ASSESSMENT OF COASTLINE CHANGE OF LAKES OF GALA LAKE NATIONAL PARK (NW TURKEY) WITH MULTI-TEMPORAL SATELLITE IMAGES

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ABSTRACT

Gala Lake national park is an A Class International Wetland and hosts different species of birds and fish. For a sustainable natural life in the park, environmental issues should be monitored. Coastline change detection is one of the important tasks of environmental monitoring. Geology, hydrogeology and hydrology are the important factors that affect coastline change. This study aims to determine the coastline change of Gala and Pamuklu lakes in Gala Lake national park with multi temporal satellite images of Landsat MSS, Landsat TM and Landsat ETM+ which were acquired between 1977 and 2011. The reasons of the changes of the coastline and the surface areas of both lakes has been investigated with geological, hydrogeological and hydrological data. Research has shown that the primary factors controlling coastline change of both lakes are precipitation and evaporation. The surface areas of both Gala and Pamuklu Lake decreased from 5.196 km^2 and 1.341 km^2 to 5.147 km^2 and 1.295 km^2, respectively, between 1977 and 2011 with an average value of % 2.2.

Keywords: Gala Lake National Park, Coastline Change, Remote Sensing, Hydrology

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GALA GÖLÜ MİLLİ PARKI (KB TÜRKİYE) GÖLLERİNİN KIYI ÇİZGİSİ DEĞİŞİMLERİNİN ÇOKLU ZAMANSAL UYDU GÖRÜNTÜLERİ İLE DEĞERLENDİRİLMESİ

ÖZET

Gala Gölü Milli Parkı birçok kuş ve balık türüne ev sahipliği yapan A sınıfı Sulak Alan-Önemli Kuş Alanıdır. Parktaki doğal hayatın sürdürülebilir olması için çevresel sorunların izlenmesi gerekmektedir. Kıyı çizgisi değişiminin izlenmesi, çevre koruma ve izleme işlemlerinin önemli görevlerinden biridir. Jeoloji, hidrojeoloji ve hidroloji, kıyı çizgisi değişimini etkileyen önemli faktörlerdir. Bu çalışma, Gala Gölü milli parkındaki Gala ve Pamuklu göllerinin kıyı şeridi değişimini, 1977 ve 2011 yılları arasında edinilen Landsat MSS, Landsat TM ve Landsat ETM + 'ın çoklu zamansal uydu görüntüleri ile belirlemeyi amaçlamaktadır. Kıyı çizgisinde ve her iki göldeki yüzey alanlarında meydana gelen değişikliklerin nedenleri jeolojik, hidrojeolojik ve hidrolojik verilerle araştırılmıştır. Araştırmalar her iki gölün kıyı çizgisi değişimini kontrol eden birincil faktörlerin yağış ve buharlaşma olduğunu göstermiştir. Gala ve Pamuklu Gölü yüzey alanları 1977 ile 2011 yılları arasında sırasıyla 5.196 km^2 ve 1.341 km^2 den 5.147 km^2 ve 1.295 km^2'ye ortalama % 2,2 değerinde azalmıştır.

Anahtar Kelimeler: Gala Gölü Milli Parkı, Kıyı çizgisi değişimi, Uzaktan Algılama, Hidroloji

1. INTRODUCTION

In recent days, due to the climate change and other environmental issues, water bodies are affected either positively or negatively [1]. With no exception, coastal zones in the world are also under pressure of natural and anthropogenic activities and climate change [2]. Coastline can be described as the boundary between water and land [3] and it is one of the most linear features of the earth surface with dynamic nature [4, 5]. This dynamic nature of coastline is controlled by different factors such as, climate, geology, hydrogeology and hydrology. Coastal wetlands are unique and important areas due to their unique floral and faunal characteristics and also an important piece of coastal ecology [6]. Remote sensing techniques provide valuable data for coastline change detection. Furthermore, maps generated by remote sensing data have a potential to project the coastal changes in time [7, 8]. In addition, remote sensing data and geographical information systems (GIS) can easily be integrated for analyzing, and interpreting satellite images to get reliable information [9-12]. More accurate results can be obtained if these data are supported by climatic, geological, hydrogeological and hydraulic data [13].

Gala Lake National Park is an A class international wetland and Important Bird Area [14], situated in Meriç Delta, in the north-west of Turkey with an area of 60 km^2. There are two lakes situated inside the park area. These are namely Gala Lake and Pamuklu Lake. These lakes host 163 different species of birds and 16 different species of fish such as carp fish and pickerel (Figure 1). Gala and Pamuklu Lakes are defined as alluvium barrier lakes, with depths varying from 2,2m and 0,4m. During summer season Gala Lake is separated into two sections, namely Big Gala Lake and Small Gala Lake, by state hydraulic works to prevent it from drying. Both lakes are surrounded by paddy fields where %24 of Turkey's rice demand is supplied [15-17].

