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RESEARCH ARTICLE

Spatial and Temporal Change Monitoring in Water Surface Area of Atikhisar Reservoir (Çanakkale, Turkey) by using Remote Sensing and Geographic Information System Techniques

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ABSTRACT

Spatial and temporal changes in surface area of Atikhisar Reservoir were monitored by using remote sensing and geographic information system techniques from 1975 to 2017. Satellite images were processed, analysed and manually digitized to reveal the changes in surface area of the reservoir. The results showed that total surface area of the reservoir was ranged between 1.72km² and 3.84km² during the monitoring period. Maximum increase in the surface area has been observed with 74.6% while maximum decrease has been observed with 31.8%. These fluctuations could be related with the climatic changes, natural and man-made processes such as sediment transportation, water leakages, excessive water exploitation for drinking, domestic or agricultural purposes, and human interventions along the reservoir. Therefore, surface area should be monitored continuously and all factors influencing the variation in surface area should be considered in decision making processes to support water sharing policy toward the management of water resources.

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Introduction

Reservoirs and lakes have significant role for hydrological cycle and they are used to water storage, irrigation, flood preventing, energy production, and moderating the impacts of the climate change. Reservoirs and lakes are affected by natural processes and human interventions. Significant changes have been observed in reservoirs and lakes worldwide such as variations in shape, size and ecology of reservoirs and lakes (Jiang et al., 2012; Feyisa et al., 2014; Pekel et al., 2016). The expansion of the surface areas was occurred in some part of the world caused by the snow melting and glacial melting due to rising temperature while decreasing of the surface areas was observed because of the global warming, increasing evaporation, and excessive water consumption.

Calculating lake surface area is more appropriate to understand the response of lake to variation in the hydrologic balance than depth and volume (Benson and Paillet, 1989). Monitoring spatial and temporal changes of water surface in lakes and reservoirs is one of the most important issue for both local and global scale within the last century. Reservoirs and lakes serve as a water supplier for the purposes of drinking, domestic usage, agricultural and anthropogenic activities. Therefore, water resources should be continuously monitored to ensure the sustainable exploitation of water from lakes and reservoirs. The management of water resources needs

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inclusive information on the water environment to make more appropriate action plans for supporting the improvement of water resources in a sustainable way (Voutilainen et al., 2007). In this context, remote sensing technologies provide comprehensive data for scientists and researchers on water resources.

Remote sensing of water resources became more important in recent decades due to the climate change and deteriorating ecology issues (Ekercin, 2007). Remote sensing systems can be used to provide historical spatial data with the advantages of acquisition frequency and synoptic capabilities (White and El-Asmar, 1999). Satellite imageries are used to determine the temporal changes in water resources and monitoring changes with satellite imageries makes it possible to achieve more successful results in a short time than traditional methods. Similarly, geographic information system (GIS) is an important technology that commonly applied in numerous fields including change monitoring in water resources and it is a crucial tool for extracting and analysing reliable information from satellite imageries. Therefore, integrating remote sensing data with GIS provides new base data for further analyses.

Monitoring of spatial and temporal changes using satellite images has globally become crucial for better understanding and explaining of environmental changes in the reservoirs. Spatial and temporal changes of water surface in lakes and reservoirs were monitored by several scientists (Sidle et al., 2007; El-Asmar et al., 2013; Abu-Faraj et al., 2014; Hossen et al., 2018; Ji et al., 2018; Tan et al., 2018; Yapiyev et al., 2019). There are few researches on change monitoring of water surface in lakes and reservoirs in Turkey (Akar et al., 2002; Reis and Yılmaz, 2008; Durduran, 2010; Avdan et al., 2013; Bahadır, 2013; Battal et al., 2016; Erener et al., 2016; Yücel and Turan, 2016; Sarp and Ozcelik, 2017; Topuz and Karabulut, 2018). However, there is no published paper on the monitoring of spatial and temporal changes in water surface area of Atikhisar Reservoir. This paper, therefore, aimed to monitor spatiotemporal changes in water surface area of Atikhisar Reservoir by using remote sensing and GIS technologies.

