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Evaluating Shoreline Changes at Ayvacık Reservoir (Çanakkale, Türkiye) Through Remote Sensing and Geographic Information System Techniques: A Twelve-Year Assessment

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ABSTRACT

This study aims to determine the spatial and temporal changes occurring along the shoreline of the Ayvacık Reservoir in Çanakkale, Türkiye. Landsat 8 OLI/TIRS and Landsat 7 ETM+ satellite images were analyzed using remote sensing and geographic information system techniques. The dataset used in the study covers the period between the completion of the dam construction in 2008 and 2019. Preprocessing of the remote sensing satellite images and digital image processing analyses were carried out using ENVI and ArcGIS software. The shoreline was determined through manual digitization. Consequently, it was found that the shoreline length was 14.994 km in 2008 and increased to 22.293 km in 2019. These values represent the observed minimum and maximum shoreline lengths, respectively. The study period revealed an increase in shoreline length. Given that this study is the first to elucidate shoreline changes occurring at the Ayvacık Reservoir, it is anticipated to provide essential insights for water resource managers by contributing significantly to the literature.

KEYWORDS: Hydrological Changes; Satellite Imagery Evaluation; Shoreline Dynamics; Temporal Analysis.

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1. Introduction

The shoreline represents one of the most dynamic processes in coastal areas. Spatial and temporal alterations encompass geomorphological, tectonic, hydrodynamic, climatic, seismic, and sedimentation/erosion events along the shorelines, which can manifest gradually (Thom and Cowell, 2005) or rapidly (Scott, 2005). Changes occurring in the shoreline due to human-induced and/or natural processes hold significant environmental implications. Monitoring shoreline changes is crucial for water resource management, urban and coastal planning, as well as the determination of sediment accumulation and erosion.

Determining the shoreline using traditional ground survey techniques is challenging and time-consuming (Aedla et al., 2015). Previous assessments of shoreline changes have been conducted using aerial photographs and satellite images. Remote sensing plays a pivotal role in acquiring spatial data. Satellite imagery can be easily obtained and interpreted through remote sensing techniques. Recent advancements in Geographic Information Systems (GIS) and remote sensing have significantly overcome the challenges in shoreline delineation, providing more successful results in a shorter time compared to conventional methods (Kale and Acarlı, 2019a). Remote-sensed images are widely used for long-term shoreline change assessments due to their advantages over traditional methods, including cost-effectiveness, higher resolution, and extensive imaging capabilities (Mahapatra et al., 2013). Additionally, as water absorbs near-infrared wavelengths, vegetation and soil exhibit strong reflection (Alesheikh et al., 2007). Hence, remote-sensed satellite images are extensively utilized in shoreline mapping.

Frequent updating of coastal information related to water resources and continuous monitoring of morphological changes resulting from natural or artificial factors are essential. There is currently no study available regarding the monitoring of the Ayvacık Reservoir’s shoreline. Therefore, the aim of this study is to identify temporal changes occurring in the Ayvacık Reservoir’s shoreline.

2. Material and Methods

2.1. Study Area

The Ayvacık Reservoir (Figure 1) is situated on the Tuzla River. It is a soil-filled dam constructed for irrigation and drinking water purposes, characterized by a clay-cored sand-gravel fill. The dam has a body volume of 1,200,000 m³, a height of 53 m from the riverbed, and a normal water level capacity of 39 hm³, providing a lake area of 3.42 km² at the normal water level (DSI, 2020). The dam serves an irrigation area of 3,419 hectares.

2.2. Data

This study utilized satellite images obtained from the Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) sensors to monitor changes in the Ayvacık Reservoir’s shoreline. Both the ETM+ and OLI/TIRS sensors have a spatial resolution of 30 m. Additionally, the panchromatic band (band 8) in both sensors possesses a 15 m spatial resolution.

The satellite images used in this study cover the period between 2008 and 2019. To mitigate potential variations in shoreline changes within the year, the dataset used in this study was selected from available satellite images taken annually in May over the specified 1-year intervals. Landsat satellite images covering the study area were obtained from the United States Geological Survey (USGS) website (https://earthexplorer.usgs.gov).

