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Determination of long-term water surface level change in lakes by integration of UAV and satellite data and future estimation with ARIMA

Yunus Kaya*[1], Fusun Balik Sanli [2], Saygin Abdikan [3]

[1]Harran University, Department of Geomatics Engineering, Türkiye, yunuskaya@harran.edu.tr
[2]Yildiz Technical University, Department of Geomatics Engineering, Türkiye, fbalik@yildiz.edu.tr
[3]Hacettepe University, Department of Geomatics Engineering, Türkiye, sayginabdikan@hacettepe.edu.tr

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Abstract

Lakes are the largest element of freshwater bodies on the Earth's surface and play an important role in the Earth's water cycle. Inland water bodies, such as natural lakes and human-made reservoirs, are vital for supplying drinking water. Some saltwater lakes, such as Lake Burdur, are not used for drinking water but are home to endangered animal and plant species. Accurate and regular monitoring of inland water bodies and estimation of future water levels are crucial for ecological conservation and management of water resources. In this study, the water surface level (WSL) changes in Lake Burdur, a Ramsar site, between 1984 and 2022 were investigated by integrating the Digital Elevation Model (DEM) obtained by Unmanned Aerial Vehicle (UAV) and shoreline information obtained from Landsat mission. In addition, annual water level elevation changes between 2022 and 2040 were estimated with the AutoRegressive Integrated Moving Average (ARIMA) time series analysis model. As a result of the study, correlation between water level and reference data was determined with r= 0.999 and an average error margin of 31 cm. In the future forecast obtained with the ARIMA model, it is seen that the water level height decreases to 830,61 m.

Introduction

Water bodies play a critical role in socio-economic development, the establishment of healthy ecosystems, energy, and food production [1]. Inland water resources such as lakes and dams are vital for people, animals, and plants that depend on wetlands. Lakes are important components of water ecosystems in regulating regional climates, providing water resources, and maintaining ecological balance [2]. Lakes such as Lake Burdur, which are home to some plants and animals despite being salty water, also play an important role in the protection and maintenance of living ecosystems. However, lakes are among the most sensitive and fragile aquatic ecosystems. Natural factors and anthropogenic activities can cause rapid short-term changes in lakes [3].

Remote sensing data has become important for earth observation since the launch of the first satellite. Landsat satellite data have been among the most widely used, especially since the United States Geological Survey (USGS) announced in 2008 that the images would be freely available [4]. Although optical images can successfully identify spatial changes in lakes, they do not provide information about water surface level (WSL). Unmanned Aerial Vehicles (UAVs), which have been used in many areas in the last decade, allow the collection of earth information more precisely than most satellite remote sensing data due to their high resolution. However, since UAVs do not have a predetermined flight plan like satellite systems, these studies focus only on current WSLs, making it difficult to assess long-term changes in WSL. In the literature review, no study was found to determine the changes in WSLs from past to present using DEMs on the lakeshore.

It is important to make estimates for the future as well as precise determinations of WSLs in terms of water resources management and action planning. The AutoRegressive Integrated Moving Average (ARIMA) model is used to estimate future WSL [5]. In this study, the WSL of Lake Burdur, a Ramsar site, was determined by UAV and Landsat integration. The obtained water level heights were then used to predict future WSLs.

Material and Method

UAV Based DEM

UAV flights were performed from 6 different locations homogeneously distributed around Burdur Lake, which was selected as the study area and is the largest Ramsar site in Turkey. Ground control points (GCPs) were used for each UAV flight to increase horizontal and vertical accuracy. Orthophotos and Digital Elevation Models (DEMs) were produced by evaluating the photographs obtained from UAV flights with the Structure from Motion (SfM) algorithm together with GCPs.

