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Water Balance of the Eğirdir Lake and the Influence of Budget Components, Isparta,Turkey

Ayşen DAVRAZ*[1], Erhan ŞENER[2], Şehnaz ŞENER[1], Simge VAROL[3]
[1] Süleyman Demirel University, Department of Geology, 32260, Isparta, Turkey
[2]Süleyman Demirel University, Remote Sensing Centre, 32260, Isparta, Turkey
[3]Süleyman Demirel University, Water Institute, 32260, Isparta, Turkey

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Keywords
Eğirdir Lake,
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Lake water level
Rainfall

Abstract: Water budget of lakes must be determined regarding to their sustainable usage as for all water resources. One of the major problems in the management of lakes is the estimation of water budget components. The lack of regularly measured data is the biggest problem in calculation of hydrological balance of a lake. A lake water budget is computed by measuring or estimating all of the lake's water gains and losses and measuring the corresponding changes in the lake volume over the same time period. Eğirdir Lake is one of the most important freshwater lakes in Turkey and is the most important surface water resources in the region due to different usages. Recharge of the Eğirdir Lake is supplied from especially precipitation, surface and subsurface water inflow. The discharge components of the lake are evaporation and water intake for irrigation, drinking and energy purposes. The difference between recharge and discharge of the lake was calculated as 7.78 hm^3 for 1970-2010 period. According to rainfall, evaporation and the lake water level relations, rainfall is dominantly effective on the lake water level such as direct recharge to the lake and indirect recharge with groundwater flow.

Eğirdir Gölü'nün (Isparta, Türkiye) Su Bütçesi ve Bütçe Bileşenlerinin Bilançoya Etkisi

Anahtar Kelimeler
Eğirdir Gölü
Su bütçesi
Göl su seviyesi
Yağış miktarı

Özet: Bütün su kaynaklarında olduğu gibi sürdürülebilir kullanım için göllerinde su bütçelerinin belirlenmesi gerekir. Göl yönetiminde başlıca problemlerden biri su bütçesi elemanlarının tespitidir. Gölün hidrolojik dengesinin hesaplanması için en büyük problem düzenli ölçülmüş verilerin bulunmayışıdır. Bir gölün su bütçesi, ölçülmüş veya tespit edilmiş gölün su kayıp ve kazançlarının ile aynı zaman periyodu içinde göl hacmindeki değişimin kıyaslanarak hesaplanmasıdır.Eğirdir Gölü Türkiye'nin önemli tatlı su göllerinden biridir ve farklı amaçları için kullanımından dolayı bölgenin en önemli yüzey suyudur. Eğirdir gölünün beslenimi özellikle yağış, yüzey suyu ve yeraltısuyu akımı ile sağlanmaktadır. Gölün boşalım elemanları ise buharlaşma, sulama, içme suyu ve enerji amaçları için alınan sulardır. 1970-2010 periyodunda gölün beslenimi ile boşalımı arasındaki fark 7.78 hm^3 olarak hesaplanmıştır. Yağış, buharlaşma ve Eğirdir gölü su seviye ilişkilerine göre gölün su seviye değişimleri üzerinde yağış miktarının göl yüzeyine direkt beslenim ve yeraltısuyu akımı vasıtasıyla indirek beslenim şeklinde etkili olduğu tespit edilmiştir.

* *İlgili yazar: aysendavraz@sdu.edu.tr*

1. Introduction

The Eğirdir Lake is located within the Lake District at latitude 37º 50' 41"- 38º 16' 55" N, longitude 30° 57' 43"- 30º 44' 39" E in southwest Turkey (Fig. 1). The Eğirdir Lake having $4x10^9$ m^3 water volume is one of the most important fresh water lakes in Turkey and covers a lake area of 457 km^2. The Eğirdir Lake is a tectonic lake that lies in the north–south direction and be formed depends on rift tectonics (Koçyiğit 1983). The length of the lake is 50 km, the coastal length is 150 km, maximum width is 16 km, minimum width is 3 km, maximum depth of the lake is 13-14 m and average depth is between 8 and 9 m. The altitude of the lake is approximately 918.96 m above sea level. According to previous investigations, average precipitation has been determined as 602.82 mm for the lake and surface flow has been measured as 838.82 hm^3/year for 1966-1995. Evaporation from the lake surface has been determined by Karagüzel et al (1995) as 504.57 hm^3/year (1966-1994). Irrigation water withdrawals have been measured as 53.3 hm^3/year (1968-1994). The flow from an outlet canal was 310.33 hm^3/year between 1966-1994. Drinking water withdrawals from the lake average 41.5 hm^3/year. The annual fluctuation in lake surface level ranges from 30-50 cm and periodical changes can reach up to 3.84 meters. The Eğirdir Lake water is renewed approximately every four years based on the hydrological balance (Karagüzel et al., 1995).

The lake is an indispensable water source for our country and region because of using for different purposes such as irrigation, tourism, fishery and also the drinking water supplied to Isparta city and neighboring settlements. Therefore, current hydrologic conditions of the lake must be estimated for various sustainable uses.