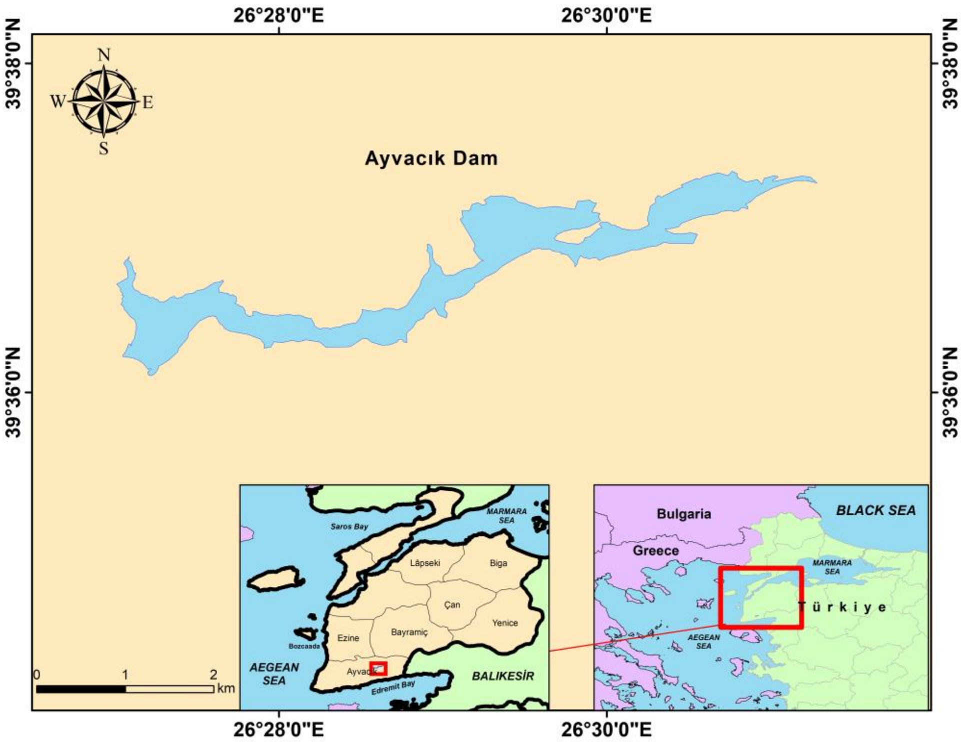

Figure 1. Map of the study area

2.3. Method

The processing and analysis of remote-sensed satellite images in this study were conducted using ENVI and ArcGIS software. Furthermore, auxiliary toolboxes and extensions within these software packages were employed as per the requirements of the processing and analysis.

Multiple methods exist for detecting and extracting the shoreline from satellite images (Dolan et al., 1991; Gao, 1996; McFeeters, 1996; Braud and Feng, 1998; Frazier and Page, 2000; Xu, 2006; Shen and Li, 2010; Feyisa et al., 2014). Some researchers have developed and recommended the use of indices and auxiliary systems such as the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), Normalized Difference Moisture Index (NDMI), Automated Water Extraction Index (AWEI), Water Ratio Index (WRI), Land Surface Water Index (LSWI), Tasselled Cap Wetness Index (TCWI), and Digital Shoreline Analysis System (DSAS) for the purpose of determining and automatically extracting the shoreline. Through remote sensing and GIS analyses applied to satellite images, these techniques are capable of semi-automatic or automatic extraction of shorelines. These recommended automatic extraction methods are frequently employed in the literature and have shown successful outcomes.

3. Results

The changes occurring in the shoreline of the Ayvacık Reservoir are presented in Table 1 and Figure 2. The total shoreline length was calculated to be 14.994 km in May 2008, the initial period when water retention began at the dam, and 22.293 km in 2019. Furthermore, the changes in the shoreline for each year are individually displayed in Figure 3.

Table 1. Changes in the shoreline of the Ayvacık Reservoir

Satellite	Image Date (YYYYMMDD)	Path/Row	Shoreline (km)	Change in Shoreline Since Establishment (km)	Shoreline Change Rate (%)	Shoreline Change Compared to the Previous Year (%)
Landsat 7 ETM+	20080528	181/033	14.994	0.00	0.00	
Landsat 7 ETM+	20090531	181/033	18.799	3.80	25.38	3.805
Landsat 7 ETM+	20100502	181/033	16.903	1.91	12.74	-1.895
Landsat 7 ETM+	20110630	181/033	19.444	4.45	29.68	2.541
Landsat 7 ETM+	20120507	181/033	20.276	5.28	35.23	0.832
Landsat 8 OLI/TIRS	20130518	181/033	20.682	5.69	37.94	0.406
Landsat 8 OLI/TIRS	20140521	181/033	21.135	6.14	40.96	0.453
Landsat 8 OLI/TIRS	20150524	181/033	20.861	5.87	39.13	-0.275
Landsat 8 OLI/TIRS	20160510	181/033	21.570	6.58	43.86	0.710
Landsat 8 OLI/TIRS	20170427	181/033	21.467	6.47	43.18	-0.103
Landsat 8 OLI/TIRS	20180430	181/032	21.721	6.73	44.87	0.253
Landsat 8 OLI/TIRS	20190519	181/032	22.293	7.30	48.68	0.572

