Article

Assessing lake shoreline change and prediction for 2030 by physical drivers: A Case Study from Lake Batur, Batur UNESCO Global Geopark, Bali

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Abstract

Over ten years, the water level of Lake Batur has increased. Agriculture area and settlements around Lake Batur are threatened by rising water level. This study aims to analyze the shoreline change of Lake Batur, located in the Batur UNESCO Global Geopark (BUGG), during the period of 2007 – 2018 and design a prediction for 2030. Understanding the shoreline change is very important for lake management and planning. Shoreline changes were analyzed in Geographic Information System (GIS) application. The data were obtained based on Remote Sensing (RS) data, Landsat ETM+ imagery on September 24, 2007, and Landsat OLI imagery on October 24th, 2018. Predictions of lake shoreline in 2030 result from modelling by integrating ASTER-GDEM V2 data, lake water level data for 2007–2018, annual average rainfall data for 2007–2018, and bathymetry data for 2013 and 2015. The results of the satellite imagery analysis show that there has been a change in the length of the shoreline, which has increased from 20.47 km in 2007 to 21.28 km (3.96%) in 2018. The lake surface area changed from 15.34 km2 in 2007 to 16.16 km2 in 2018 (5.35%). The prediction of lake shoreline changes in 2030 showed that Lake Batur will increase to 26.90 km (26.41%), and lake surface area is predicted to increase by 17.67 km2 (9.34%) from 2018. This is because of the morphological change of Lake Bottom.

Keywords: *Shoreline change; Lake Batur; Landsat; GIS; BUGG*

1. Introduction

Lake Batur is the largest lake in Bali and located in the Batur UNESCO Global Geopark region (Sukmawantara et al., 2021). This lake is a volcanic lake trapped in the caldera of an active volcano, Mount Batur (Insani et al., 2022). Lake Batur naturally becomes the foundation of water reserves for Bali and creates a distinct ecosystem around it to maintain the continuity of Bali's hydrological cycle (Macklin et al., 2018). The surrounding community utilizes the lake to support daily activities such as providing water for household needs, fisheries, agriculture, recreation, and transportation (Handayani et al., 2011; Sulawesty & Satya, 2013; Budiasa et al., 2018).

Several research results revealed that Lake Batur experienced low to moderate eutrophication (Radiarta & Sagala, 2012; Sidaningrat et al., 2018). The water quality of Lake Batur tends to decrease based on the index of biological and non-biological contamination (Wijana, 2010). Apart from eutrophication, the primary problem in Lake Batur is sedimentation. Sedimentation in water resources occurred due to soil erosion in their catchment area. Erosion, sedimentation, and siltation in the lake are influenced by the management of agricultural land around the lake; this does not consider the aspects of soil and water conservation (Nada et al., 2019). This sedimentation is potentially increasing water level of the lake and changing the shoreline.

The shoreline is the line between water and land. Surface water and its interaction is one of the strategic resources in the environment for sustainable development (Dereli & Tercan, 2020). To achieve the sixth SDG's goal, a concerted effort is needed to maintain the aquatic environment for sustainable water resources. Shoreline change is very complex, influenced by various parameters such as meteorological factors, geology, hydrology, land use, vegetation, agricultural policies, and human activities (Duru, 2017; Mohsen et al., 2018; Ciritci & Turk, 2019). Research on shoreline changes using multi-spectral satellite imagery data has been carried out in various regions, such as Lake Sapanca Turkey and Lake Burullus Egypt (Duru, 2017; Mohsen et al., 2018).

