 to 2015. Statistical models were developed using statistical tools. The models indicated that the water bodies of the lake will be reduced by 58.95% (19,013.42 ha) in 2030. The results of the present study shall help the decision-makers to take the necessary measures to reduce the environmental risk and maintain the lake in order to sustain the lake water area against further reduction.

* Corresponding author. Tel.: +20-1007767223; fax: +20-34599520
E-mail address: hickmat.abdullah@ejust.edu.eg , negm@ejust.edu.eg

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1. Introduction

Changes in land use and land cover (LU/LC) are (a) essential to the study of sustainable development [1], (b) an important factor to understand the interaction and the relationship of anthropogenic activities on the environment [2] and (c) its spatial and temporal scales is indispensable to achieve environmental sustainability [3]. On the other hand, to ensure the sustainable management of natural resources, it is essential to monitor and control the processes of change [4]. The spatial and temporal distribution of LU/LC using satellite images is crucial to understanding the phenomenon of global environmental change. Change in LU/LC leads to the impact on the socio-economic, biological, climatic and hydrological systems [5]. The importance of the changes in the size and quality of many of the world's wetlands has arisen mainly as a result of increased urban development and agricultural development [6]. High concentrations of nutrients from agricultural and urban runoff, or those produced by coastal upwelling, are causing algal blooms in many estuaries and coastal waters [7]. Remote sensing tecnology is appropriate for wetland mapping and monitoring where funds are limited and information on wetland areas, surrounding land uses, and wetland losses over time are not available [8]. The remote sensing and GIS methods provide useful information on spatial and temporal changes in aquatic vegetation in the lakes [9]. In fact, Burullus Lake had changed due to the discharge of agriculture wastes and municipal wastes in the lake without adequate treatment. Six drains are collecting agricultural and municipal wastes and draining into the lagoon [10]. Draining the discharge of agriculture and municipal wastewater in the lake without adequate treatment caused an increase in floating vegetation and decrease in water bodies. A continual growth of the floating vegetation impacts the functioning and biodiversity of Lake ecosystem negatively and consequently threatens the lake sustainability. Dark, anoxic conditions under floating vegetation leave little opportunity for animal or plant life, and they can have large negative impacts on fisheries and navigation in lakes. To learn about the changes occurring in land use and land cover somewhere, the analysis of the spatial and temporal variations is a must [11]. Remote sensing is an effective way in term of cost to detecting a change in LU/LC wide geographic areas [12]. Satellites work to provide a wide range of data to somewhere in the temporal variations. Remote sensing techniques are practical and effective in a cost for monitoring natural and human-induced coastal changes after improvements in sensor design and data analysis techniques [13].

Classification and mapping of LU/LC by high accuracy are significant issues to support the sustainability of natural resources. To assessment the impact of change in LU/LC on ecosystems, it is essential to provide information on what and where and when changes occur, and the rates of changes, and forces that drive those changes [14]. To detect the change in LU/LC with high accuracy is a must to develop a classification system for the whole region [15]. To detect the change from one category to another is a must to conduct statistical processes that depend on classification of LU/LC. To conduct images classification and change detection there are numerous techniques. In this study, five different techniques are applied to detect the change in the water bodies of the lake using ERDAS Imagine and ArcGIS software. The used techniques encompass Mahalanobis distance supervised classification, Minimum distance supervised classification, Maximum likelihood supervised classification, Unsupervised classification, and Normalized difference water index. Landsat OLI/TIRS image with 30 m ground resolution acquired on 2015 are used to compare the performance of these techniques. The optimal technique that has the highest accuracy will be applied to subsets of Landsat TM, ETM+ and OLI/TIRS images acquired on 1984, 1990, 1998, 2003 and 2015, respectively to monitor changes in the Lake. The study aims to provide an accurate estimate of the land use and land cover in Burullus Lake and predict the future situation.