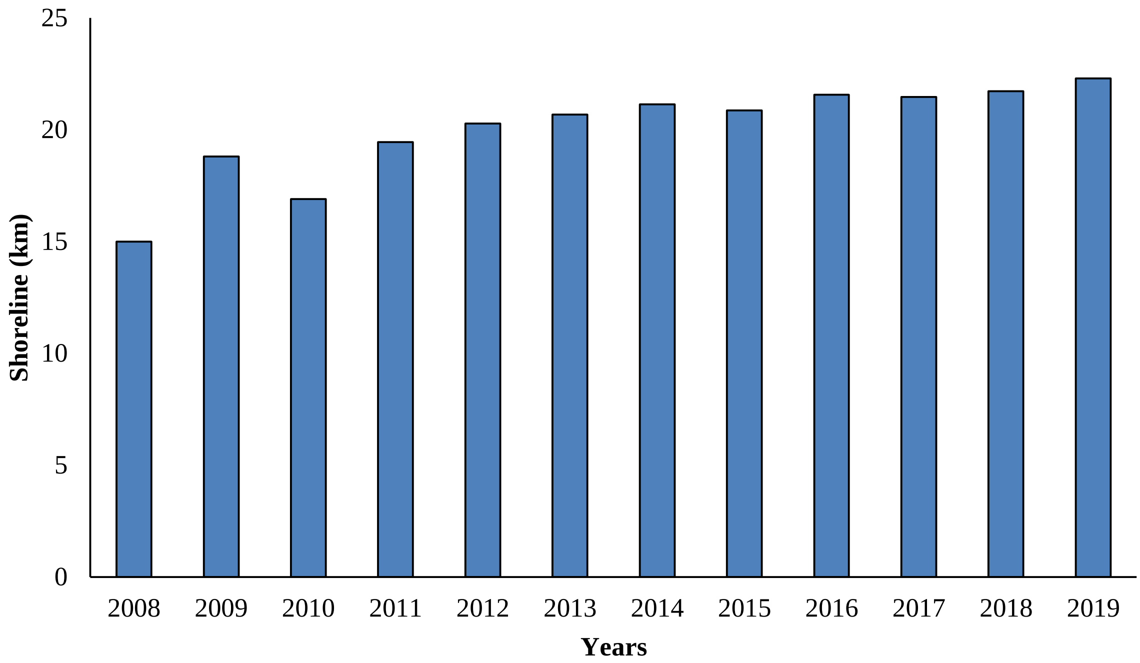

Figure 2. Changes occurring in the shoreline of the Ayvacık Reservoir

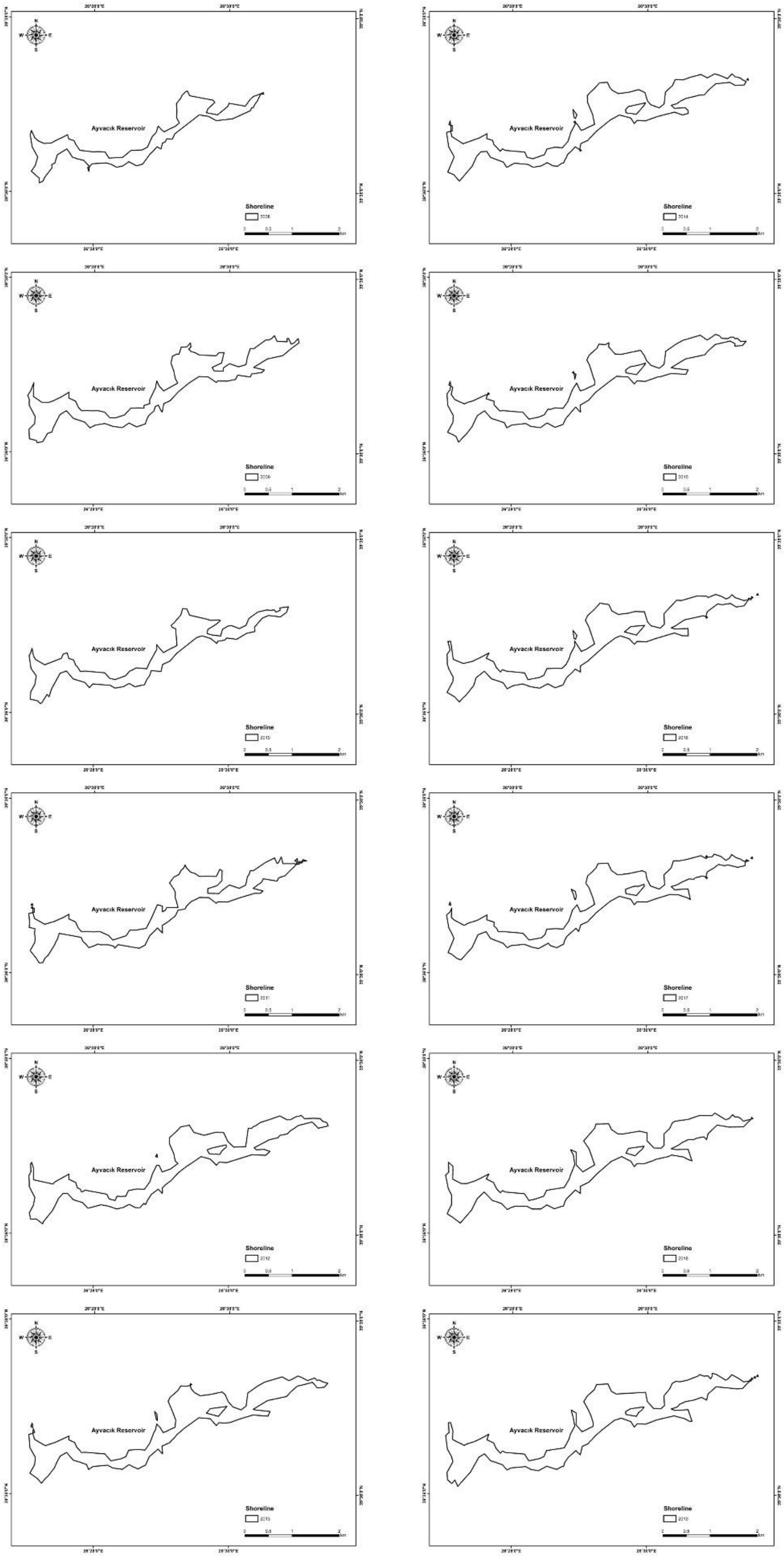

Figure 3. Shoreline changes identified in the Ayvacık Reservoir between 2008 and 2019

4. Discussion

Many researchers worldwide have engaged in studies aiming to identify and track alterations in shoreline. Alesheikh et al. (2007) investigated changes occurring in the shoreline of Lake Urmia between 1989 and 2001, reporting a 3-meter reduction in the shoreline. This change was noted to have led to a decrease in the lake's surface area by approximately 1000 km². Aedla et al. (2015) reported the highest shoreline advancement of 8.69 meters per year for the Netravati and Gurpur river mouths in India, along with the highest erosion rate of 4.31 meters annually. Erener and Shirzad (2016) applied remote sensing and GIS techniques to identify coastal changes in the part of the Amu Darya River within the boundaries of Kunduz city in northern Afghanistan, reporting that the banks along the river eroded due to continuous erosion, primarily caused by high river flow rates, wind, and waves. The changes along the river's shoreline not only presented environmental problems in the study area but also raised new potential political issues between Afghanistan's northern region and Tajikistan, as it forms the border between these regions.