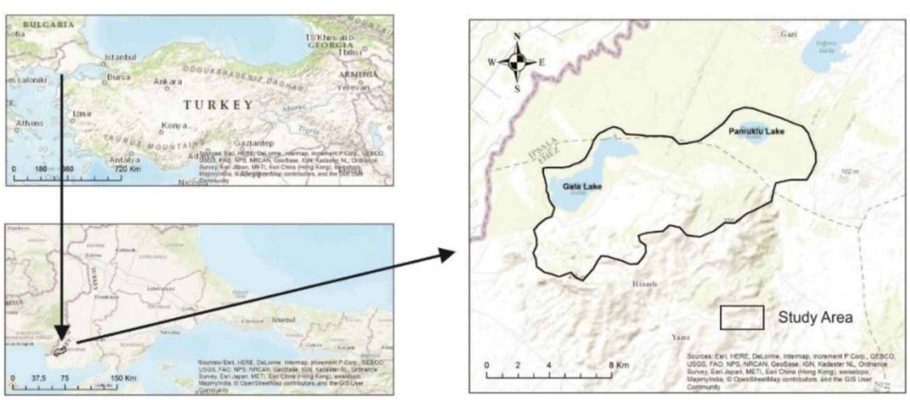

Figure 1. Location Map of The Study Area

2. MATERIALS AND METHODS

For the determination of coastline changes of the studied lakes, following methodology has been applied;

a) Data collection

b) Pre-processing of image data

c) Hydrological, geological and hydrogeological data interpretation

d) Coastline detection

Flowchart of the research methodology is given in Figure 2.

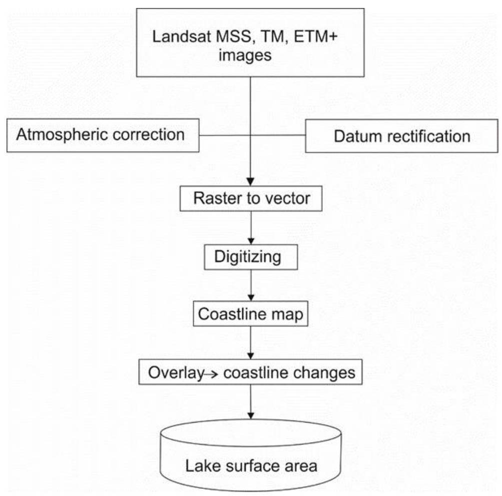

Figure. 2 Flowchart of The Research Methodology

2.1. Data collection

Multi-temporal analysis of the coastline change for both lakes has been made by images of Landsat ETM+ (Enhanced Thematic Mapper), Landsat TM (Thematic Mapper), Landsat MSS (Multispectral Scanner), downloaded via internet from USGS Center for Earth Resources Observation and Science (EROS) [18]. Landsat ETM+ has 8 spectral bands with 30m resolution, Landsat TM has 7 spectral bands with 30m resolution while Landsat MSS has 4 spectral bands with resolution of 80m. Acquisition dates of the satellite images are; 2011 and 2001 for Landsat ETM+, 2007 and 1987 for Landsat TM and 1977 for Landsat MSS. All the properties of the acquired images are given in Table 1.

Table 1. Properties of The Images Used In This Research

Satellite	Acquisition date	Spatial Resolution	Spectral Band
Landsat ETM+	27.06.2011 - May	30m	8
Landsat ETM+	31.07.2007 - May	30m	7
Landsat ETM+	16.04.2001 - August	30m	8
Landsat TM	31.08.1987 - June	30m	7
Landsat MSS	21.05.1977 - May	80m	4

2.2. Pre-processing of image data

In order to make satellite images more accurate and interpretable, pre-processing procedures such as geometric and atmospheric corrections should be applied. The Landsat images had already been georeferenced, therefore, these images were only rectified to European Datum 1950 (ED50) with coordinate system of Universal Transverse Mercator (UTM-Zone35) using Globalmapper11 software (Blue Marble Geographics, Maine, USA) for geometric correction. Since a large percentage of Landsat imagery was severely contaminated by aerosols, clouds and cloud shadows, these images had to be corrected in order to obtain actual clear sky surface reflectance. This procedure is called as atmospheric correction [19-21]. The atmospheric correction of the images was done by haze reduction tool in Geomatica software (PCI Geomatics, Ontario, Canada) (Fig.3).