The shoreline is dynamic and often experiences changes in both spatial and temporal dimensions (Ruiz-Beltran et al., 2019). Knowing shoreline changes is essential for management and planning around the lake. Lake provides various ecosystem benefits and environmental services, as they play role in nutrient, carbon and water cycle. Lake also provides habitat for various freshwater species. Many of the ecosystem services offered by lake also benefited to humans (Carpenter et al., 2011; Moss, 2012; Dornhofer & Oppelt, 2016). The utilization of lake waters for transportation, energy generation, recreation, tourism, and irrigation of agricultural areas can cause several problems. The main concerns for lake waters are anthropogenic exploitation, morphological changes, inorganic and organic pollutants, temperature changes, and eutrophication (Bronmark & Hansson, 2002; Dudgeon, 2006).

Therefore, predicting shoreline changes is very important for future management and planning. Monitoring of shoreline changes can be carried out more quickly, inexpensively, and accurately than conventional field survey methods using RS and GIS data. To understand the potential threat of water level rise in the Lake Batur, an approach is needed to predict the affected areas due to changes in the Lake Batur coastline that will occur in 2030.

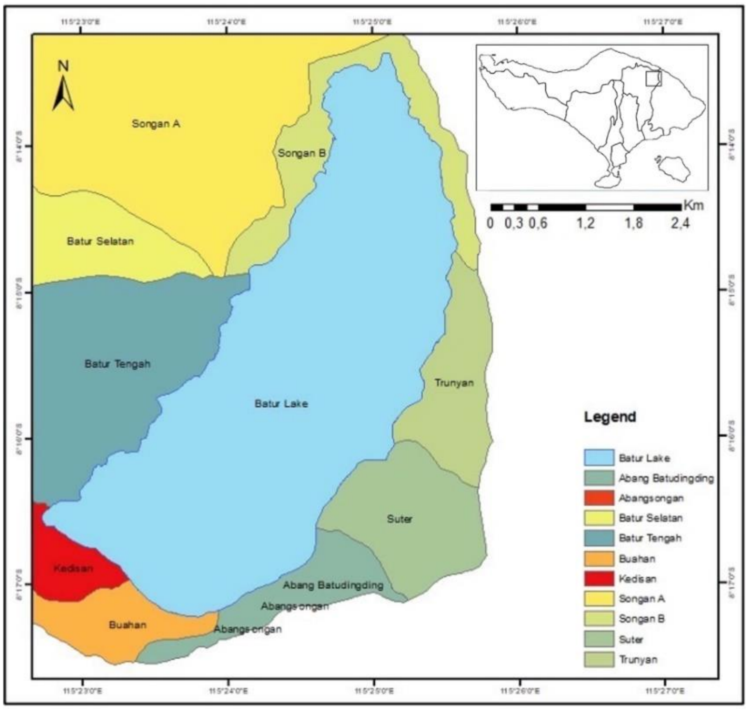

Figure 1. Map of Study Area

2. Materials and methods

2.1 Study area

This study located in the Batur UNESCO Global Geopark area, Kintamani District, Bangli Regency, Bali Province. Geographically, it is located at 8° 13' 19"–8° 17' 14" South Latitude and 115° 22' 42"–115° 25' 33" East Longitude (Figure 1). Lake Batur is surrounded by 7 villages: Abang Batudinding, Abangsongan, Batur Selatan, Batur Tengah, Buahan, Kedisan, Songan A, Songan B, Suter, and Trunyan. These villages are part of 15 villages in the Batur UNESCO Global Geopark area.

2.2 Data collection

This study used multi-temporal satellite imagery from Landsat 7 ETM+ and Landsat 8 OLI, as well as ASTER GDEM V2. It was supported by field data on bathymetry measurements from 2013 and 2015, lake water level data from 2007–2018, and average annual rainfall data (Table 1).