Materials and Methods

Study Area

Çanakkale is located in the north-western part of Turkey along the coasts of Aegean Sea. The city was divided by the Çanakkale Strait and located on both Asia and Europe continents. The climate in Çanakkale is typical transition climate which winter is rainy and cold, and summer is dry and hot (Kale 2017a). Atikhisar Reservoir (Figure 1) was built on Sarıçay Stream which it has its source from Ida Mountains and runs into Çanakkale Strait (Ejder et al., 2016a). The water storage was started in June 1975 in the reservoir. Atikhisar Reservoir is the only drinking water source for more than 130 thousand inhabitants. The reservoir supplies water for the purposes of drinking and irrigation to the people in the basin and it also serves for preventing floods. Normal water level was described as 61 m for the reservoir by The General Directorate of State Hydraulic Works (SHW). SHW also indicated that the surface area is 3 km^2 and volume is 40 hm^3 when the reservoir has normal water level. The reservoir is under pressure of agricultural activities and discharged wastes from rural areas (Akbulut et al., 2010; Selvi and Kaya, 2013). The climate of the basin is largely defined as transition climate by Koç (2001) and the basin shows mountainside characteristic that predominantly formed with Eosen-Oligosen andesite, tuffs, and dacite (Koç, 2007).

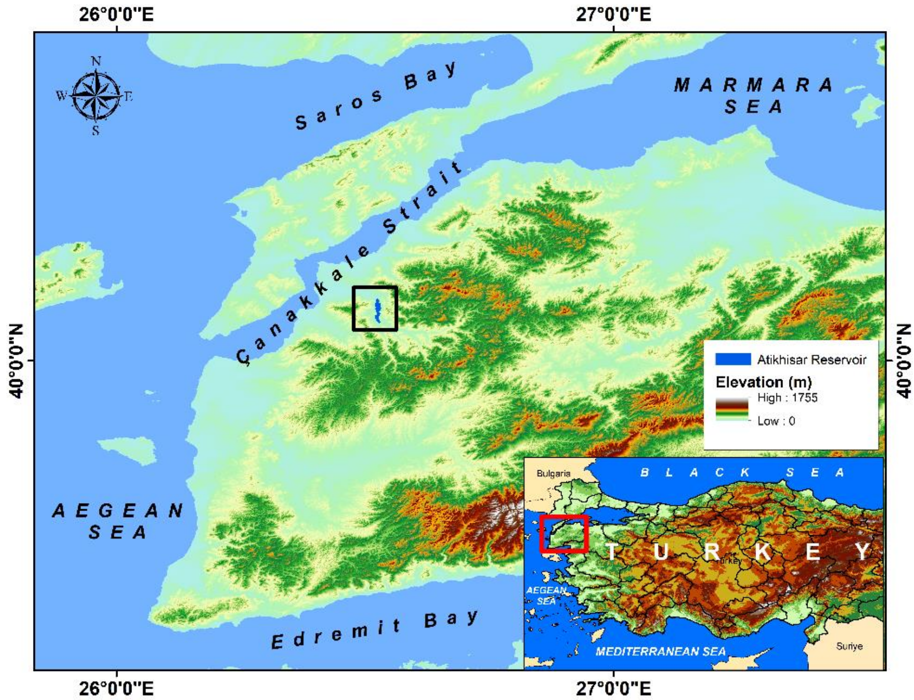

Figure 1 The location of Atikhisar Reservoir

Satellite Imageries

Satellite images are appropriate for monitoring and mapping of wetlands where information about wetland is unavailable and funds are limited (Ozesmi and Bauer, 2002). The most common satellites used to explore the Earth are Landsat satellites. Landsat makes available the longest continuously obtained assembly of space-based remote sensing data for earth surface. Satellite images used in the study were obtained from the United States Geological Survey (USGS) data archive at the same month (i.e., June) in each year between 1975 and 2017 to avoid inter-annual and seasonal variations (https://earthexplorer.usgs.gov). June was selected because of the reservoir gets started to storage water in June 1975. Remotely sensed satellite imageries were collected by satellites of Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). Spatial resolution is 60 m for MSS, 30 m for TM, ETM+, and OLI/TIRS while panchromatic band (band 8) has 15 m spatial resolution for both ETM+ and OLI/TIRS.