A lake water budget is computed by estimating all parameters of the lake's water budget; such as gains and losses and determining the corresponding change in the lake volume over the same time period. Dynamic changes in water level are controlled by the balance between inputs and outputs of water, which are in turn controlled by different hydrological processes. Meanwhile, many hydrological processes are sensitive to changes in climate (Hayashi et al. 2007). Understanding these hydrologic processes is a fundamental key, for determining different parameters of the lake exists in the landscape where the water balance ensures an adequate water supply. Therefore a sustained lake functioning requires proper land use and water management (Bocanegra et al. 2013). The main purpose of the present study is to develop a preliminary hydrological model of the Eğirdir Lake. The water budget components of the lake were estimated and the parameters were compared with annual lake level variations during 1970 - 2010.

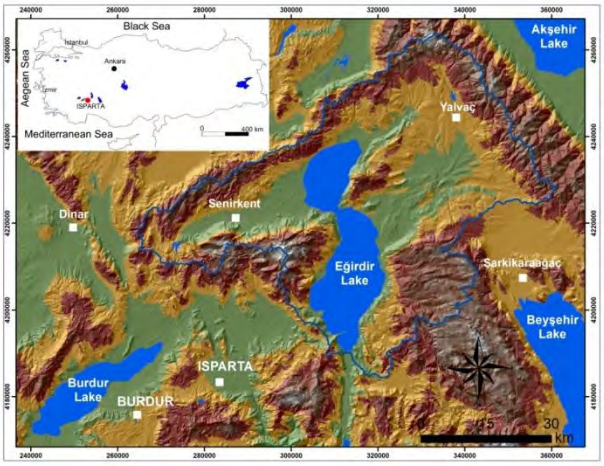

Figure 1. Location map

2. Methods

The water level data of Eğirdir Lake were provided from State Hydraulic Works (SHW) for 1962-2010 periods. A Bathymetry map of the lake (SHW), were used in determining the changes of surface area and water volume of the lake. Rainfall measurements of the researched basin were provided from State Meteorological Service (SMS). Average annual rainfall of the lake basin is calculated by using Isohyet method. Evaporation and irrigation water intake data were provided from SMS. Drinking water intake measures were also provided from SHW and Isparta municipality. Recharge – discharge balance of the lake is determined considering the difference between the sum of all water inputs and the sum of all water outputs from the lake.

3. Results

3.1. Changes of level, area and volume in the Eğirdir lake

The lake level measurements have been performed by SHW. The lake level is balanced at 918.19-918.84 m between the years of 1962-1969. Then the lake level dropped to 915.74 m in 1975. The lake water level risen from 1975 to 1985 and max. level measured as 918.41 m. The water level was decreased from 1985 to 1995 and the level is 916.12 m. A rise observed since 1995 and the lake level was measured at 917.76 in 2000. The lake water level decreased 916.70 m, however, it again risen 918.19 m in 2005. The continuous decreases was observed since 2005. The lake level is 916.21 m at November 2009 (Fig. 2).

The area and volume of the lake graphs were prepared for 1962-2009 (Fig. 2). While the lake surface area is 480.54 km^2 and the lake volume 3724.51 hm^3 in 1962, they is decreased to 447.73 $km^2$and 2585.47 hm^3 in 1975, respectively. The area