Table 1. Data, date of acquisition, and source

Num.	Data	Date of data	Source	Description
1	Landsat 7 ETM+	24/09/2007	www.earthexplorer.usgs.gov.	30m spatial resolution,
2	Landsat 8 OLI	24/10/2018	www.earthexplorer.usgs.gov.	30m spatial resolution
3	ASTER GDEM V2	16/03/2011	www.earthexplorer.usgs.gov.	30 m spatial resolution
4	Bathymetry	2013	BRIN	Survey method using echo sounders
5	Bathymetry	2015	BWS Bali-Penida	Survey method using echo sounders
6	Lake Water Level	1/01/2007 - 31/12/2018	BWS Bali-Penida	Daily Survey on site
7	Average Annual Rainfall	1/01/2007 - 31/12/2018	BMKG	Daily Survey on site

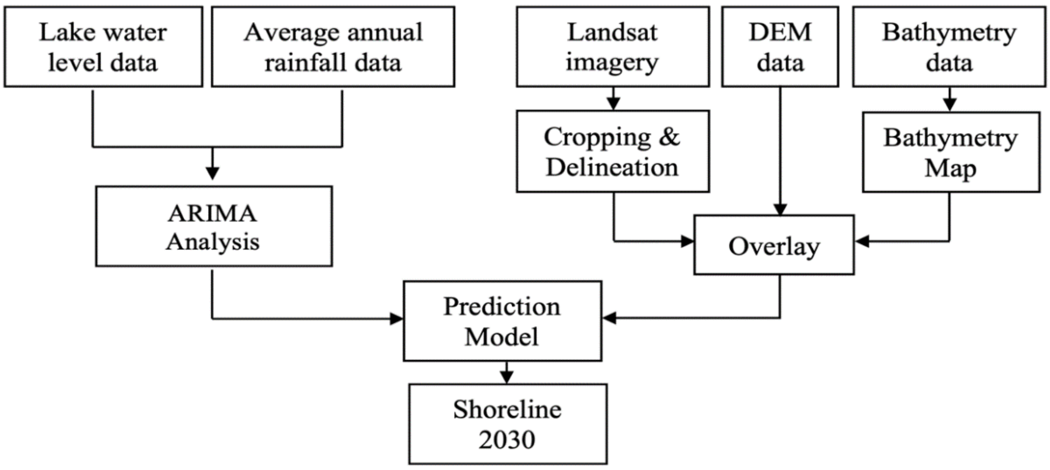

Figure 2. Data Analysis

2.3 Method

Landsat satellite imagery data have been extensively used to detect shoreline changes (Cham et al., 2020). The integrated use of multi-temporal satellite imagery and statistical parameters is very effective and beneficial for the analysis of lake shoreline variations (Dereli & Tercan, 2020). The combination color of red, green, and blue (RGB) colors in Landsat satellite imagery can display images according to the purpose of the analysis. In this study, for shoreline identification purposes, a combination of RGB bands 4-5-3 on Landsat 7 ETM+ and a combination of 5-6-4 on Landsat 8 OLI is used. The combination results were then cropped based on the study area and continued with visual delineation to determine the lake shoreline. Bathymetry data from 2013 to 2015 and DEM data were used to determine the morphological changes of Lake Batur and the surface topography of the study area.

Data on changes in water level during the period 2007–2018 are time series data as input for forecasting the Autoregressive Integrated Moving Average (ARIMA) method. The ARIMA method is a statistical method for analyzing historical data to obtain a model equation that describes the relationship between the time series data (Ghashghaie & Nozari, 2018). ARIMA model as a function of p, d, q, where p is the order of the operator from AR, d as differencing order, and q as order operator from MA. The general form of the ARIMA model equation can be written as follows.

$$(B)(1 - B)\ dZt = \mu' + \theta(B)at \quad (1)$$

where (B) is a p order AR component and $\theta(B)$ is a q order component. Furthermore, the results of ARIMA are used as input in GIS modeling to further develop the spatial prediction model. A data analysis chart is shown in Figure 2.