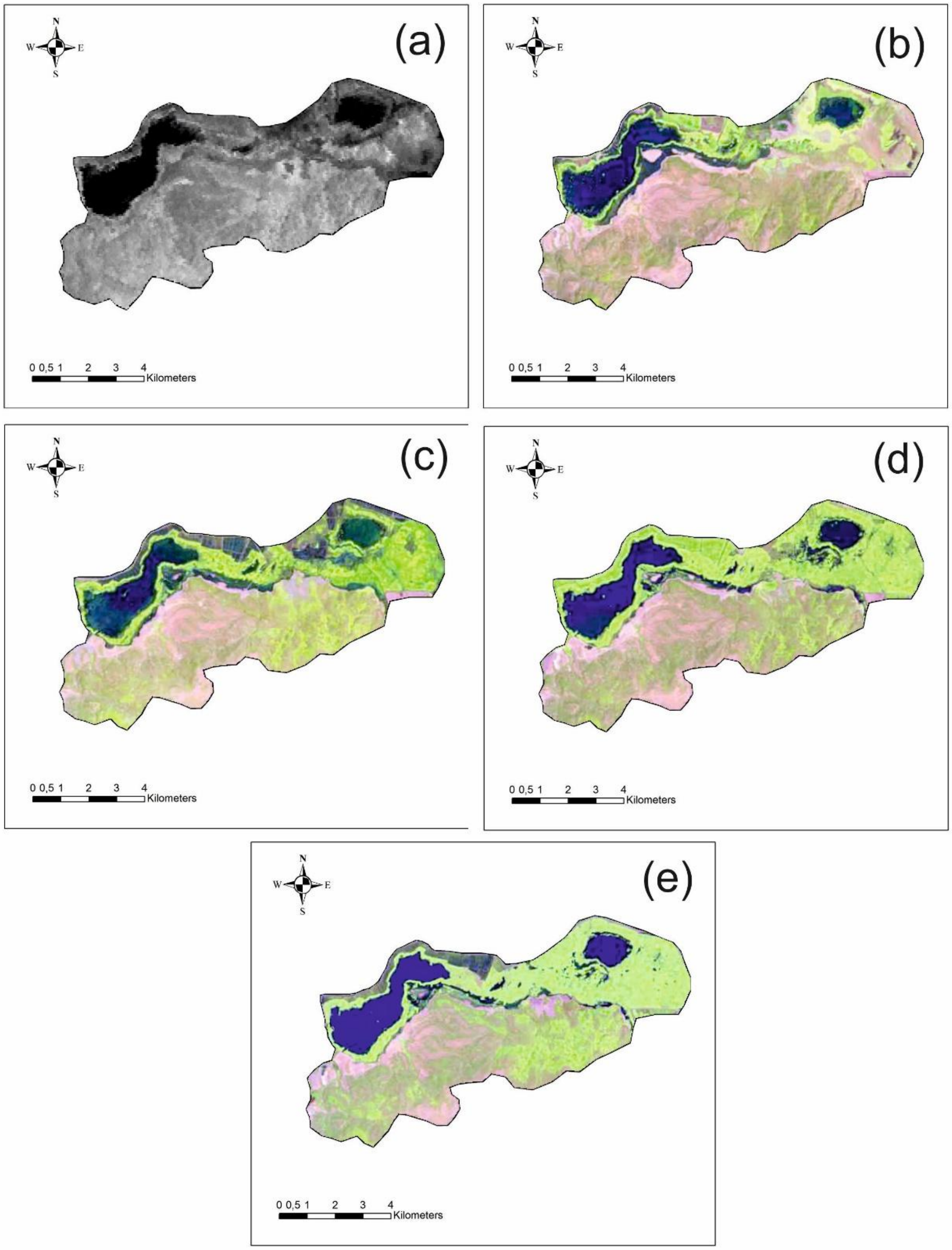

Figure 3. Satellite Images:

a) Landsat MSS (1977), b) Landsat TM (1987), c) Landsat ETM+ (2001), d) Landsat ETM+ (2007), e) Landsat ETM+ (2011) images

2.3. Hydrological, geological and hydrogeological data

For the analysis of the reasons of the coastline change in the study area, hydrological, geological and hydrogeological properties of the study area have also been investigated. The main components of the water balance in the study area can be stated as rainfall, recharge from streams and irrigation waters, recharge from groundwater, evaporation and discharge from lake foot. For the determination of rainfall and evaporation in the study area, data have been obtained from Turkish State Meteorological Service portal [22]. In the study area irrigation waters of paddy fields is conducted through May, June, July and August, as a result, returning irrigation waters to the main irrigation canal is assumed to be a component of recharge for both lakes. Unfortunately end of the main irrigation canal is equipped with a cover by State Hydraulic Works (SHW) and during irrigation season this cover is kept closed. For this reason, irrigation waters do not enter both lakes. Due to this, irrigation component for water balance is neglected. The flow of ephemeral streams recharging both lakes was stopped by construction of Sığırcı pond and Hamzadere dam in 1990 and 2000, respectively. As stated, due to nature of these streams, no flow observation stations were situated and later on these streams are being used as irrigation canals by the irrigation companies. Therefore, recharge from these streams could not be determined and since these recharges were stopped by SHW as mentioned above, this component of recharge is also not considered. The main discharge components in the study area are the evaporation and flow from foot of Gala Lake.