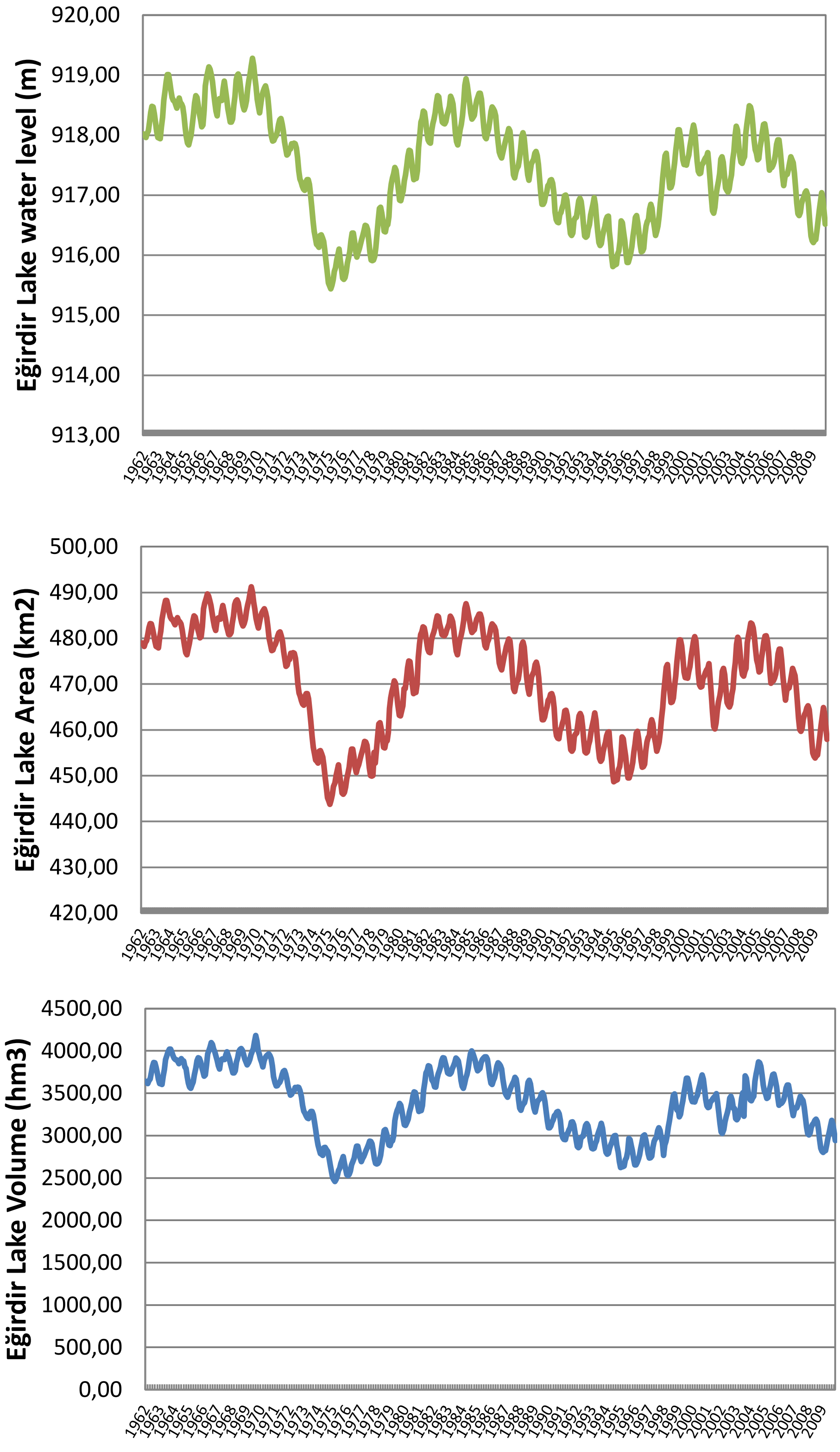

Figure 2. The Eğirdir lake water level, area and volume graphs

and volume data risen between the years of 1975-1985, and decreased between 1985-1995. In 2000, the lake area and volume again risen to 475.215 km^2 and 3525.31 hm^3, respectively (Fig. 2).

3.2. Recharge of the lake

The Eğirdir Lake is recharged by rainfall, surface flow, springs and groundwater inflow. Annual average rainfall data which have been measured at the State Meteorological Services in the Eğirdir lake basin and its vicinity area were used for calculating average rainfall. The annual precipitation maps were prepared in order to determine of recharge volume from precipitation (Fig. 3 and Fig. 4). The mean rainfall for the catchment area and the surface area of the Eğirdir Lake are calculated as 558.66 mm and 593.88 mm, respectively. Direct recharge from precipitation at the surface area of the lake is calculated with multiplying average rainfall value and surface area corresponding to water level. The amount of direct recharge from precipitation at the lake for the period 1970-2010 is 272.84 hm^3/year. The recharge amount from precipitation at the Eğirdir lake catchment area (3417.04 km^2) is calculated as 1908.96 hm^3/year.

The cumulative deviation curve from annual precipitation as plotted by using the mean annual rainfall data from the meteorological stations (Eğirdir, Uluborlu, Yalvaç) at the Eğirdir lake catchment area (Fig. 5). The water level variations of the lake (1970-2010) were investigated using monthly time steps. The Eğirdir lake water levels and cumulative deviation from annual precipitation curves of Eğirdir, Uluborlu and Yalvaç SMS were compared. Generally, precipitation curves and water level data of the lake are harmonic (Fig. 5). According to precipitation data, the dry periods were observed between 1981 and 1994. During these period, although the discharge components of the lake did not changed (stable) , the water level of the lake decreased approximately 2 m (Fig. 5). It is shown that recharge from precipitation has great influence on the changes of the lake water levels.

Another recharge component of the Eğirdir lake is the surface flows. Eğirdir lake is recharged with Pupa, Hoyran, Yalvaç (Gelendost) and Çay streams (Karagüzel et al., 1995; Davraz et al., 2012). There are deficiencies in the flow data of these streams due to closed of the current stations from time to time. The deficiency of data is completed by using correlation and simple regression analyses methods. These methods were carried out considering the measured flow data and average rainfall of the lake catchment area. The annual average flow from the streams to Eğirdir Lake is calculated as 127.87 hm^3.