2. Description of study area

Burullus Lake is one of the most vulnerable lakes and is the second largest lake of the Egyptian northern lakes along the Mediterranean coast and is located in the Nile Delta between the two Nile River branches: Damietta and

Rosetta. The Burullus region is located in the central part of the northern shoreline of the Nile Delta in Egypt. Geographically, it is situated between longitudes 30° 30′ and 31° 10′ E and latitudes 31° 21′ and 31° 35′ N (see Fig. 1). In addition to the importance of the Burullus lake from fishing resources, it is importance from being a habitat for domestic fauna and a route for wintering migratory birds [10]. The Burullus lagoon is one of the sites of the International Conventions on Wetlands (known as Ramsar) and was declared as a national protected area in 1998 [16]. The total area of the Burullus region is about 163961.4 ha (1639.614 Km2), includes the lake. The surface area of Burullus Lake is about 515 Km2. The lake is shallow, with a maximum depth of about 2.0m in the middle and western parts. Salinity levels in the lake, ranging from 2.1 % in the West to 17.2 % in North [17]. There are six drains collecting agricultural and municipal wastes and pouring them into the lagoon [10].

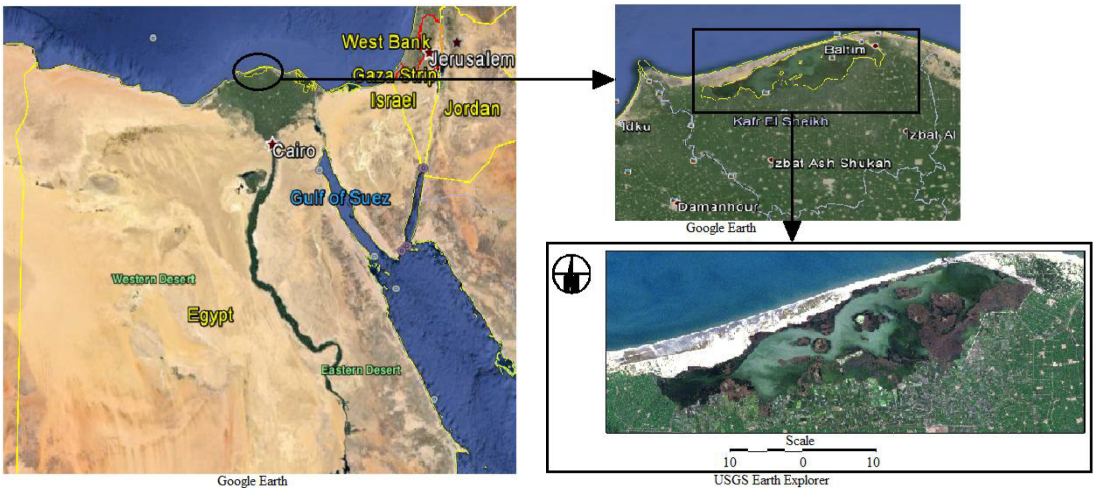

Fig. 1. Location of the study area of Burullus Lake.

3. Data and methodology

Landsat TM, ETM+ and OLI/TIRS images with 30 m ground resolution acquired on 1990, 2003 and 2015, respectively have been used to detect the change in Sea water, Lake water, Sand bar and urban, Floating vegetation and Agriculture, from 1990 to 2015. These images are downloaded from United States Geological Survey [18]. Image processing and detecting the changes in land use and land cover have been through the use of ERDAS 9.1 and ArcGIS 9.3 software.

3.1. Image preprocessing

Geometric correction of the images has been using ERDAS 9.1 program through using of first order polynomials. The order of polynomial represents the order of transformation in the geometric correction processes. The nearest neighbor method was used in the resampling processes of the images. The nearest neighbor method is appropriate before starting the classification process because it does not change the cell values of the image. The nearest neighbor method is easy to account and fast in use [19]. All images were registered in the same projection system (UTM, WGS 84).