3. Results

3.1 Lake area estimations by remote sensing

The shoreline changes experienced at Lake Batur were analyzed by visual interpretation using a combination of RGB bands 4-5-3 on Landsat 7 ETM+ and combination of 5-6-4 on Landsat 8 OLI. Using GIS software, the result of deleniation is shown in Figures 3a and 3b. The analysis of shoreline length in 2007 were 20.47 km and increased to 21.28 km in 2018. During the 2007–2018 period, it was known that the increase in shoreline was 0.81 km (3.96%). While the lake shoreline showed that the area of Lake Batur in 2007 was 15.34 km2 in 2018, it increased to 16.16 km2. During the 2007–2018 period, there was a change in the surface area of the lake, which was 0.82 km2 (5.35%).

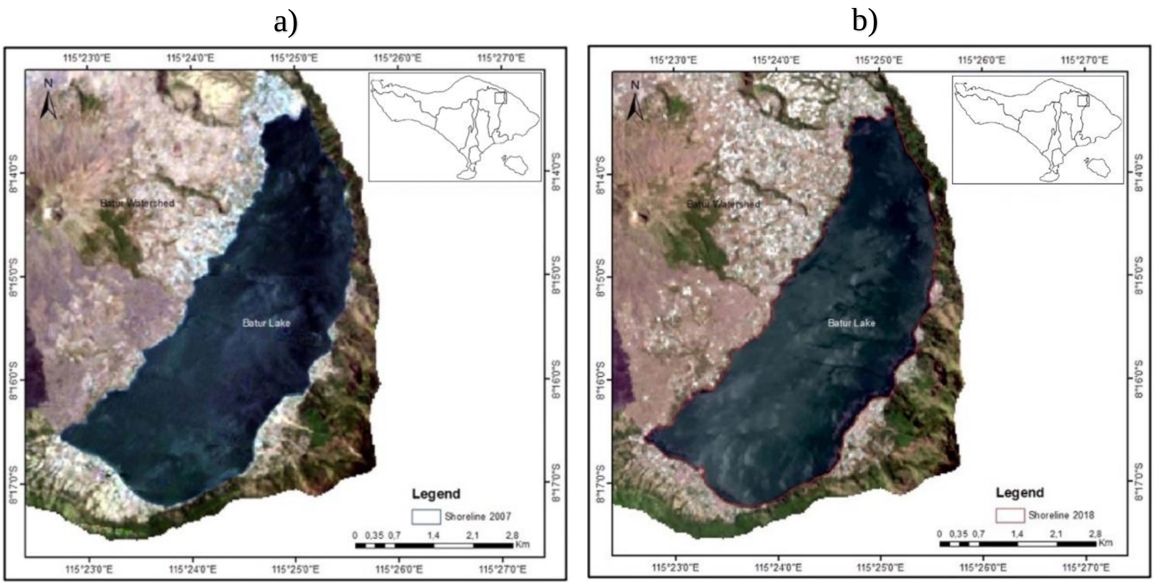

Figure 3. shoreline interpretation. *(a)* Landsat 7 ETM+ 2007, *(b)* Landsat 8 OLI 2018.

3.2 Digital elevation and bathymetry models

Bathymetry data and RS imagery are spatially complementary in conducting modeling for predictions of lake shoreline changes. Digital elevation data combined with bathymetry data was used to describe the morphometry of the lake. Using GIS analysis, the potential areas that increase in water level can be predicted. In three dimensions, it will be shown in Figure 4.