Geology of the study area is mainly composed of volcanic rocks and alluvium. Southeast of the study area is mountainous (Hisarlıdağ) with an elevation of 381m. Hisarlıdağ Mountain, which is composed of Oligocene aged volcanic rocks of andesite, tuff, basalt and ignimbrite (Th), is situated in the southeast of the lakes. Sandstone, limestone and claystone successions are observed at the western part of the study area and named as Çanakkale Formation (Teç) and alluvium deposited in Meriç delta with a thickness of 35-40m is consisted of gravels, sands and clay bands, comes over all units (Qa) [23] (Fig. 4). Due to the nature of clays in alluvium and volcanic rocks, recharge from groundwater does not play an important role in the study area. Lake foot of Gala is also covered with a valve equipped orifice and discharge from foot lake is controlled by SHW. Therefore, no natural flow is being observed. For this reason, this component for discharge is also not taken in account. As stated above, for the investigation of the reasons of the coastline change of both lakes, only rainfall and evaporation data trends of years between 1977 and 2011 are taken into consideration.

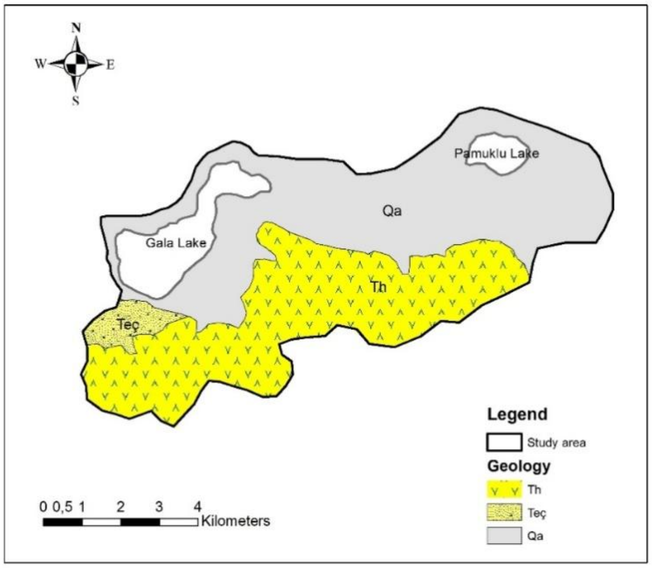

Figure 4. Geological Map of The Study Area [22]

2.4. Coastline detection

Different methods were used for the detection of coastline from optical imagery in literature. In reflective infrared bands, reflectance of water is nearly equal to zero and majority of other land covers have greater reflectance than water [24]. For this reason, coastline can even be extracted from a single band image. Using this method change in coastline could easily be detected. Usage of near infrared bands (NIR) are fairly proper to separate water bodies from other land covers, therefore, different combinations of NIR bands of these images are used to detect coastline changes. Images of the study area obtained from Landsat ETM+ , Landsat TM, Landsat MSS satellites (Fig.3) are exported to ArcMap software and coastline of the lakes is extracted in raster format. Later surface area of each lake for each image is calculated by area function in ArcMap.

3. RESULTS AND DISCUSSION

3.1. Rainfall (Precipitation)

Rainfall data for the study area is obtained from İpsala meteorological station. Annual average precipitation is determined as 244.82mm with a maximum of 368.7mm in 1994. According to annual precipitation versus cumulative deviation graph of the study area (Fig 5), between 1977 and 1983 a uniform period is observed, after 1983 a dry period prevailed up to 1994. Furthermore, from 1994 a rainy period continued till 2011.

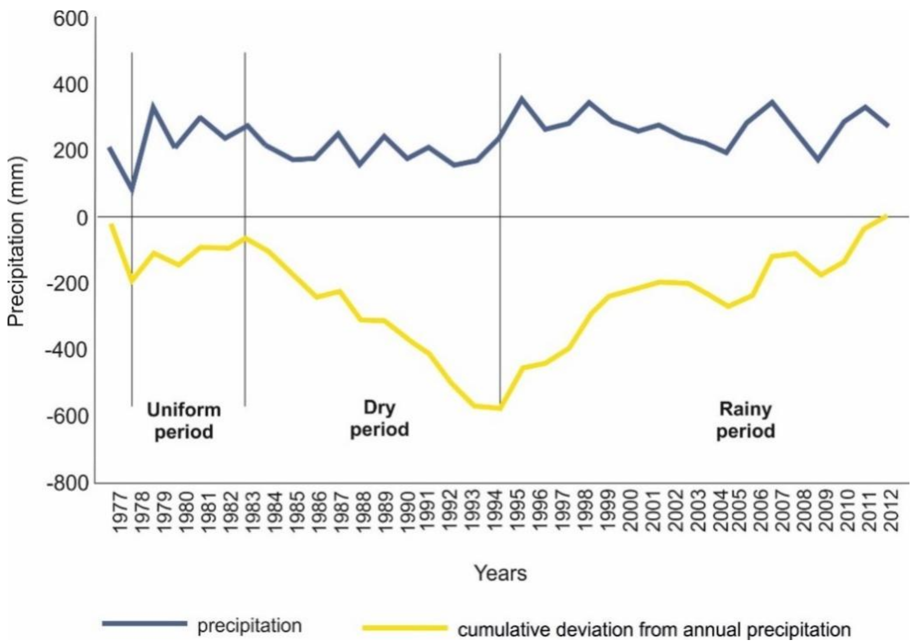

Figure 5. Annual Average Precipitation and Cumulative Deviation From Annual Precipitation Curves Between Years 1977-2011