To perform image processing techniques, a digital database was created in GIS environment. Then, remotely sensed satellite images were imported and processed by using Erdas Imagine 2014 and ENVI 5.2 software. Radiometric and geometric corrections were executed and images were rectified using geographical projection with World Geodetic System 1984 (WGS84) datum. To extract the water surface area, shapefiles were generated for each images in ArcMap 10.3 software. The water surface area was detected for each images by using appropriate band combination and selection for each satellite sensors. Afterwards, water surface areas were digitized manually by delineating each water body for each time frame.

Results and Discussion

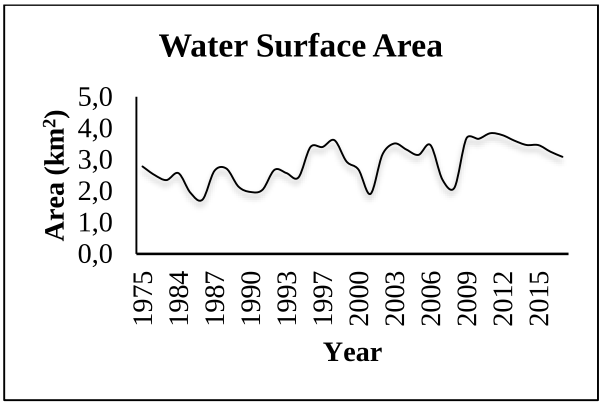

Figure 2 Temporal change in water surface area

Water surface areas were extracted from satellite images between 1975 and 2017. The changes in water surface area were presented in Figure 2. Total area of water surface was calculated 2.78 km^2 in the first year of water storage while 3.09 km^2 in 2017. Total area of the lake water surface ranged between 1.72 km^2 to 3.84 km^2 and minimum surface area was calculated in 1986 while maximum was calculated in 2011 (Figure 2).

Decrease and increase in the surface area were observed during the monitoring period. Maximum increase in the surface area has been observed in 2009 with 74.6% increase while maximum decrease has been observed in 2007 with 31.8% (Figure 3).

The results indicate a significant decreasing trend in surface area during the period between 1975 and 1986. Reservoir significantly lost its water surface area in 1986 with a 38% decrease when compared to the year 1975. Water surface area increased for a short term and decreased again in 1990. Surface area could not reach the initial amount until 1996 and it increased for 3 years between 1996 and 1998 as compared to 1975. Then, water surface area exhibited a sharp decrease in 2001. This decrease was calculated 47.3% when compared with 1998 and 31.5% when compared with the initial amount of area (Table 1).

Spatial and temporal changes in water surface area of Atikhisar Reservoir were presented in Figure 4 by thematic maps created in GIS environment. Figure 4 clearly demonstrates the changes in the water body for the monitoring period from 1975 to 2017.

Surface waters are essential part of the water cycle even though freshwater in lakes covers 0.007% of total water reserves on the earth while the total freshwater reserves account for 2.53% of the total global water reserves (Shiklomanov, 1993). Lakes and reservoirs are the most reachable and available water resources for human consumption and ecosystem (Abdallah et al., 2011). Henceforth, observation stations were built on lakes and reservoirs to observe and collect data for the management of water resources in many parts of the world. However, measurements in the field still require in situ effort, time, and relatively high cost. Nevertheless, several water resources located in the back of beyond have never been observed or measured. Even though observation stations existed in lakes and reservoirs, they commonly measured only water level of the resources while area and volume of the water resources could not measure. However, the measurement of both water surface area and volume of the resources is crucial to the best understanding the responses of water resources to the climate change on regional and global scale. In this respect, the progresses in the remote sensing and GIS technologies have provided novel approaches for monitoring water surface areas and levels of water resources to the scientists.