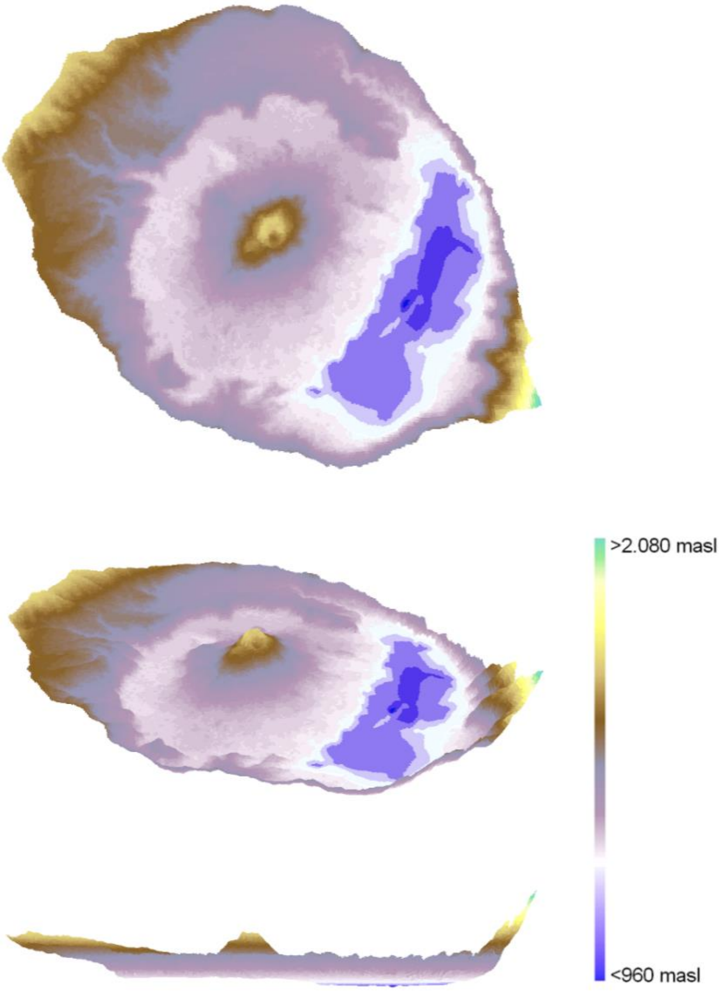

Figure 4. Digital 3D model of Batur lake basins derived from combining DEM and bathymetry data

3.3 Lake water level change and precipitation

Based on field data released by Balai Wilayah Sungai (BWS) Bali-Penida and Badan Meteorologi, Klimatologi dan Geofisika (BMKG) agencies, changes in the Lake Batur water level between 2007-2018 can be identified. The highest lake water level occurred in early April 2018, while the lowest occurred in November 2008. The average water level of Lake Batur is increasing by 0.35 m/year (Figure 5a).

Meanwhile, the average rainfall data obtained from the Kedisan monitoring post between 2007 and 2018, it was found that the average rainfall decreased by 1.79 mm/year (-9.37%) (Figure 5b). The peak of the rainy season in this area generally occurs from January to February, and the lowest occurs in August. Rainfall levels fluctuate greatly every year, with the highest average of 134.24 mm/year in 2015 and the lowest average of 48.34 mm/year in 2016.

3.4 Lake shoreline prediction for 2030

Predictions of the lake shoreline in 2030 are analyzed using GIS based on ARIMA results of lake water level, changes in lake morphology in 2013–2015, and DEM data. Based on the data analysis for the period of 2007 to 2018, the average water level increased by 0.35 m/year. The results of forecasting ARIMA (0,1,1) model in Figure 6 show that the model is relatively capable of forecasting the series. The values of R2; MSE; and RMSE are 0,94; 0,008; and 0,092.