3.2. Evaporation

Evaporation is the most important discharge component of the lakes while direct measurement of evaporation is not easy and needs more time and cost [25, 26]. Therefore, evapotranspiration (ETo) is usually estimated from meteorological parameters obtained from a near meteorological station. Different methods have been developed to estimate ETo [26-29]. Among this FAO Penman-Monteith method [29] is considered to be the most suitable model for the prediction of ETo.

The Penman-Monteith formula [29] for the estimation of ETo is given as follows;

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where ET_o is reference evapotranspiration (mm day^{-1}) Δ is the slope of vapor pressure versus temperature curve at temperature T_{mean} (KPa.°C^{-1}), γ is the psychrometric constant (KPa.°C^{-1}), u_2 is the wind speed at a 2 m height ($m.s^{-1}$), R_n is the net radiation at crop surface ($MJ.m^{-2}.d^{-1}$), G is the soil heat flux density ($MJ.m^{-2}.d^{-1}$), T is the mean daily air temperature at 2 m height (°C), and (e_s-e_a) is the saturation vapor pressure deficit (KPa C^{-1}).

Data obtained from İpsala meteorological station is used for the calculation of evaporation values due to its nearness (Table 2).

Table 2. Evaporation Data of Gala and Pamuklu Lakes (mm)

Years	January	February	March	April	May	June	July	August	September	October	November	December	Total
1977	10,1	12,9	20,1	25,9	47,2	94,4	129,0	130,3	78,4	42,2	18,0	14,0	622,5
1978	10,0	15,7	23,5	22,6	52,4	92,5	137,1	68,0	76,6	40,9	17,6	12,9	569,7
1979	10,7	15,7	23,9	24,1	53,0	106,1	124,7	71,2	80,8	49,4	18,3	13,7	591,7
1980	9,4	12,7	25,7	20,4	52,6	91,0	142,4	68,3	67,3	51,4	18,0	14,8	573,9
1981	9,3	13,2	25,2	25,9	53,7	98,4	124,3	69,1	74,6	49,4	20,4	14,4	578,0
1982	9,2	51,3	28,5	44,8	34,5	34,0	54,5	27,3	33,7	69,6	18,3	18,0	423,7
1983	14,9	21,4	13,0	12,5	26,8	66,2	160,5	26,6	121,5	57,9	43,8	15,5	580,5
1984	11,1	18,0	146,2	19,0	24,6	37,8	70,4	37,0	31,8	21,9	16,5	13,6	447,8
1985	14,7	20,3	23,4	11,0	21,4	42,3	52,6	26,4	33,7	27,3	51,9	12,5	337,5
1986	14,6	30,1	13,8	11,2	26,1	46,3	50,6	46,9	33,5	35,8	14,0	13,0	335,7
1987	10,0	9,6	24,5	19,1	26,4	83,2	54,0	36,7	33,0	43,0	30,6	163,4	533,5
1988	5,8	13,7	21,3	13,0	21,9	35,2	57,5	26,1	44,3	34,1	38,9	13,2	324,9
1989	4,7	14,0	34,3	16,7	25,7	52,6	58,3	140,2	42,4	78,5	14,1	30,7	512,2
1990	9,6	17,4	29,0	24,1	67,1	100,9	141,8	74,9	90,0	54,6	20,7	13,6	643,9
1991	9,5	15,2	22,9	24,3	48,1	102,2	137,1	68,8	81,4	63,3	17,4	12,1	602,3
1992	9,1	13,8	22,3	28,7	55,4	91,0	119,3	68,5	79,0	48,1	20,0	14,2	569,4
1993	9,3	12,7	21,7	19,6	48,1	86,3	119,3	77,0	79,3	50,0	19,0	13,7	556,1
1994	9,8	12,9	24,3	26,5	67,4	98,4	132,5	81,1	85,9	57,2	18,5	13,8	628,4