Numerous methods were used for detection and extraction of water bodies from satellite imageries (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). Water reflectance is closely equal to zero and has lower value than land in reflective infrared bands. Extracting water bodies can be easier because of darker appearance of water bodies (Raju et al., 2015). Shih (1985) recommended that using band 5 and band 7 could successfully classify the water surface of a lake. Furthermore, USGS stated that band 7 for MSS, band 5 for OLI/TIRS, and band 4 for TM, ETM+ were advantageous for mapping shorelines. In this paper, satellite images obtained from Landsat have been successfully used to extract water surface area by combining and selecting appropriate bands.

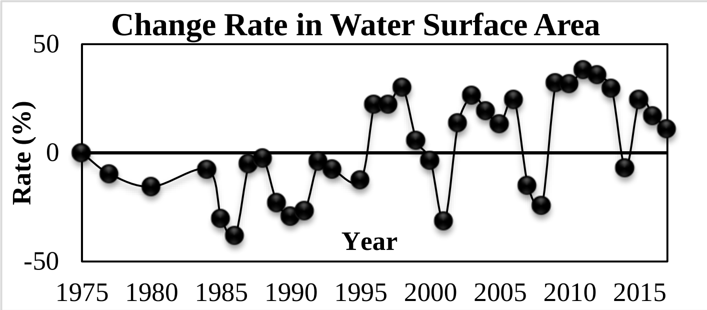

Figure 3 Change rate in water surface area compared to the initial area in 1975

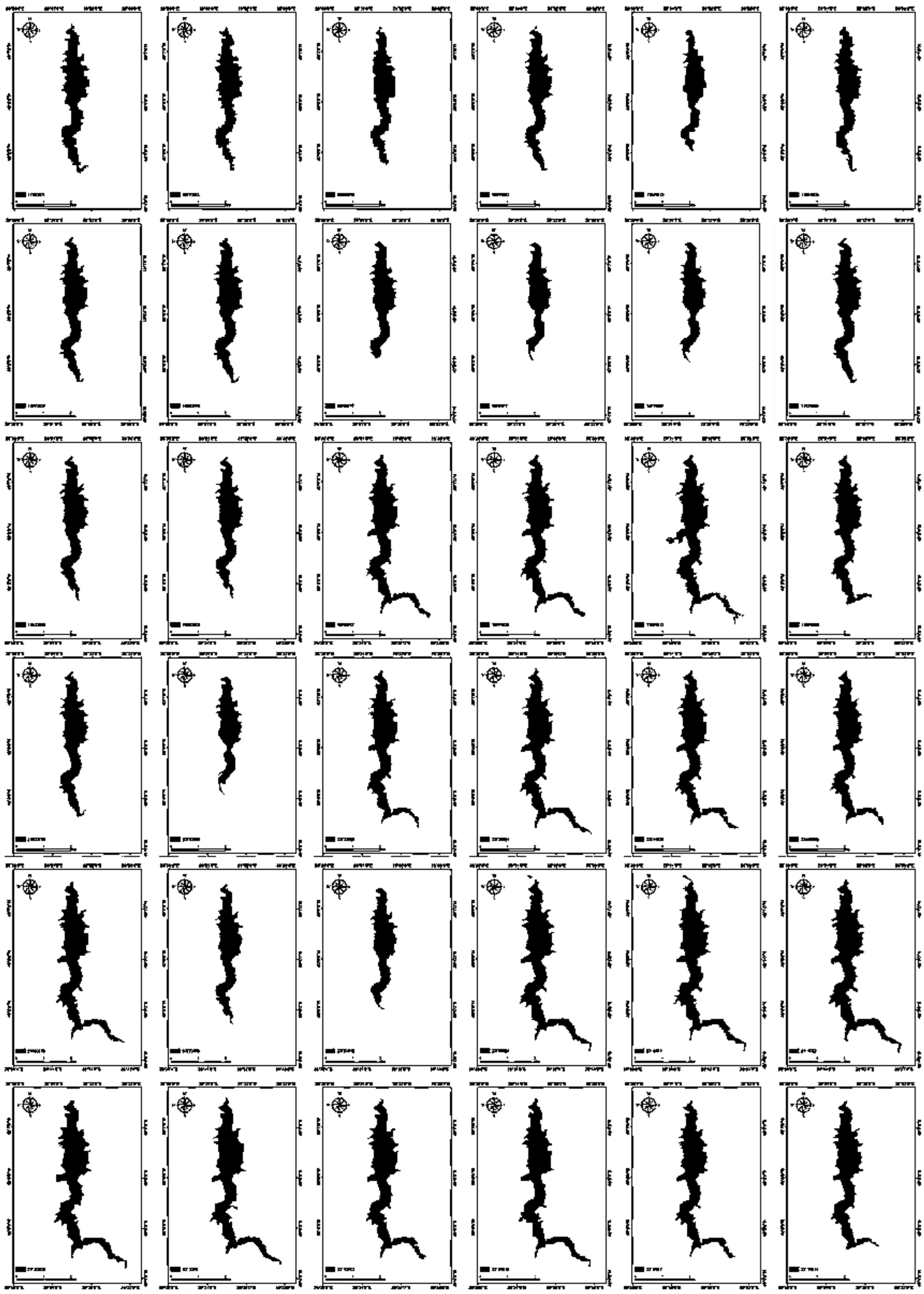

Figure 4 Spatial and temporal changes of water surface in Atikhisar Reservoir

Table 1. Lake surface area and areal change rates in Atikhisar Reservoir

Satellite	Image Date	Spatial Resolution	Surface Area (km^2)	Change Rate of Surface Area Compared with Initial Area (%)	Change Rate of Surface Area Compared with Previous Year (%)
Landsat 2 MSS	01.06.1975	60 m × 60 m	2.783	-	-
Landsat 2 MSS	21.05.1977	60 m × 60 m	2.511	-9.76	-9.76