3.2. Image Classification

In this study, the different techniques are applied to detect the change in the water bodies of the Burullus Lake using Remote sensing and GIS techniques. The used techniques encompass Mahalanobis distance supervised classification, Minimum distance supervised classification, Maximum likelihood supervised classification, Normalized difference water index, and Unsupervised classification. Landsat image acquired on 2015 are used to compare the performance of these techniques.

4. Results and discussion

4.1. Classification accuracy assessment

Accuracy is the degree of trust, defined as the degree of assemblage between the results and the truth. The results are compared with a map of LU/LC cover of reference data (map) to evaluate the classification accuracy. There must be suitability between the number and location of samples of category and type and size of that category, to obtain a high accuracy of the classification [20]. There are two methods for accuracy assessment, error matrix and Kappa coefficient. Results of image classification are compared with true information on the surface of the earth using the error matrix. We can determine the overall accuracy of the classification through dividing the total number of the correct pixel on the total number of all pixels. Accuracy assessment contains of two indicators, user's accuracy and the producer's accuracy. User's accuracy indicates to the possibility that the pixels on the image represent that category on the ground [21]. Producer's accuracy is known as the likelihood of correctly classified pixels and is used primarily to determine the extent of the area to be classified [19]. The Kappa is a multi-separate variables method used to determine the accuracy of maps classification. It is calculated from the error matrix and implemented over the classification based on the data reference [22]. Overall accuracy for the classification of Landsat OLI/TIRS image with 30 m ground resolution acquired on 2015 for Minimum distance supervised classification, Mahalanobis distance supervised classification, Maximum likelihood supervised classification, Unsupervised classification, and Normalized difference water index are 78.33%, 93.33%, 97.53%, 60.83% and 84.17% respectively. It is clear that the Maximum likelihood supervised classification technique has the highest accuracy for the study area and areas with similar conditions as the study area (heterogeneous area). Based on these results, the maximum likelihood supervised classification technique have been used to subsets of the Landsat images acquired on 1984, 1990, 1998, 2003 and 2015, respectively to monitor changes in Burullus Lake to assess the water body sustainability of the lake. The overall accuracy for the classification of the captured images using the maximum likelihood supervised classification technique in 1984, 1990, 1998, 2003 and 2015 are 94.67%, 88.7%, 87.2%, 92.39% and 97.53% respectively. Typical results of classifications are presented in Figures 2 and 3 for the years 1984 and 2015 using the maximum likelihood classification method.

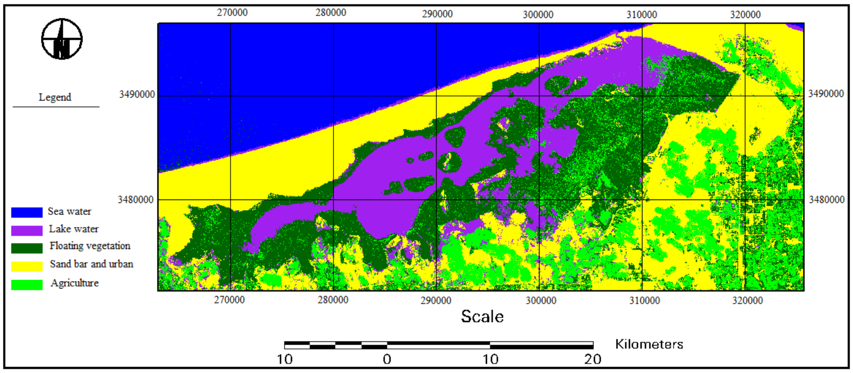

Fig. 2. The 1984 image maximum likelihood classification.