Table 2 continuing

1995	11,0	16,0	23,4	24,8	56,1	94,4	122,5	65,9	71,9	40,4	16,7	14,8	557,9
1996	8,0	14,8	19,1	26,2	61,2	100,5	138,6	74,3	71,1	42,8	17,8	15,1	589,5
1997	10,2	15,0	20,9	22,4	60,7	95,6	143,5	64,9	71,6	44,6	17,8	13,6	580,8
1998	8,6	13,4	18,5	23,2	48,7	95,2	138,1	87,5	74,3	48,7	19,2	14,9	590,3
1999	10,5	14,5	22,3	25,2	56,1	93,6	138,1	79,5	87,3	55,7	17,6	15,1	615,6
2000	9,3	14,3	26,1	26,4	53,3	105,2	168,9	79,8	83,6	46,0	20,8	15,5	649,1
2001	11,2	15,7	28,0	28,0	62,6	106,1	136,0	84,7	83,6	52,0	20,4	12,6	641,0
2002	10,5	15,9	25,0	24,2	60,4	101,7	138,6	77,9	74,6	44,1	17,6	13,6	604,3
2003	11,0	13,1	22,7	25,5	65,7	98,4	131,0	76,4	84,6	49,4	19,8	13,7	611,3
2004	10,4	16,2	24,3	24,1	50,2	87,3	132,5	71,5	79,6	48,3	19,9	16,5	580,8
2005	11,5	14,0	23,8	29,2	56,8	85,2	124,7	72,6	82,7	43,9	16,8	15,3	576,7
2006	9,3	14,1	23,2	25,6	61,8	97,2	130,5	77,9	82,7	44,4	16,3	12,9	595,9
2007	10,6	13,7	31,1	35,0	77,0	114,9	146,3	82,7	89,3	48,9	16,6	14,4	680,5
2008	8,4	17,3	23,5	27,0	57,1	106,5	130,0	77,9	82,4	42,5	21,7	16,7	611,0
2009	11,2	15,1	30,4	26,5	66,8	98,4	139,2	74,1	82,7	49,6	19,4	15,6	629,0
2010	12,0	17,3	24,8	25,0	62,9	98,8	124,3	79,5	89,3	40,4	19,5	17,8	611,6
2011	9,3	14,3	23,1	21,6	54,7	87,0	132,5	71,2	84,6	46,3	14,9	14,5	573,9

3.3. Coastline change of lakes

According to the maps produced from satellite imaginary, between 1977 and 1987 the surface area of Gala Lake increased from 5,196 km^2 to 5,336 km^2 with a ratio of 2,69% and the surface area of Pamuklu Lake increased from 1,341 km^2 to 1,352 km^2 with a ratio of 0,8% (Fig. 6 and Fig.7). During this period, evaporation of the lakes was calculated as 5594,4 mm and annual precipitation was measured as 2466,4 mm).