Landsat 3 MSS	19.06.1980	60 m × 60 m	2.348	-15.63	-6.50
Landsat 5 TM	03.06.1984	30 m × 30 m	2.568	-7.70	9.39
Landsat 5 MSS	13.06.1985	60 m × 60 m	1.941	-30.24	-24.42
Landsat 5 TM	09.06.1986	30 m × 30 m	1.723	-38.07	-11.23
Landsat 5 TM	03.06.1987	30 m × 30 m	2.644	-4.99	53.42
Landsat 5 TM	05.06.1988	30 m × 30 m	2.713	-2.51	2.62
Landsat 5 TM	17.06.1989	30 m × 30 m	2.140	-23.10	-21.13
Landsat 5 TM	11.06.1990	30 m × 30 m	1.969	-29.24	-7.98
Landsat 5 TM	07.06.1991	30 m × 30 m	2.038	-26.76	3.50
Landsat 5 TM	25.06.1992	30 m × 30 m	2.674	-3.92	31.19
Landsat 5 TM	28.06.1993	30 m × 30 m	2.571	-7.61	-3.84
Landsat 5 TM	25.06.1995	30 m × 30 m	2.433	-12.58	-5.38
Landsat 5 TM	27.06.1996	30 m × 30 m	3.403	22.27	39.87
Landsat 5 TM	30.06.1997	30 m × 30 m	3.403	22.29	0.01
Landsat 5 TM	17.06.1998	30 m × 30 m	3.619	30.07	6.36
Landsat 5 TM	29.06.1999	30 m × 30 m	2.943	5.75	-18.69
Landsat 5 TM	15.06.2000	30 m × 30 m	2.683	-3.57	-8.82
Landsat 7 ETM+	10.06.2001	30 m × 30 m	1.906	-31.51	-28.97
Landsat 5 TM	21.06.2002	30 m × 30 m	3.165	13.75	66.08
Landsat 5 TM	24.06.2003	30 m × 30 m	3.516	26.34	11.08
Landsat 5 TM	26.06.2004	30 m × 30 m	3.320	19.32	-5.56
Landsat 5 TM	29.06.2005	30 m × 30 m	3.152	13.25	-5.08
Landsat 5 TM	16.06.2006	30 m × 30 m	3.464	24.49	9.92
Landsat 5 TM	10.06.2007	30 m × 30 m	2.361	-15.15	-31.84
Landsat 5 TM	12.06.2008	30 m × 30 m	2.107	-24.30	-10.79