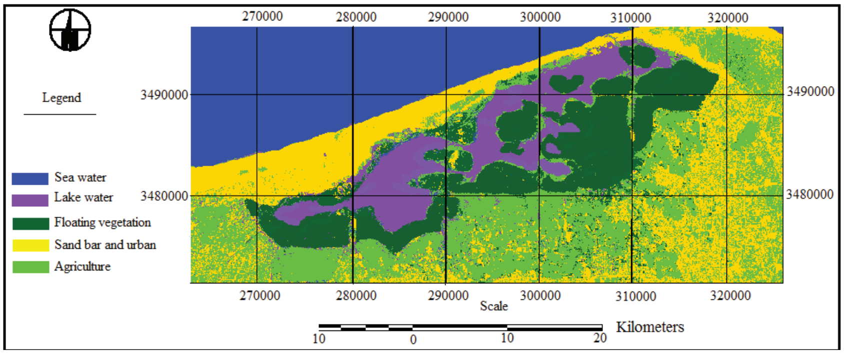

Fig. 3. The 2015 image maximum likelihood classification.

4.2. Change detection analysis

Change detection in the Burullus Lake in the period from 1984 to 2015 indicates to deterioration in the water bodies of the lake due to increasing in the area of the floating vegetation. This increase in floating vegetation is probably due to discharging of agriculture wastes and possible other waste such as municipal wastes in the lake without adequate treatment. Table (1) shows the change in the area of each category during the five periods in ha. Also, figure 4 presents the same results as a percentage of the total area for each class for the five periods. It is clear that lake water and sandbars/urban are decreasing while floating vegetation and agriculture land are increasing. The results of the areas from this study correspond to some extent with some prior results. For example, El-Adawy [23] evaluated the lake water area in 2003 is 21,422 ha (compare with 21,008 ha in this study). Also, Donia [2] evaluated the lake water area in 1990 as 25,793 ha (compare with 28,629 ha in this study).

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

Class	Area in 1984 (ha)	Area in 1990 (ha)	Area in 1998 (ha)	Area in 2003 (ha)	Area in 2015 (ha)
Sea water	42285.28	42762.7	42872.36	41982.7	42244.6
Lake water	32250.78	28629.6	22996.86	21008.1	17747.1
Floating vegetation	20549.88	22902.4	27663.96	30503.9	33714.2
Sand bar and urban	45744.38	43476.4	40036.56	39515.1	36595.4
Agriculture	23131.08	26190.3	30391.66	30951.6	33660.1
Total area	163961.4	163961.4	163961.4	163961.4	163961.4

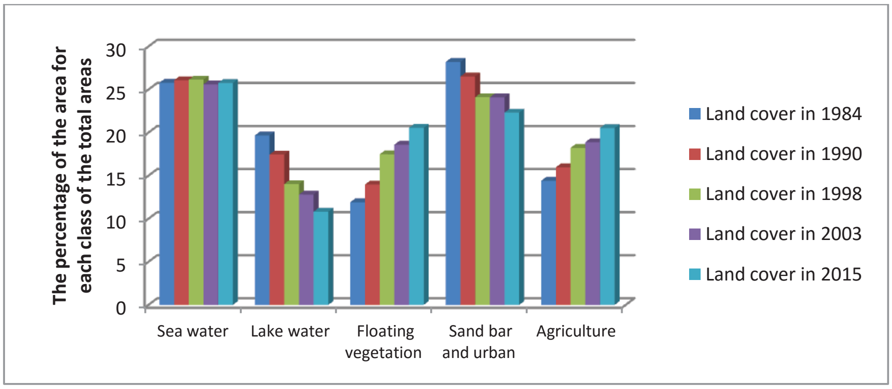

Fig. 4. Land cover for the study area in 1984, 1990, 1998, 2003 and 2015.