In addition, the most important springs recharging to the lake are Kanlıpalamut and Kayaağzı springs in the west of the lake, Karaot Avlağı and Havutlu springs in the south of the lake and karstic discharges in the east of Eğirdir lake (Atay and Bulut, 2005; Şener and Soyaslan, 2006; Şener, 2010; Davraz et al., 2012). Unfortunately, there aren't regular flow measurements of these springs. According to hydrogeological investigations, the Eğirdir lake catchment area had researched as three groundwater sub-basins (Soyaslan 2004; Seyman 2005; Tay 2005). Senirkent-Uluborlu basin is located in the west of the lake, Yalvaç-Gelendost basin is located in the east of the lake, and Hoyran basin is also located in the northeast of the lake. The Quaternary alluvium and the Mesozoic carbonate rocks are classified as aquifer units in the Eğirdir lake basin. Alluvium is the most important aquifer due to the porous structures and it covers an area of 525 km^2 in the basin (Şener et al., 2013). The groundwater depth is 3–36 m in the Senirkent-Uluborlu basin, 0.15–51.2 m in the Yalvaç-Gelendost basin, and 2.6–38.7 m in the Hoyran basin. The groundwater flow direction of the alluvium aquifer is toward the Eğirdir Lake in the lake catchment basin (Soyaslan, 2004; Seyman, 2005; Şener and Soyaslan, 2006; Davraz et al, 2009; Şener, 2010; Şener et al., 2013). Limestone and dolomites which have aquifer properties have high permeability due to the presence of fractures and karstic holes. In the east of the lake, the amount of groundwater discharge to the Eğirdir lake by means of the karstic aquifer was determined as 114 hm^3/year using the MODFLOW model (Soyaslan 2004). In addition, the groundwater flow from porous and karstic units is determined as 37.8 hm^3/year in the Senirkent-Uluborlu basin (Seyman, 2005).

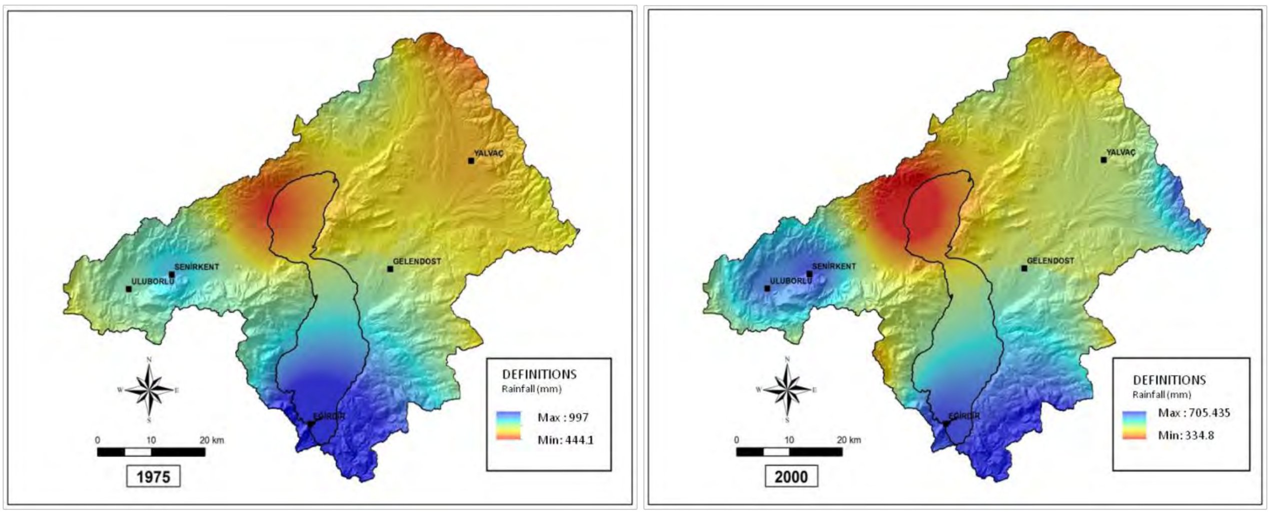

Figure 3. Annually average precipitation map of the Eğirdir Lake catchment area for 1975 and 2000 years