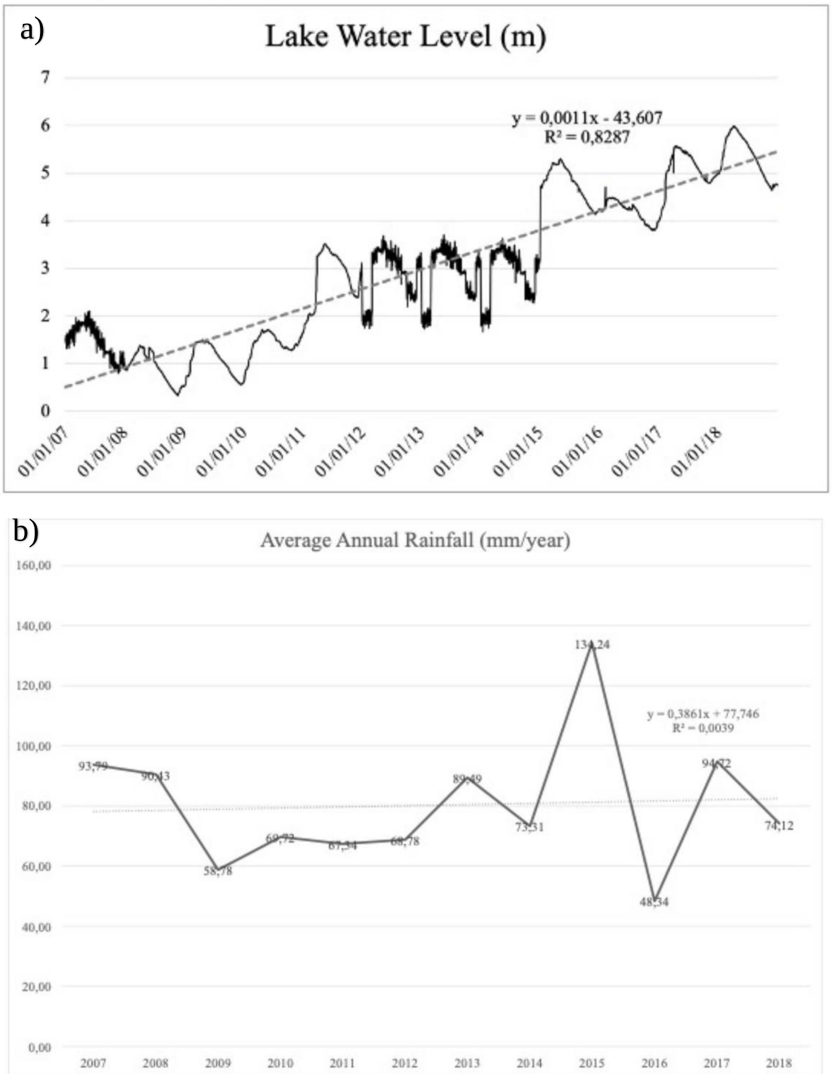

Figure 5. *(a)* Lake Water Level Period 2007-2018, *(b)* Average Annual Rainfall Period 2007-2018.

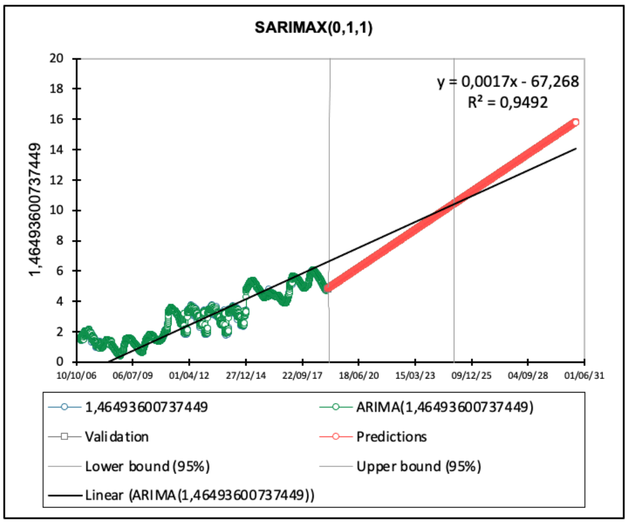

Figure 6. The Result of ARIMA (0,1,1) Model

With GIS modeling based on bathymetry data and ARIMA forecasting, the length of shoreline was calculated, and in 2030 the length of shoreline had significantly increased to

26.90 km, from 26.41% in 2018. The shoreline change prediction for Lake Batur in 2030 is shown in Figure 7a, and comparison changes in the shoreline period 2007–2018 and prediction changes for 2030 are shown in Figure 7b. Furthermore, an analysis of the predicted lake surface area has increased to 17.67 km2 of the lake surface area in 2018.

a)

b)