In the entire period from 1984 to 2015, Lake water area decreased by 44.97% (14,503.68 ha), while floating vegetation area increased mostly by the same amount (see Table 2). The main reason for overgrowth of floating vegetation in surface water is the discharge of wastewater into the lake without adequate treatment, because the wastewater has plant nutrients e.g., nitrates (NO3) and phosphate (PO4). These nutrients cause overgrowth of aquatic plants in surface waters. The results showed that the urban area decreased by 9148.98 ha (20.00%), while agriculture area increased mostly by the same quantity in the period from 1984 to 2015 (see Table 2). This increase in the agriculture area causes an increase in wastewaters discharge. The sea water has minor changes during the period of study. Statistical models are used to predicting the expected change in the future (see Fig. 5). Forecasting results indicate that the water bodies of the lake will decrease by 19,013.42 ha (58.95%) over the period from 1984 to 2030, (see Table 3), while floating vegetation area will increase mostly by the same quantity. Also, the agriculture area will increase by 16,146.82 ha (69.81%) over the period from 1984 to 2030 (see Table 3), while sand bar and urban area will decrease mostly by the same quantity. The continual increase of floating vegetation results in more darkness of the hidden water body and lack of oxygen under the floating plants which negatively affects the ecosystems of Lake aquatic plant system. Also, this will negatively impact fisheries and navigation on the lakes. Figure (6) shows projected area of each class in the year 2030 compared to the current situation based on the year 2015.

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

Class	Area in 1984 (ha)	Area in 2015 (ha)	Total Change (ha)	% Total Change of the total area	Change/year (ha/year)
Sea water	42285.28	42244.6	-40.68	0.02%	-1.31
Lake water	32250.78	17747.1	-14503.68	8.85%	-467.86
Floating vegetation	20549.88	33714.2	13164.32	8.03%	424.66
Sand bar and urban	45744.38	36595.4	-9148.98	5.58%	-295.13
Agriculture	23131.08	33660.1	10529.02	6.42%	339.65
Total area	163961.4	163961.4	--------	--------	--------

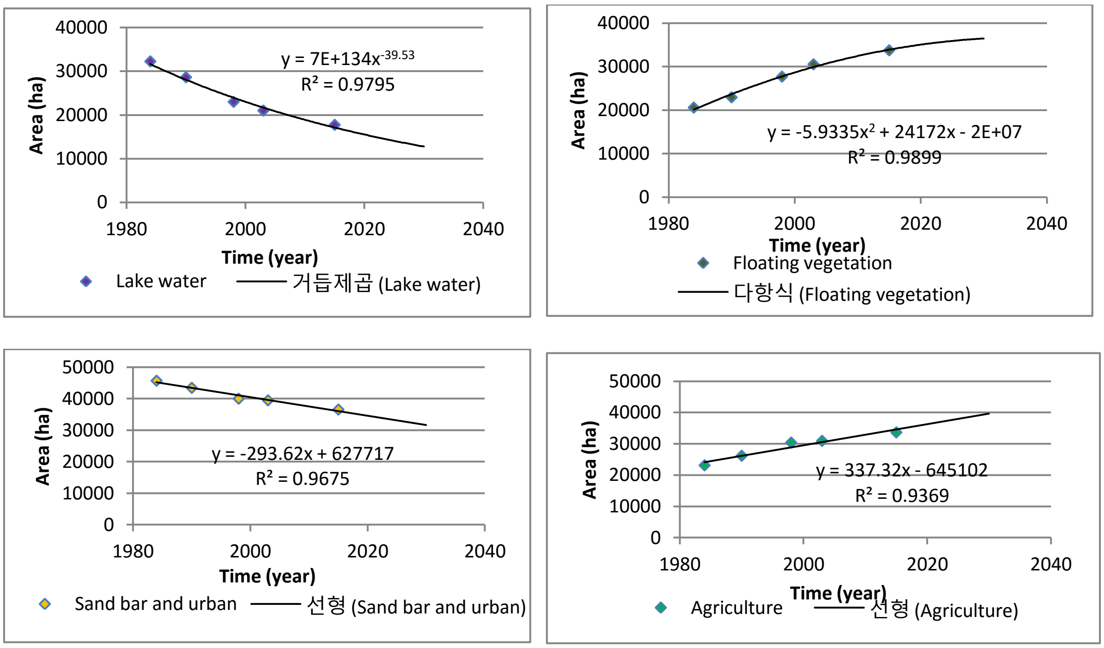

Fig. 5. The statistical model used to predict the change in the future.