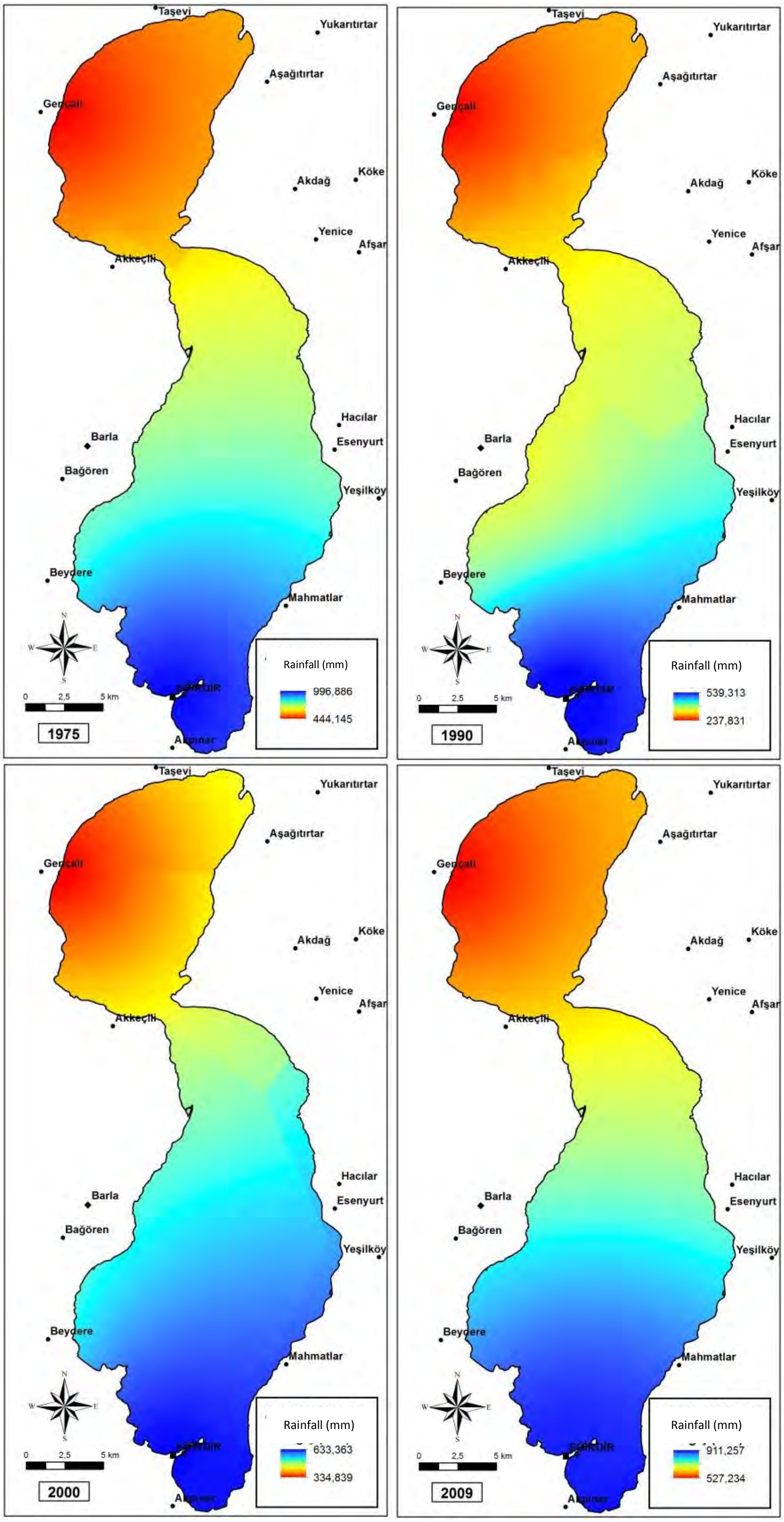

Figure 4. The average annually rainfall map of the lake surface area for 1975, 1990, 2000, 2009 years