Shoreline changes in various coastal areas of Türkiye have been extensively studied by many researchers. However, while coastal changes in marine coastal areas have been widely investigated, changes occurring in reservoirs and lakes have not been studied with the same intensity. Few studies focusing on monitoring shoreline changes in Turkish lakes have yet to reach a sufficient level. Temiz and Durduran (2016) reported a significant decrease in the shoreline of Lake Acıgöl between 1985 and 2015. Similarly, Kale (2018) noted shoreline regression in Lake Akşehir between 1990 and 2016. Kesikoglu et al. (2017) observed seasonal variations in the shoreline of the Yamula Reservoir Lake, reporting both increments and reductions throughout the year. Duru (2017) reported an average rate of shoreline change for Sapanca Lake between 1975 and 2016 as an advancement of 2.7 meters per year. Kale and Acarlı (2019b) conducted research on monitoring shoreline changes in Atikhisar Reservoir Lake, noting significant variations throughout the monitoring period and fluctuations in shoreline length among the years. The current study highlights varying shoreline length that demonstrates a rising pattern, diverging from prior research findings.

Shoreline changes can be attributed to various natural and/or artificial factors. Sener et al. (2010) highlighted the influence of surface runoff, precipitation, and evaporation on shoreline changes. Similarly, Arkoc and Özşahin (2018) attributed changes observed in the Gala and Pamuklu Lakes' shorelines primarily to precipitation and evaporation. Duru (2017) indicated that the primary reasons for changes in the shoreline were natural fluctuations in rainfall and reductions in water due to excessive water consumption and development projects associated with human activities. On the other hand, Yıldırım et al. (2011) attributed observed shoreline changes to population growth, increased domestic and agricultural water consumption, construction of reservoirs and ponds, and irrigation system installations driven by human activities. Likewise, Bayram et al. (2013) emphasized the substantial impact of human-induced activities on shoreline changes and highlighted the significant effects of land use differences.

Kaya (2016) reported changes in the shoreline of Lake Terkos (Istanbul, Türkiye) without a specific identifiable cause, but suggested that excessive water consumption from the lake for domestic and agricultural irrigation and sand extraction could be influential. The current study suggests that due to relatively lower human activities and a lower population in the region, the shoreline is not negatively affected as the demand for domestic/agricultural water consumption might be lower compared to other studies.

Although Kale et al. (2018) reported decrease in the runoff of Tuzla River (dataset cover the period between 2006 and 2013) and precipitation, and increase in the evaporation over the region, our study revealed that the shoreline perimeter was increased. Kale et al. (2018) illustrated that the runoff of Tuzla

River and rainfall tended to decrease until 2013. However, the rainfall tended to increase and evaporation tended to decrease in the period between 2008 and 2013 as presented in their Figures 2 and 3. Our study analyzed data period between 2008 and 2019. And, after 2013, our data showed that the perimeter of the shoreline increased. On the other hand, there are several papers reporting decrease in the runoff of some rivers located close area to our study area (Kale et al., 2016a, 2016b; Ejder et al., 2016a, 2016b). However, each water resource may react in different way to the affecting factors.

The monitoring of these areas is necessary for achieving ecological balance, preserving biological diversity, sustainably utilizing natural resources, and executing planned urbanization and development. Additionally, it's crucial to assess potential future changes in these areas by considering both anthropogenic and natural alterations and making predictions about their possible consequences. To achieve this, monitoring shoreline changes is of vital importance. In this context, this study represents the first attempt to identify and monitor changes in the shoreline of the Ayvacık Reservoir, the sole source of drinking, domestic, and agricultural water for Ayvacık district. This study will enable future predictions by monitoring spatial and temporal changes in the dam. Changes in population and climatic events affect water demand, leading to an increase in the required amount of water. Considering these factors, continuous monitoring of changes in the dam is crucial to ensure sustainable water use and prevent the deterioration of societal welfare and the reduction of economic contributions derived from agricultural activities. In future studies, monitoring seasonal changes considering the variations within a year would be beneficial for detecting possible abrupt changes in the shoreline.

5. Conclusion

In conclusion, this study examined the shoreline changes occurring from the inception of the Ayvacık Reservoir in 2008 until 2019. Analysis of the spatial and temporal variations in the dam's shoreline revealed the preservation and expansion of water resources. Consequently, it is anticipated that the Ayvacık Reservoir will continue to fulfill its role in providing water supply services.

Compliance with Ethical Standards

Conflict of interest

The authors declared that for this research article, they have no actual, potential or perceived conflict of interest.

Author contribution

SK: Conceptualization, Writing – original draft, Writing – review and editing, Data curation, Formal analysis, Methodology, Visualization

SB: Methodology, Investigation, Data curation

DA: Investigation, Writing – review and editing

All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

Ethics committee approval is not required.

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Data availability

The authors confirm that the data supporting the findings of this study are available within the article.

Consent for publication

Not applicable.

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