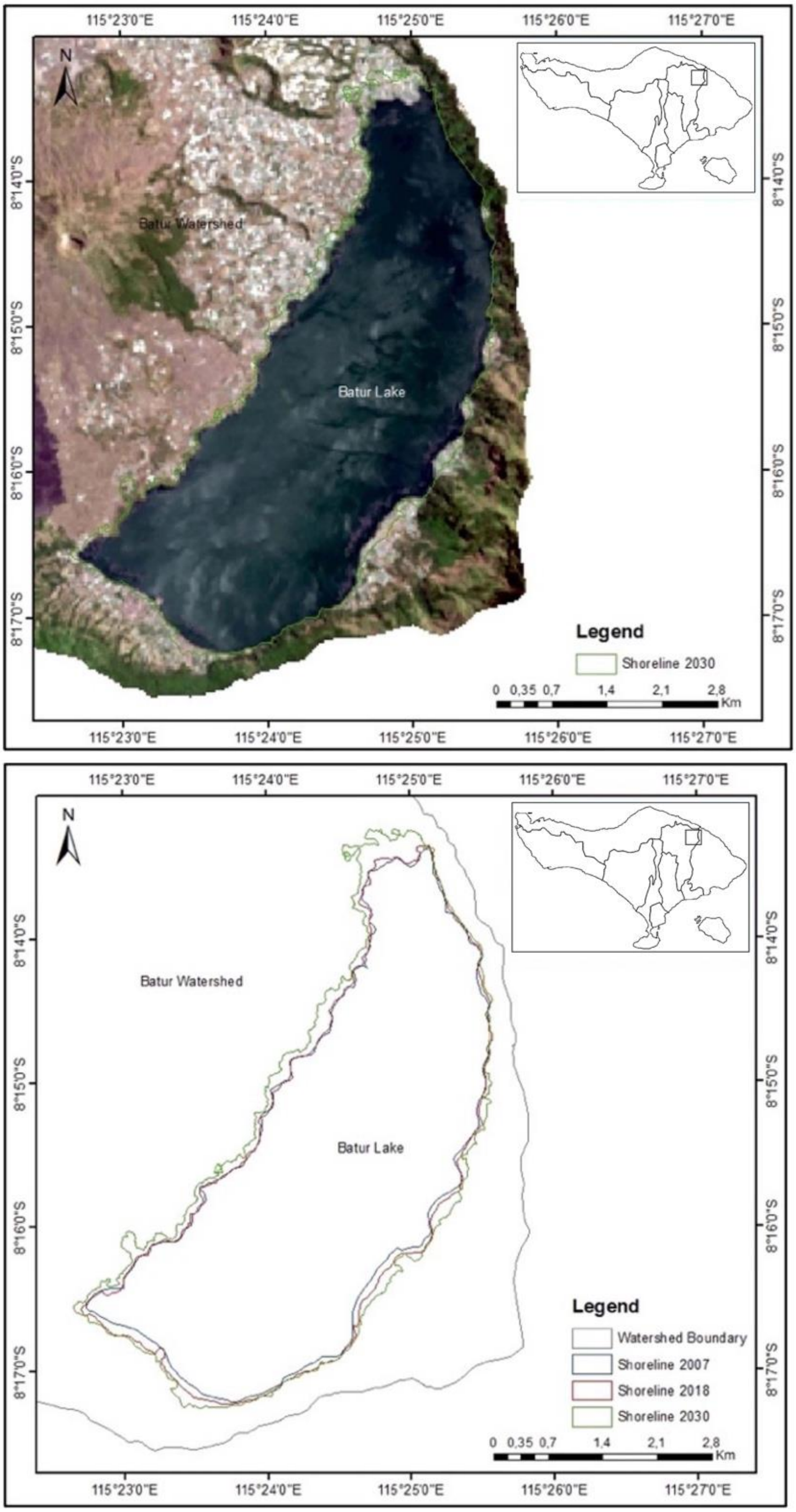

Figure 7. *(a)* Shoreline change prediction for Lake Batur in 2030, *(b)* Comparison changes in the shoreline period 2007, 2018, and prediction 2030