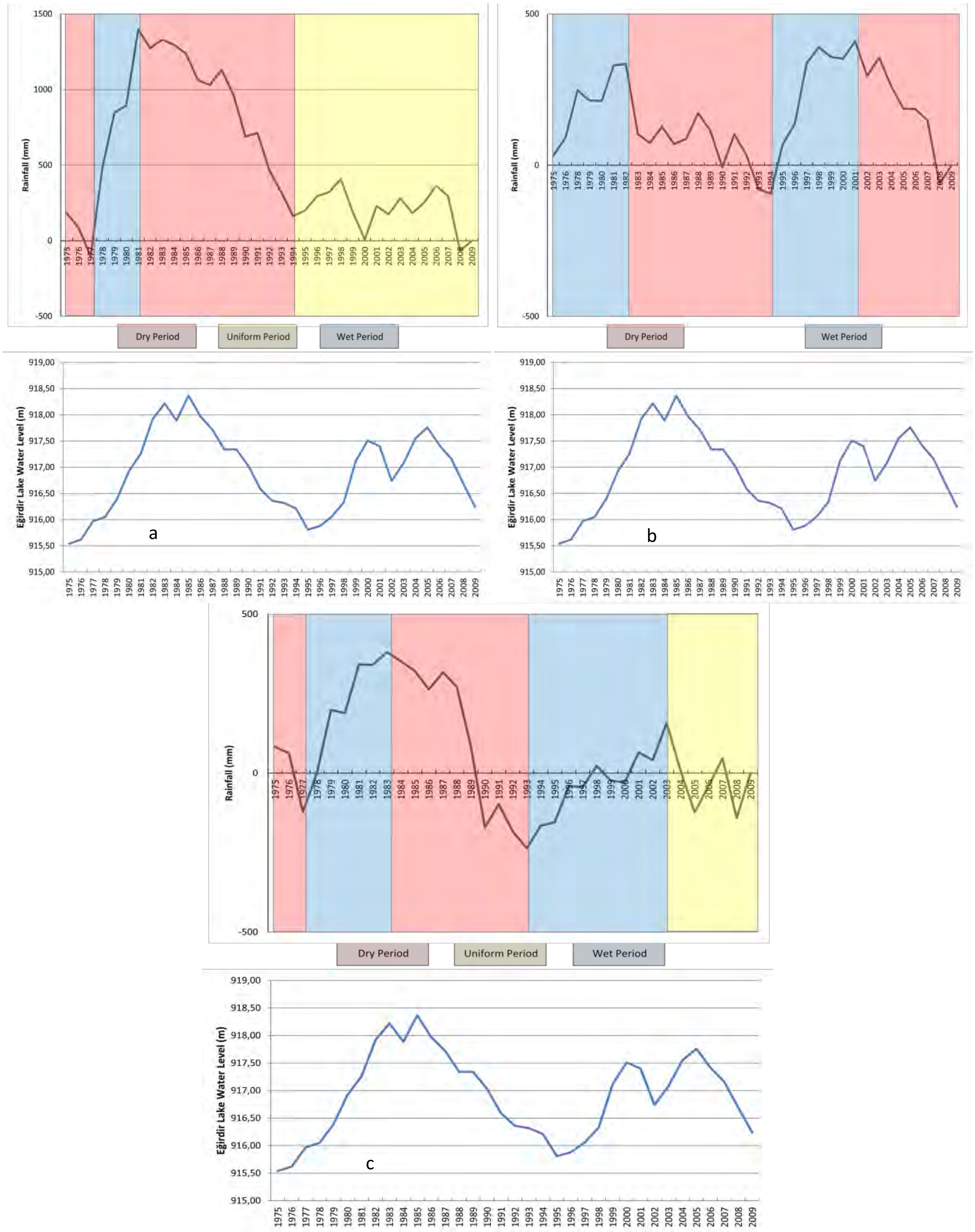

Figure 5. The cumulative deviation curves and lake level variations, a:Eğirdir SMS, b:Uluborlu SMS, c:Yalvaç SMS

3.3. Discharge of the lake

Evaporation is the most important water loss. In the research area, evaporation which are measured on the basis of United States Class A pan values are used. Evaporation pan values measured for 7 months except for December, January and February. The absent evaporation data were completed with calculated values using Penman–Monteith method in the near meteorological station. Nowadays, Penman–Monteith method is accepted as the most widespread and the most valid method due to calculation with energy balance approach taking into consideration whole meteorological factors (Allen et al. 1998). The

Eğirdir meteorological station data was used for evaporation calculations in this method due to its location close to the lake. According to Class A pan values, the annual average evaporation is 1459.93 mm for 1970-2010 period. The average evaporation amount from the lake surface area is determined as 484.7 hm^3. While the amount of evaporation from the lake partially increased between 1962 and 1974, it decreased as 560 mm from 1974 until 2008 (Fig. 6). When lake level, rainfall and evaporation data are together evaluated, it is shown that evaporation is not as effective as rainfall for variation of the lake water level (Table 1).

The other discharge components of the lake are water abstractions for the irrigation, drinking and energy purposes and sinkholes. Water which is taken from the lake to produce energy is given Kovada-1 and Kovada-2 hydro-electric power plants. This amount is 159.14 hm^3 for 1970-2000 period (SHW 2002). Taking water from the Eğirdir lake for energy production is stopped from 2000 year (SHW 2002). Only, the Eğirdir lake water is given as approximately 2-4 m^3/s to Kovada canal in summer months. The amount of irrigation water which is taken from the lake is 4.83 hm^3 in 1971. This value is increased as 183.76 hm^3 in 2000 year. The annual average water amount used for irrigation is 111.27 hm^3 in 1970-2010 period.

In addition, the lake water has been used for drinking water supply of Isparta city since 1995. But, the amount of intake water is decreased in the recent years. For drinking water of Isparta, water is taken from the lake average about 8.5 hm^3 in 1995-2010 period. One of the factors that cause water loss in the lake is sinkholes which are developed within Mesozoic limestone in the west-coast of the lake. These sinkholes are covered in the 1970s by SHW.

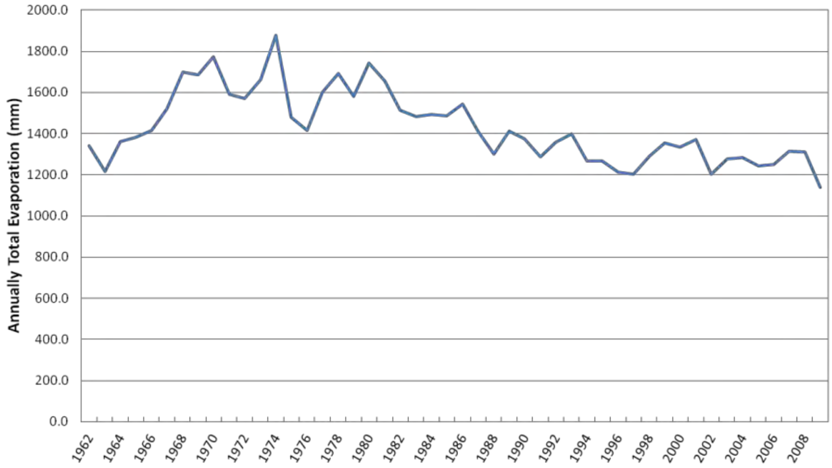

Figure 6. The amount of evaporation from the lake surface area between 1962-2008

Table 1. Water level of the Eğirdir Lake, precipitation periods and evaporation

State	**Years**	**Water Level (m)**	**Precipitation periods in the basin**	**Average evaporation from the lake (mm)**
Stable	1962-1969	918.19 - 918.84	Uniform	1452.4
Decline	1969-1975	915.74	Dry	1939.6
	1985-1995	916.12	Dry	1373.5
	2000-2002	916.70	Dry	1302.9
	2005-2009	916.21	Uniform	1251.4
Rising	1975-1985	918.41	Rainy	1558.2
	1995-2000	917.76	Rainy	1277.6
	2002-2005	918.19	Uniform	1251.9

3.4. Recharge-discharge balance of the Eğirdir lake

All water balance equations are based on the premise that the difference between water inflow and water outflow over a given time period for the hydrologic system of a lake must equal the change in water storage in that system (Kebede et al. 2006, Hayashi et al. 2007). Using the hydrological parameters of the Eğirdir lake, water balance were calculated for separately each year between 1970 and 2010 years (Table 2). Sum of recharge data from precipitation, flows of streams represents the measurable and calculable recharge amounts from the lake. Sum of data abstraction data of drinking, irrigation, energy and evaporation from the lake water surface represents the measurable and calculable discharge amounts from the lake.