Determination of Shoreline with Landsat Data

In order to determine the shoreline of the lake, Landsat images from June of each year were used. Suitable (cloud-free) images covering the study area were processed by Google Earth Engine (GEE), a cloud-based geographic analysis platform, to determine the shoreline. Water and non-water areas were determined using the Modified Normalized Difference Water Index (MNDWI), Automatic Water Extraction Index (AWEI) and Normalized Difference Vegetation Index (NDVI) (Table 1). After the indices were calculated, the pixels were filtered using Eq. (4) to obtain the lake area.

Table 1. Water and vegetation indices used in the study.

$MNDWI = \frac{(Green - SWIR)}{(Green + SWIR)}$	(1)
$AWEI = 4 * (Green - SWIR2) - (0.25 * NIR + 2.75 * SWIR1)$	(2)
$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$	(3)

$$\text{Lake} = \text{NDVI} < 0 \text{ and MNDWI} > 0 \text{ and AWEI} > 0 \quad (4)$$

Points were generated at 2 meters intervals on the shorelines. Then, UAV based DEMs were integrated with the points. The heights of the point were determined from the DEM data closest to the point. Outliers in the generated points were eliminated with the Interquartile range (IQR) method [6]. Since the ellipsoidal height obtained from UAV data does not represent the water level height, the ellipsoidal heights were converted to orthometric heights using Eq. (5).

$$H = h - N \quad (5)$$

Where;
H represents the orthometric height,
h represents the ellipsoidal height,
N represents the geoid height.

Average WSLs were obtained by averaging all points converted to orthometric heights.

Future WSL Estimation with ARIMA Model

ARIMA is a data analysis model used to determine the dynamics of time series and includes AutoRegressive (AR), Integrated (I), and Moving Average (MA) components [7]. AR behaves like a multiple regression model. However, it uses past values of the same series instead of external factors. The AR process is commonly used in time series where the current value is directly influenced by previous values. The MA model is a time series analysis that investigates the link between the current value of a time series and previous error components or residual values. It is a statistical model that recognizes that the current value of a series is driven by a linear combination of error terms at past time points. 'I' eliminates any trends or seasonality in the data by measuring the difference between consecutive data.

Results

Water surface level and accuracy analysis

The shorelines of the lake were determined from cloud-free Landsat data in June from 1984 to 2022. Points were created at 2-meter intervals along the shorelines, to which elevation information was added from a high-resolution UAV-based DEM. Outliers between points were removed using the IQR method. Orthometric heights were then obtained by subtracting the geoid height in the flight area from the ellipsoidal heights. After removing the outliers, the measurement accuracy was significantly improved in some years. The difference between the non-filtered and filtered dataset and the reference value was 30 cm and 21 cm, respectively (Figure 2). This indicates that removing outliers improved the overall accuracy by 9 cm. Across all 39 years of dates, the maximum WSL was 854,466 m in 1984 and the minimum WSL was 838,226 m in 2022. Over 38 years, the WSL increased only between 2002 and 2004, with a downward trend in all other years (Figure 1). There is a 99.9% correlation between the calculated WSL and the reference data.