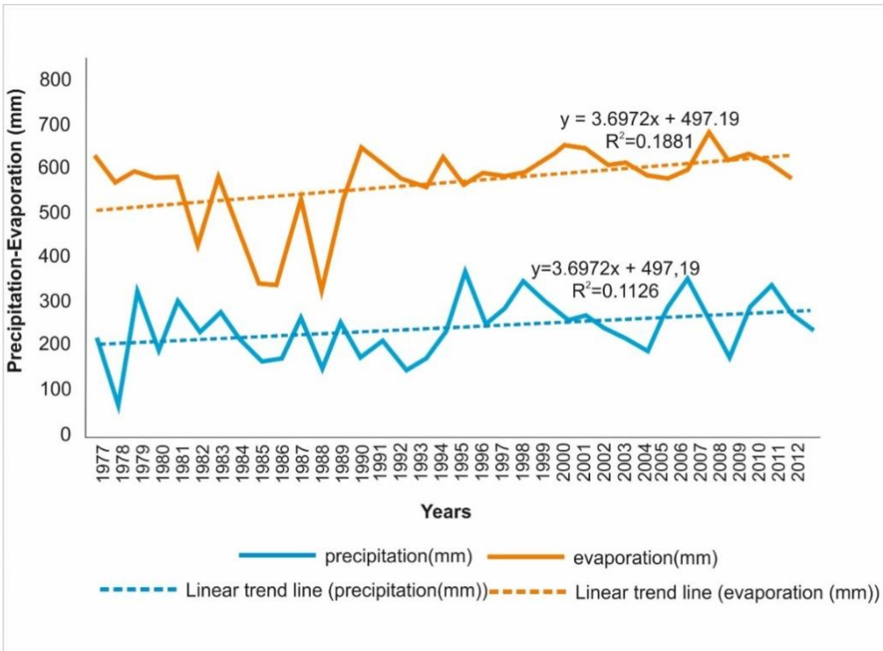

Figure 6. Precipitation and Evaporation Trends of the Study

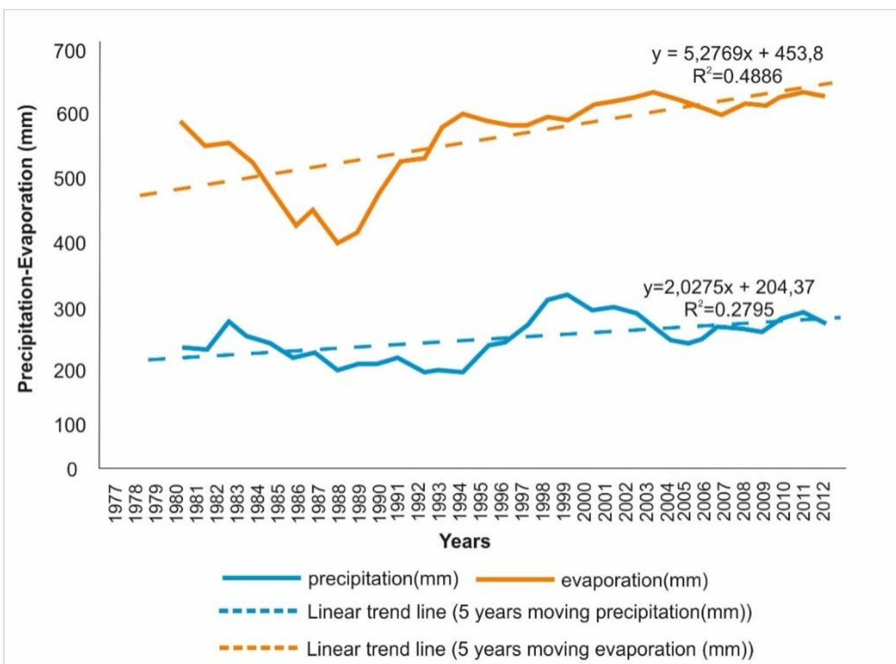

Figure 7. 5 Year Moving Trends of Evaporation and Precipitation

Between 1987 and 2001, the surface areas of the lakes decreased to 4,985 km^2 and 1,352 km^2 for Gala Lake and Pamuklu Lake, respectively, and evaporation calculated as 8061,2 mm and precipitation was measured as 3464,1 mm. According to the graph of annual cumulative precipitation (Fig. 5), between the years 1983 and 1994, a dry period of 11 years, from 1994 to 2001 a rainy period of 6 years was observed. Between 2001 and 2007, the surface area of both Gala Lake and Pamuklu Lake increased to 5,142 km^2 and 1,289 km^2, respectively (Table 3). This fluctuation of rainfall and high evaporation values could be the reason for the decrease in the surface areas of both lakes.

Table 3. Changes in Surface Areas of The Lakes in the Study Area

Time	Image	Gala Lake/km^2		Pamuklu Lake/km^2	
		Area	Change rate*	Area	Change rate*
1977	Landsat ETM+	5.196		1.341	
1987	Landsat ETM+	5.336	+ 2.7	1.352	+ 0.8
2001	Landsat ETM+	4.985	- 6.5	1.234	- 6.6
2007	Landsat TM	5.142	+ 3.1	1.289	+ 4.5
2011	Landsat MSS	5.147	+ 0.1	1.295	+ 0.4

* Average per year change rate from last image acquisition time.

Table 4. Changes of Evaporation and Precipitation Values of Both Lakes During Observation Periods

Period		Evaporation(mm)	Change rate	Precipitation(mm)	Change rate
1977-1987	10y	5594,4		2466,4	
1987-2001	14y	8061,2	+	3464,1	+
2001-2007	5y	3609,0	-	1827,2	-
2007-2011	4y	3701,8	+	1344,8	-

Between 2001 and 2007, evaporation was calculated as 3609 mm and precipitation was 1827,2 mm. and a rainy period was observed. Furthermore, this increase continued till 2011 for Gala Lake with a surface area of 5,147 km^2 and for Pamuklu Lake with a surface area of 1,295 km^2 and evaporation was 3701,8 mm and precipitation was 1344,8 mm. Changes of the surface area of the lake surfaces are given in Table 4. According to these results, no significant coastline change was observed for both lakes. Since 1977, both precipitation and evaporation values showed a trend of slight increase while 5 year moving average values of both precipitation and evaporation values also support that surface area change for both lakes was proportional with precipitation and evaporation values respectively (Fig 8 and Fig 9). It should be also noted that, as seen in figure 10, annual evaporation values had shown greater increase than precipitation values in the study area.