Taking into consideration of the hydrogeological properties of the Eğirdir lake catchment area, the presence of groundwater inflow into the lake is determined. The groundwater into the lake comes from the immediate vicinity of the lake through discharge from the alluvium aquifer and limestone in the catchments area. The groundwater inflow into the lake was determined as 151.8 hm^3/year Yalvaç-Gelendost and Senirkent-Uluborlu basins (Soyaslan, 2004; Seyman, 2005). Groundwater discharge to a lake is one of the most difficult components of the water balance to measure. In the case of lake systems, determinations may also be limited by very low hydraulic gradients, which could be difficult to measure accurately. On the other hand, water balance methods that measure other components of the water balance and calculate groundwater inflow by difference are limited by the errors in the other water balance components, which may be larger than the groundwater inflow term (Cook et al. 2008). In this study, groundwater inflow was calculated by subtracting annual measured volume difference from annual total discharge by taking into account of other considered recharge components (Table 2). The unmeasured average recharge from groundwater was calculated as 355.12 hm^3. Unmeasured groundwater inflow represents 18% of the annual mean rainfall falling to the Eğirdir Lake catchment area.

Table 2. Annual Eğirdir Lake water budget components (units in hm^3)

Years	Rainfall	Surface Flow	Evaporati on	Irrigation	Energy	Drinking	Total discharge	Measured volume difference	Total recharge	Unmeasurable recharge
1970	210.98	94.62	626.35	4.83	1146.4	0	2396.22	-294.76	2101.46	1795.86
1971	263.67	11840	556.79	4.83	508.8	0	1183.74	-93.66	1090.08	708.01
1972	202.51	100.90	508.40	6.09	463.8	0	978.29	-238.84	739.45	436.04
1973	189.57	43.90	551.07	6.51	453.6	0	1011.18	-397.15	614.03	380.56
1974	232.45	53.56	643.41	9.06	443.5	0	1095.97	-390.47	705.50	419.49
1975	336.19	102.80	547.12	9.00	208.02	0	764.14	36.33	800.47	361.48
1976	271.33	108.56	514.61	17.41	130.46	0	662.48	158.91	821.39	441.50
1977	210.16	117.76	555.57	32.93	106.97	0	695.47	-22.7	672.77	344.85
1978	394.15	195.52	562.57	37.57	166.68	0	766.82	213.39	980.21	390.54
1979	376.16	150.25	548.07	45.92	174.89	0	768.88	240.64	1009.52	483.12
1980	278.34	177.51	562.20	58.74	231.2	0	852.14	156.37	1008.51	552.66
1981	381.47	159.71	556.79	67.64	221.7	0	847.15	309.08	1156.23	615.05
1982	258.81	109.89	474.49	78.44	224.4	0	837.46	141.41	978.87	610.17
1983	314.13	132.63	502.22	76.64	351.6	0	930.46	-155.46	775.00	328.24
1984	250.81	193.43	499.64	81.14	282.7	0	1010.10	227.09	1237.19	792.95
1985	274.86	91.03	52983	86.5	307.2	0	923.53	-189.62	733.91	368.02
1986	213.27	86.42	516.74	68.63	216.9	0	802.27	-117.08	685.19	385.51
1987	284.12	88.38	494.65	103.61	230.1	0	828.36	-177.95	650.41	277.92
1988	288.83	123.06	462.40	112.76	158.1	0	733.26	0	733.26	321.38
1989	213.80	68.74	506.08	136.55	141.5	0	784.13	-217.8	566.33	283.80
1990	173.06	80.64	470.19	113.83	87.2	0	671.22	-110.58	560.63	306.92
1991	293.54	114.17	434.03	117.02	22.4	0	573.45	-91.83	481.62	73.91
1992	204.57	107.60	469.23	122.95	23.17	0	615.35	-22.92	592.43	280.26
1993	209.96	109.36	467.66	134.02	21.76	0	634.70	-54.91	579.79	260.48
1994	264.56	111.14	424.75	159.97	25.29	0	614.04	-173.129	440.92	65.21
1995	298.40	113.14	425.81	158.86	18.09	5	607.76	27.25	635.01	223.47
1996	306.34	114.31	420.23	155.2	22.75	5.5	603.68	91.068	694.75	274.10
1997	303.21	123.01	405.64	139.85	39.69	6.0	591.18	105.15	696.33	270.12
1998	310.93	311.18	450.95	152.7	23.35	6.5	633.50	354.826	988.32	366.22
1999	264.55	225.70	513.56	166.18	39.07	6.8	725.61	204.8	930.41	440.16
2000	242.32	153.42	470.06	173.49	33.29	7.0	683.84	-56.013	627.83	232.09
2001	331.68	60.31	501.57	236.41	0	7.5	745.49	-301.385	444.10	52.11
2002	280.12	174.39	395.22	191.99	0	7.77	594.98	152.596	747.58	293.07
2003	331.06	242.18	421.48	199.83	0	9.46	630.77	-72.118	558.65	-14.58
2004	249.12	176.96	430.68	199.68	0	8.32	638.68	108.79	747.47	321.38
2005	272.74	81.45	413.79	200.31	0	8.49	622.60	-136.93	485.67	131.48
2006	354.80	86.92	409.79	201.12	0	10.48	621.39	-150.08	471.31	29.59
2007	263.59	85.45	430.34	167.50	0	11.06	608.90	-207.09	401.81	52.77
2008	179.19	57.56	417.81	167.50	0	11.43	596.74	-209.93	386.81	150.06
2009	334.17	184.74	365.93	175.34	0	12.26	553.53	95.76	649.29	130.38
2010	272.84	211.81	415.10	183.76	0	12.76	611.62	196.505	808.12	323.47