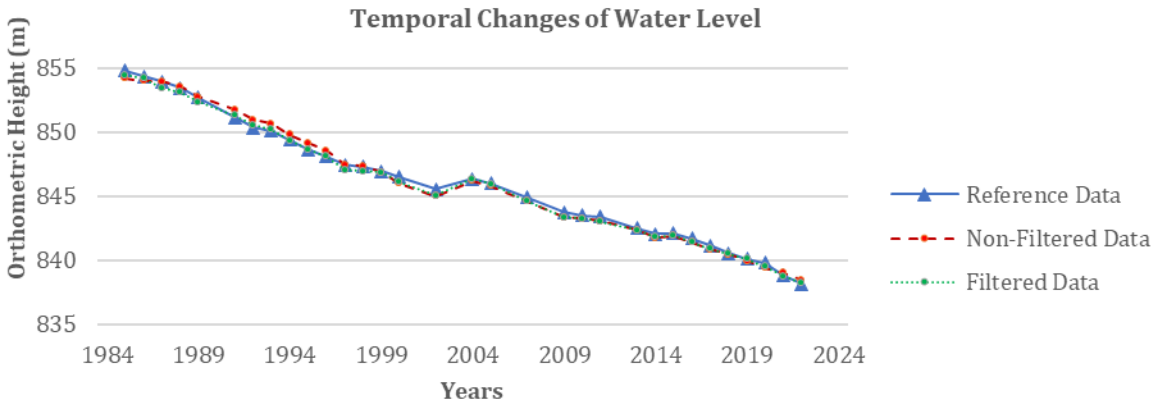

Figure 1. Temporal changes of water level with filtered, non-filtered and reference data [Adopted from [8]]

Future Estimation with ARIMA Model

In order to determine future WSLs with the ARIMA model, 70% of the 39 years of elevation data produced between 1984 and 2022, i.e. 27 of them (1984-2010) were used as the train set and 30% (2011-2022) was used as the validation set. In the study, the p parameter of the AR model and the d parameter of the I model are taken as 1 [7]. For the q parameter, a combination between 0-3 values was made. The accuracy of the validation set was investigated using different parameters (Table 2).

Table 2. Different ARIMA parameters and accuracy.

Parameters	RMSE (m)	Correlation
1, 1, 0	0.45	0.99
1, 1, 1	0.46	0.99
1, 1, 2	0.45	0.99
1, 1, 3	**0.43**	**0.99**

The most appropriate parameter was ARIMA (1, 1, 3), which has the least Root Mean Square Error (RMSE). Then, future estimation was performed with ARIMA (1, 1, 3) parameters for the years 2023-2040 (Figure 2).

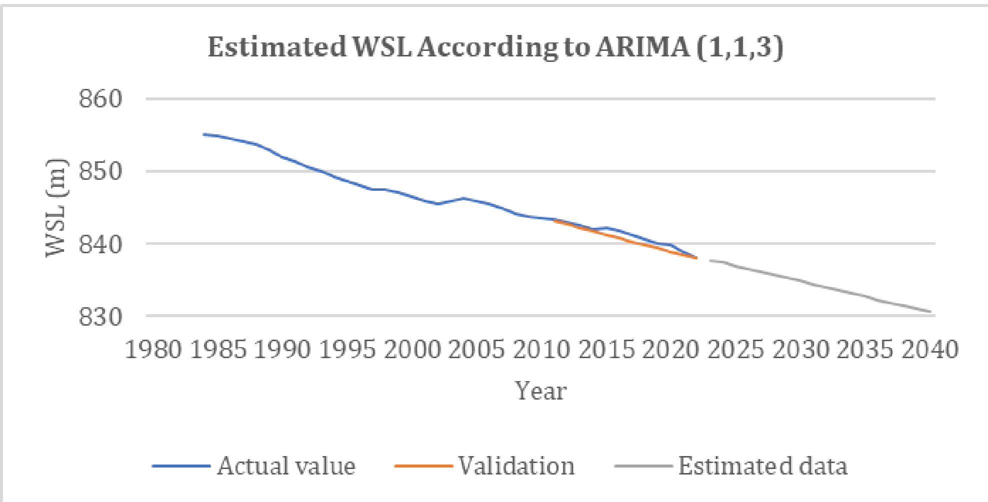

Figure 2. Estimation of WSLs between 2023 and 2040 with ARIMA model.

Conclusion

It is important to determine lake WSL changes and to plan water management using future WSL estimation. In this study, we investigated the long-term changes of WSLs using UAV-Landsat integration. We found a high correlation of r=0.999 between the calculated WSL and reference elevations, and the average ΔH elevation error was 21 cm. The ARIMA model was also used to estimate the WSL for the next 18 years.

Our proposed method for WSL determination in inland waters has the advantage of long-term change detection and high accuracy and correlation compared to other methods. In addition, future WSL estimation can be used as data for environmental planning on the lake.

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