Table 3. Statistical models for the five classes and the predicted land cover area in the year 2030.

Class	Area in 2015 (*ha*)	The equation that was used to predict	Area in 2030 (*ha*)
Sea water	42244.6	$Y= -10.494\ x + 63397$	42094.18
Lake water	17747.1	$Y= 7.3641e{+}134\ x^{-39.53}$	13237.36
Floating vegetation	33714.2	$Y= -5.9335x^2 + 24172x - 24581520$	36279.85
Sand bar and urban	36595.4	$Y= -305.81\ x + 652083$	31288.7
Agriculture	33660.1	$Y= 325.13\ x - 620736$	39277.9

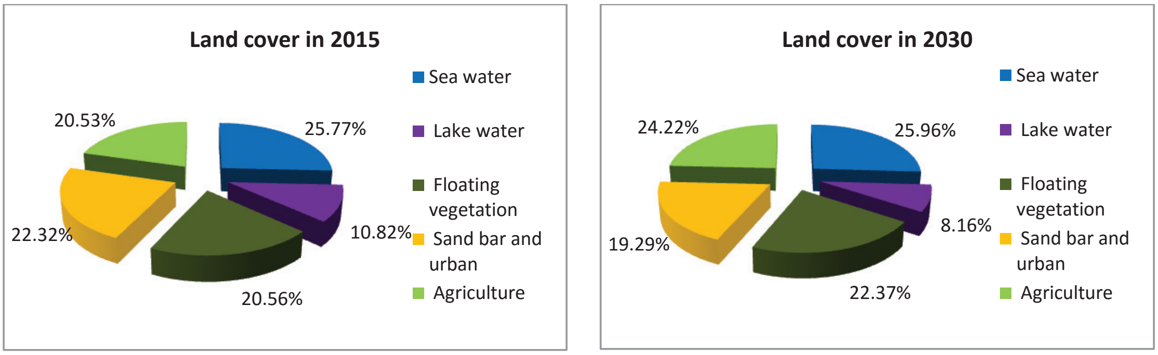

Fig. 6. Land cover for the study area in 2015 and 2030.

5. Conclusions

This paper focused on the temporal change of water bodies for Burullus Lake, Northern Egypt, using remote sensing techniques and geographic information systems. Five techniques are applied to detect the change of the lake water bodies using ERDAS Imagine and ArcGIS software. The Maximum likelihood supervised classification technique has the highest accuracy for the study area and areas with similar conditions as the study area (heterogeneous area). Therefore, the maximum likelihood supervised classification is 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 Burullus Lake. The overall accuracy for the classification of the captured images in 1984, 1990, 1998, 2003 and 2015 are 94.67%, 88.7%, 87.2%, 92.39% and 97.53% respectively. In the entire period from 1984 to 2015, Lake water area decreased by about 44.97% (14,503.68 ha), while floating vegetation area increased mostly by the same amount. The agriculture area increased by 45.52% (10529.02 ha), while sand bar and urban area decreased mostly by the same percent during the period from 1984 to 2015. Future predictions are conducted using the statistical models. The developed model indicated that the water bodies of the lake will be reduced by 58.95% (19013.42 ha) in 2030 if the same trend continues without taking any action from the side of the decision takers and stakeholders. Based on these results, it is recommended that the decision-makers/takers must take appropriate measures to avoid further reduction of the lake water to protect the lake environment. This might be achieved in the short term by cleaning the lake from floating vegetation. The cleaning can take place at a rate of 424.66 ha/year to maintain the current water body area. While the long-term strategy might be achieved by conducting adequate treatment for agriculture and municipal wastes before being discharged into the lake for better sustainability of the water bodies of the lake. It is also recommended to detect the other dimensions of sustainability of the Lake such as, e.g., water quality and biodiversity.

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