4. Discussion and Conclusion

In this study, conceptual water balance model of the Eğirdir Lake was developed taking into consideration hydrological model of the Eğirdir Lake. The general lake water balance equation is (Hayashi et al. 2007):

$$Q_{in} - Q_{out} = A(dh/dt) \quad (1)$$

where Q_{in} is the sum of all water inputs, Q_{out} is the sum of all outputs, A is the surface area of the lake, and dh/dt is the rate of water-level (h) change. Recharge of the Eğirdir Lake is supplied from especially precipitation, surface and subsurface water inflow. The discharge components of the lake are evaporation and water abstracted for the purposes of irrigation, drinking and energy (Fig. 7). The above equation was detailed according to hydrological model of the Eğirdir Lake as follows.

$$P_{cp} + I_s + I_g - E - I_i - I_d - I_e = C_v \quad (2)$$

where P_{cp} is recharge from precipitation, I_s is recharge from surface flow, I_g is unmeasured recharge from groundwater, E is evaporation from lake, I_i is water intake for irrigation, I_d is water intake for drinking, I_e is water intake for energy, C_v is changes volume of the lake. The difference between recharge of the lake and discharge of the lake is calculated as 7.78 hm^3 for 1970-2010 period (Table 3). The source of the difference in the budget can be attributed to the lack of direct measurement of accurate evaporation rate or the fact that we assumed net groundwater flux and inflow from the un-gauged catchment to be negligible.

The water level in a lake is controlled by the balance between input and output. Precipitation and groundwater flow are the most important recharge parameters and evaporation is the most important discharge parameter in the Eğirdir lake water level change. Changing of rainfall is fairly suitable with the lake water level, but, changing of evaporation isn't as effective as rainfall on the lake water level. However, human activities affected the lake water level change. For sustainable usage of a lake, hydrological properties of the lake should be taking into consideration. The lake level model by the graphical approach can be used as a simple tool to check of sustainable usage of a lake.

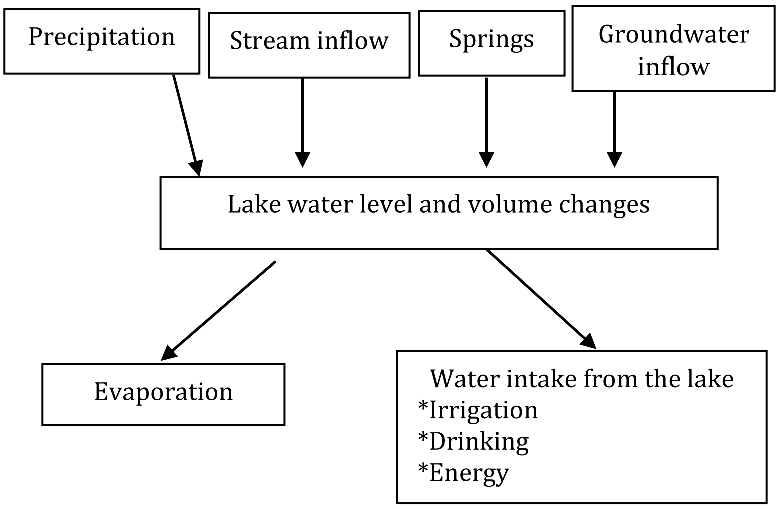

Figure 7. Conceptual diagram of water balance method of the Eğirdir Lake

Table 3. The hydrology data of the Eğirdir Lake (1970-2010)

Recharge Components	**hm^3**	**Discharge Components**	**hm^3**
Recharge from precipitation	272.84	Evaporation from lake	484.70
Recharge from surface flow	127.87	Water intake for irrigation	111.27
Measured recharge from groundwater flow	151.8	Water intake for energy	159.14
Unmeasured recharge from groundwater and spring	203.32	Water intake for drinking	8.5
TOTAL	**755.83**	**TOTAL**	**763.61**

Acknowledgments

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