Landsat 5 TM	24.06.2009	30 m × 30 m	3.679	32.19	74.64
Landsat 5 TM	11.06.2010	30 m × 30 m	3.664	31.66	-0.40
Landsat 5 TM	21.06.2011	30 m × 30 m	3.843	38.11	4.90
Landsat 7 ETM+	08.06.2012	30 m × 30 m	3.781	35.87	-1.62
Landsat 7 ETM+	11.06.2013	30 m × 30 m	3.605	29.56	-4.65
Landsat 8 OLI/TIRS	22.06.2014	30 m × 30 m	3.468	24.61	12.25
Landsat 8 OLI/TIRS	16.06.2015	30 m × 30 m	3.462	24.42	-3.96
Landsat 8 OLI/TIRS	11.06.2016	30 m × 30 m	3.254	16.93	-6.02
Landsat 8 OLI/TIRS	14.06.2017	30 m × 30 m	3.089	11.01	-5.06

Several researches have conducted to monitor the water surface area of the lakes and reservoirs by using remote sensing and GIS techniques. Zhu et al. (2014) monitored the fluctuation of Lake Qinghai using multi-source remote sensing data and they reported that surface area has increased 77 km^2 from 2003 to 2009. Sidle et al. (2007) assessed contemporary changes in water surface area of Lake Inle in Myanmar during the period from 1935 to 2000. Authors pointed out that a loss of 32.4% was occurred in monitoring period attributed to anthropogenic and agricultural activities ongoing in-lake and near-lake. El-Asmar et al. (2013) quantified the changes in surface area of Burullus Lagoon in Egypt between 1973 and 2001 by applying Normalized Difference Water Index (NDWI) and Modified Normalized Difference Water Index (MNDWI). Authors documented that 42.8% of the total surface area of the lake was declined for this period due to the anthropogenic activities. Abu-Faraj et al. (2014) calculated water surface area of the Dead Sea in Jordan for the period from 1984 to 2012. Authors indicated that water surface area declined from 679 km^2 to 620 km^2 during the monitoring period. Liu and Yue (2017) evaluated the changes in Lake Hulun in China between 1975 and 2015. Authors indicated that lake area fluctuated during this period and presented both decreasing and increasing trends. Hossen et al. (2018) evaluated the changes in surface area of Manzala Lake in Egypt. Authors noted that water surface area of the lake declined by 46% for the period between 1984 and 2015. Ji et al. (2018) investigated the changes in the surface area of Tonle Sap Lake in Cambodia from 2000 to 2014. Authors stated that water surface area showed an overall decreasing trend during this period. This reduction in the surface area of the lake was found to be related with runoff from river. Mohsen et al. (2018) detected changes in Lake Burullus using GIS and remote sensing. Authors reported that there was a significant decrease in the water area about 49% from 1972 to 2015. In addition, a rapid reduction was noticed in the surface area of the lake between 1972 and 1984. Tan et al. (2018) analysed areal changes of 24 lakes along the Silk Road from China to Europe. Authors indicated that surface areas of 15 lakes had decreased while areas of 9 lakes had increased from 2001 to 2016. Yapiyev et al. (2019) estimated water storage changes in small endorheic lakes in Northern Kazakhstan and they documented that total water surface area of the lakes reduced 7% from 1986 to 2016 although surface area of some smaller lakes had increased.