4. Discussion

This study presents predictions of changes in the shoreline of Lake Batur in 2030 based on data for the 2007–2018 period. Based on the analysis of Landsat 7 ETM+ 2007 (Figure 3a) and Landsat 8 OLI 2018 (Figure 3b) satellite imagery, it can be seen that there has been a change in the area of Lake Batur in 2018, an increase of 0.82 km^2 or an increase of 5.35% from the area of Lake Batur in 2007. Meanwhile, the length of the shoreline in 2018 has increased by 0.81 km (3.96%) from 2007.

Lake Batur is a closed lake where the source of its water comes from rain and underground water (Batur Springs) (Polkowska et al., 2014). Based on field data released by BWS Bali-Penida, the water level of Lake Batur fluctuates throughout the year. The water level of Lake Batur during the 2007–2018 period experienced its lowest point on November 22-23th, 2008, by 0.33 m from the estimator board, which was built in 1967 at an elevation of 1192 masl, and the highest point was 5.99 m on April 6-7th, 2018. Based on these data, the lake's water level has fluctuated, increasing up to 5.66 m between 2008 and 2018.

From the average rainfall data released by the BMKG for the 2007–2018 period (Figure 5b), rainfall in the Lake Batur area over the past 11 years has tended to decrease by 1.79 mm/year (-9.37%). If these two data are juxtaposed, the average lake water level rise of 0.52 m/year is not directly proportional to the rainfall data; even rainfall in the Lake Batur area has decreased by 1.79 mm/year (-9.37%) during the period 2007–2018. This indicates that sedimentation in Lake Batur has gotten worse in the last 15 years. This also correlates positively with the results of the research by Nada et al., 2019, which found that Lake Batur sedimentation reached 1,993.49 m^3/year in 2018.

Due to the significant changes in the area of the lake during the 2007–2018 period, using GIS, a prediction analysis was carried out on changes in 2030. From the results obtained, the surface area of Lake Batur in 2030 will have increased by 1.51 km^2 (9.34%) from 2018, and the shoreline length will have increased by 5.62 km (26.41%). Detailed calculations of variations in the shoreline and surface area of Lake Batur are shown in Table 2.

Table 2. Shoreline and surface area of Batur Lake

Year	Shoreline (km)	%	Area (km^2)	%
2007	20.47	-	15.34	-
2018	21.28	3.96	16.16	5.35
2030	26.90	26.41	17.67	9.34

This research is helpful for planning and mitigating the impact on the affected communities of increased lake water levels. The community and local government can think about development near the present lake boundary based on the findings of this study. It is also intended that the results of this study will help the local administration choose the best course of action for dealing with Lake Batur's increasing water level. So that the estimate of the damaged region may be established better, this study still has to be followed up using satellite images with higher resolution and combined with more reliable field data.

5. Conclusions

Changes in the shoreline of Lake Batur from 2007 to 2018 were analyzed using GIS and remote sensing imagery. During this period, the shoreline of the lake increased by 0.81 km (3.96%), and the surface area increased by 0.82 km^2 (5.35%). Based on linear regression analysis, the water level of Lake Batur shows an annual average increase of 0.35 m/year, but this data is not directly proportional to the annual average rainfall. This indicates the presence of sedimentation in Lake Batur. The results of modeling carried out on the shoreline of Lake Batur in 2030 show that it predicted an increase of 26.90 km (26.41%) from the shoreline in 2018. The surface area of the lake is predicted to increase from 16.16 km^2 in 2018 to 17.67 km^2 (9.34%) in 2030.

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Statement of data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflict of interest

The author declares that publication of this manuscript presents no conflicts of interest. In addition, the authors have observed all ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy.

Declarations

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors.

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