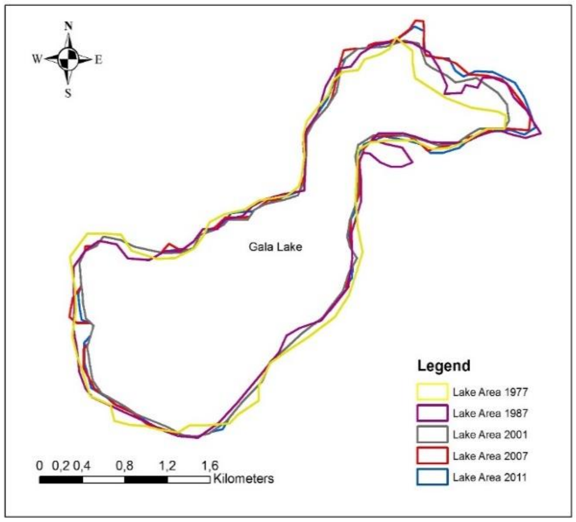

Figure 8. Coastline Change of Gala Lake Area

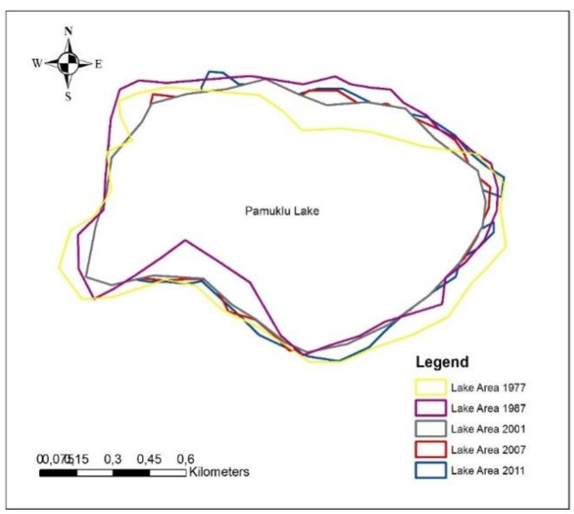

Figure 9. Coastline change of Pamuklu Lake

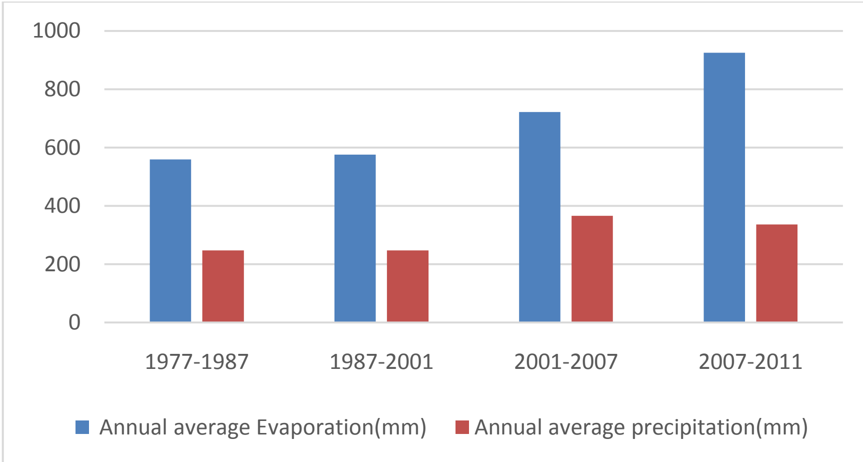

Figure 10. Annual Average Evaporation and Average Precipitation Changes in the Study Area

4. CONCLUSIONS

In different parts of the world, levels of water bodies tend to decrease. In order to resume the sustainability of water bodies, factors affecting them should be determined. Especially adverse impacts of anthropogenic activity can easily be removed after their determination. This study aims to determine the coastline change of Gala Lake and Pamuklu Lake of Gala Lake National Park and to discuss its reasons.

For this purpose, remote sensing techniques and multi temporal satellite images of Landsat ETM+, Landsat TM, Landsat MSS which were achieved in 1977, 1987, 2001, 2007 and 2011 have been investigated. After haze and cloud reduction of the images, ideal band for coastline detection is selected (Atmospheric correction). Eventually, the changes of coastline for both lakes from 1977 to 2011 are specified. These investigations are supported by hydrogeological, geological and hydrological data. For this purpose, precipitation data, as foremost important data of recharge, and evaporation data for discharge, are used. Additionally, the surface area changes of both lakes are also determined from shore lines. In the study area it has been observed that due to precautions taken by SHW for irrigation of the paddy fields the flow of the streams feeding the lakes and flow from lake foot had been interrupted. These components for recharge and discharge for water balance are neglected.

In 1977, the surface areas of Gala Lake and Pamuklu Lake were 5.196 km^2 and 1.341 km^2, respectively. In 2011, the areas of both lake surfaces were 5.147 km^2 and 1.295 km^2 during this period of time, the surface area of Gala Lake decreased %1 while the surface area of Pamuklu Lake decreased % 3.4. This decrease in surface areas was mainly caused by rainfall and evaporation and the dry period occurred during this time interval of the study. Studies revealed that coastline change of the lakes are mainly controlled by precipitation and evaporation. Water entry of stream waters and exit from lake foot is restricted to due to the work carried out for irrigation purposes. This resulted the precipitation as the only component of recharge and evaporation as discharge component. Consequently, both lakes have not been seriously affected from negative impacts of climate change reported by the Intergovernmental Panel on Climate Change in latest decade.

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