In Turkey, Akar et al. (2002) determined changes in surface area of Acıgöl and Urmia (in Iran) lakes by using different digital image processing techniques such as manual digitalization, semi-automatic vectorization, supervised classification, unsupervised classification, and object based classification methods. The results of all methods pointed out that water surface area of both lakes were reduced from 1975 to 2010. Ekercin and Örmeci (2008) explored the changes in water reserve of Tuz Lake and they indicated that water reserve has decreased markedly in the lake with a decrease of 43 ha. Reis and Yılmaz (2008) monitored changes in water of Seyfe Lake using remote sensing from 1975 to 2001 and stated that a decrease of 33% was observed in the water surface area of the lake for this period. Durduran (2010) investigated changes in the lakes of Beyşehir, Tersakan, Kulu, Suğla, Bolluk, Samsam, Tuz in Konya. Author reported that increases were detected in Bolluk and Samsam lakes while decreases were observed in Tersakan, Kulu, Beyşehir, and Tuz lakes. Furthermore, author pointed out that Suğla Lake was completely dried. Avdan et al. (2013) analysed temporal changes of water surface area in Akşehir Lake and documented that a decline of 43% was occurred in the water surface area of the lake for the period from 1984 to 2005. Bahadır (2013) determined spatial changes of Akşehir Lake and indicated that lake area was reduced from 354 km^2 to 119 km^2 between 1975 and 2010. This reduction was found to be affected by decrease in precipitation and streamflow on the contrary of increase in water consumption and evaporation. Şanlıyüksel Yücel et al. (2014) investigated change detection of acid mine lakes in Çan county (Çanakkale, Turkey) using satellite images and they reported that the numbers and total areas of acid mine lakes were increased from 1987 to 2011. Total area of all acid mine lakes reached maximum level of 12.42 ha in 2011. Authors have highlighted that the increase in total area and number of acid mine lakes lead to significant environmental risks such as fish death in the other surface waters. Erener et al. (2016) determined the changes in reservoir area of Yuvacık Dam Lake in Kocaeli by applying of remote sensing and GIS technologies. Authors reported that water surface area had declined 10% from 2001 to 2005. Yücel and Turan (2016) analysed areal changes in two mine lakes in Çanakkale, Turkey. Authors reported a reduction in the total areas of the mine lakes from 25 ha to 21 ha between November 2014 and October 2015. They indicated that these changes in total areas of the lakes were attributed to mean precipitation. Sarp and Ozcelik (2017) assessed the spatiotemporal changes in water surface area of Lake Burdur and also compared different water body extraction methods such as Support Vector Machine (SVM) classification, NDWI, MNDWI, Automated Water Extraction Index (AWEI). Authors declared that a reduction of approximately 20% in water surface area was determined between 1987 and 2000 while a decrease by nearly 10% was observed from 2000 to 2011 in lake area. Consequently, a total of 32% decline was detected in water surface area of the lake. Şanlıyüksel Yücel and Yücel (2017) determined surface areas of mine lakes in abandoned coal mines of Çan coal basin in Çanakkale by using remotely sensed satellite imageries and unmanned aerial vehicle (UAV). Authors reported that total surface area of all lakes were decreased even two lakes were completely dried from 2013 to 2014. On the other hand, if these dried lakes are excluded from the calculation, total area of lakes found to be increased. The reasons for decrease and increase in the total area of lakes have been attributed to natural and anthropogenic processes such as erosion, precipitation, wind, mining activities, draining water to the stream.

In this paper, fluctuations were observed during the monitoring period in the water surface area of the reservoir. The minimum area has been calculated in 1986 while the maximum has been calculated in 2011. On the other hand, maximum decrease in the surface area has been observed in 2007 with 31.8% while maximum increase has been observed in 2009 with 74.6% increase. These changes could be related to the climatic changes such as rising temperature, declining precipitation, increasing evaporation, decreasing surface runoff and snow melting. Similarly, Kale (2017a) reported that the temperature had an increasing trend in addition to the document reported by Kale (2017b) claiming that evaporation had increasing trend in Çanakkale for future periods. Moreover, Ejder et al. (2016a) noted that annual streamflow of Sarıçay Stream was decreasing and streamflow presented a decreasing trend. Likewise, decreasing trends caused by the climate change have been reported for other rivers. For instance, Ejder et al. (2016b) reported that the streamflow of Kocabaş Stream showed a decreasing trend, Kale et al. (2016a) documented that Bakırçay River streamflow had a tendency to decrease, Kale et al. (2016b) stated that streamflow of Karamenderes River had a decreasing trend. Kale et al. (2018) reported that streamflow for Tuzla, Büyük Menderes, and Gediz Rivers presented decreasing trends. Kale and Sönmez (2018a) documented that streamflow of Akkaya Stream had decreasing trend. Kale and Sönmez (2018b) pointed out that the streamflow of Daday Stream tended to decrease. Sönnmez and Kale (2018) noted a significantly decrease in the streamflow of Filyos River. As seen in the literature, the climate change is commonly the driving force for the variations in the amounts of water resources. However, there are some other factors affecting the water resources beside the climate change such as anthropogenic activities (Gao et al., 2011; Jackson et al., 2011; Zhou et al., 2015), agricultural activities (Dügel and Kazanci, 2004; Yercan et al., 2004; Kaçan et al., 2007; Durdu, 2010), excessive consumption of water, and unsustainable usage of the water. Turkey is not a water rich country on the contrary to popular belief (Hisar et al., 2015). Therefore, water resources should be used in a sustainable way.

Reservoirs can also be used for fish production and recreational fisheries. It supplies extra economic income and employment opportunities by fish restocking activities in the reservoirs. Reservoirs present different horizontal and vertical characteristics in terms of primary productivity, physical habitat, and fish distribution (Kale and Acarli, 2018). Şaşı and Berber (2012) noted that coastal vegetation is predominantly key for keeping species alive to allow feeding, breeding, and growing activities in the reservoirs. Coastal vegetation presents variation according to the changes in water surface area and water level. Changes in water surface area of the reservoir may also affect the fish distribution, population structure, reproduction, feeding, survival rate, and habitat sharing by causing variations in bathymetric zone and shoreline.

The limitation of this study could be the only usage of single band selection to detect water bodies from satellite imageries. Some classification methods could be used for differentiating the water and land surfaces. However, actually, single band selection is not a weakness due to water has lower values (equivalent to zero) than land features. Both features were distinguished successfully from satellite images by single band selection. Lower valued pixels have demonstrated the water bodies in the available images and then shapefiles were digitized and extracted manually. Therefore, the limitation has been overcome. Furthermore, to extract water bodies from satellite imageries, different unsupervised (Isodata) and supervised (Maximum Likelihood, Mahalanobis Distance, Minimum Distance) classification methods, automated water extracting indices such as NDWI, MNDWI, AWEI, and Water Ratio Index (WRI) should be used and the results of these methods should be compared for further studies.

Conclusion

Atikhisar Reservoir provides water for the purposes of drinking, domestic usage, agricultural and other anthropogenic activities. It is of great importance since it is the only water resource in the basin. In this paper, spatial and temporal changes were monitored in water surface of the reservoir from the first construction time of the reservoir to the present time (1975-2017) by using remote sensing and GIS technologies. Satellite imageries provide historical data and the integration of remote sensing and GIS techniques has many advantages and benefits to monitor spatiotemporal changes. This paper presents the richest assessment for monitoring of spatial and temporal changes in surface area of Atikhisar Reservoir from the first construction time to the present. During the monitoring period, spatially decrease and increase were observed in water surface of the reservoir. These variations could be related with the climatic changes including rise in temperature and evaporation on the contrary of decline in precipitation regimes, excessive water exploitation for drinking, domestic, or agricultural purposes, sediment transportation, and water leakages. Therefore, the relationships between water surface and other driving forces should be investigated in further studies. Moreover, continuously monitoring is compulsory for supporting decision-making processes to take measures or to establish appropriate water sharing policy toward ensure the sustainability of water resources in Atikhisar Reservoir. This paper also noticeably confirms that integrating remote sensing and GIS techniques is valued to extract better results from historical satellite imageries.

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