Assessing the impact of climate change on the hydroperiod of two Natura 2000 sites in Northern Greece

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Abstract

PURPOSE: Greece is included among the most vulnerable regions of Europe on account of higher temperatures and reduced rainfalls in areas already facing water scarcity. With respect to wetland systems, many ephemeral ones are expected to disappear and several permanent ones to shrink due to climate change. As regards two specific wetlands of Greece, the change in hydroperiod of Cheimaditida and Kerkini Lakes due to climate change was studied.

METHODS: Lakes' water balance was simulated using historical climate data and the Emissions Scenarios A1B for the period 2020-2050 and A1B and A2 for the period 2070-2100. Emissions Scenarios data were provided in the context of the study of Climate Change Impacts Study Committee.

RESULTS: The surface area of Lake Cheimaditida will undergo a substantial decrease, initially by 20% during the period 2020-50 and later until 37% during the period 2070-2100. In Lake Kerkini, the surface area will decrease, initially by 5% during the period 2020-2050 and later until 14% during the period 2070-2100.

CONCLUSIONS: Climate change is anticipated to impact the hydroperiod of the two wetlands and the sustainable water management is essential to prevent the wetland's biodiversity loss.

Keywords

Climate change, wetlands, hydroperiod, hydrological modelling

1. Introduction

Climate change will exert an influence upon wetlands, and especially for freshwater wetlands, the most pronounced impacts will be associated with modifications to hydrological regimes [1]. These impacts will outcome from decreased rainfall and higher evaporation (due to warmer temperature) as well as the combined impact of these changes upon the runoff of wetlands' catchment. Wetland systems are vulnerable and particularly susceptible to changes in quantity and quality of water supply, and even small hydrological changes can lead to major changes in plant communities and habitat for animals [2]. To assess the changes and the impacts due to climate change in a wetland, a combination of climatic, hydrological and biodiversity models may be applied. The combined modelling framework, in conjunction with wetland monitoring, would lead to a series of measures for the mitigation of the impacts due to climate change.

Several researchers have discussed the potential impacts of climate change on wetlands [2-4]. Acreman et al [2] provided examples of case studies for wetland restoration and focused on the need for sound hydrological science. Erwin [3] discussed the role of wetland restoration in the light of climate change and provided recommendations for wetland conservation. Other researchers have addressed the assessment of climate change impacts on wetlands [5-7, 1]. Harrison et al. [5] adopted a meta-modelling approach to link hydrological simulations of low and high water flows with biodiversity simulations of suitable climate space for a selection of fen and bog, in order to examine the impacts of socio-economic and climate change scenarios on two wetlands in UK. Acreman et al. [6] discuss a generic, quantitative, method for assessing the likely impacts of climate change on wetlands at a regional scale. Thompson et al. [1] simulated the hydrological impacts of climate change upon the Elmley Marshes using a coupled hydrological/hydraulic model developed using MIKE SHE/MIKE 11. Zhang et al. [7] examined the uncertainties of climate change impacts on the hydrology of a small prairie wetland by developing downscaled climate scenarios and conducting distributed hydrological modelling.

In this paper, two wetlands in Greece – Lake Cheimaditida and Lake Kerkini – were studied on the potential impact of climate change on their hydroperiod. In particular, their water balance was simulated using historical climate data and future data resulted from the Emissions Scenarios A1B for the period 2020-2050 and A1B and A2 for the period 2070-2100. The simulation of water balance was based on the assessment of water inputs and outputs in the lakes using monthly time step while catchment runoff into the lakes was assessed by a rainfall-runoff model. Future climatic data were produced in the context of the study of Climate Change Impacts Study Committee [8].

2. Methodology

The hydrological simulation of the lakes has been performed using MIKE BASIN, which is a GIS tool developed by DHI and can be used for water resources management and planning at catchment scale. In MIKE BASIN environment, the rivers and lakes/reservoirs are represented by a network model of branches and nodes while the water users are represented as nodes that extract water from rivers, lakes/reservoirs and catchments [9]. The model output time-series of flows at all nodes, providing information on the performance of each lake/reservoir and water user node.

As a first step, the rainfall-runoff models of the lakes' catchments were set up to estimate the water inflow into the lakes. Afterwards, the water balance of the lakes was simulated using as input data the rainfall-runoff model results and the other parameters of water balance. The calibration of the hydrological models was based on observed time series of water level of the lakes [10, 11].

Rainfall-Runoff modeling in MIKE BASIN has been undertaken using its NAM module. NAM module was originally developed at the Technical University of Denmark [12] and has been modified and applied extensively by the DHI [9, 13]. The NAM module represents various components of the rainfall-runoff process by continuously accounting for the water content in different and mutually interrelated storages, each one representing different physical elements of the catchment. It is a deterministic, lumped, conceptual model with moderate input data requirements and is based on theoretical and semi-empirical equations. Precipitation and potential evapotranspiration are used as driving forces in the simulation of interception, actual evapotranspiration, overland flow, interflow, groundwater recharge and baseflow. The model parameters are average values for the entire catchment and represent surface-root zone storages as well as groundwater storage (Table 1). The NAM module was applied to the catchments of the lakes to estimate the total runoff – as the sum of overland flow, interflow and baseflow – that enters into the lakes for the corresponding drainage area.

Table 1. The NAM module parameters for Lake Cheimaditida and Lake Kerkini catchments

Parameters	Description and bandwidth	Cheimaditida	Kerkini
Umax (mm)	Max. water content in surface storage	15	15
Lmax (mm)	Max. water content in root zone storage	120	100
CQOF (-)	Oveland flow runoff coefficient	0.6	0.15
CKIF (hour)	Time constant for routing interflow	700	850
CK1,2 (hour)	Time constant for routing overland flow	20	25
TOF (-)	Threshold value for overland flow	0	0.4
TIF (-)	Threshold value for interflow	0	0.5
TG (-)	Threshold value for groundwater recharge	0	0.3
CKBF (hour)	Time constant for routing baseflow	2500	2200

The simulation of the lakes' water balance was based on the simple algebraic equation that takes into account the water inputs and outputs of a lake for each time step:

$$S\,(i+1) = S(i) + Qin + P - E - I - Qusers - Qout \tag{1}$$

where S is the volume of water stored in the lake in time i and i+1, Qin is the catchment runoff into the lake, P is precipitation and E is evaporation from the lake's surface, I is the infiltration from the lake's bottom, Qusers is the water outflow to water users and Qout is the downstream water outflow. The simulation time step is monthly and the equations' terms are expressed in m^3. Precipitation, evaporation and infiltration are converted from mm to m^3 by taking into account the hypsometric curves of the lake (elevation-area, elevation-volume curves) of the lake.

It has to be mentioned that the influence of groundwater table depth in the water balance of the above lakes is not taken into account in this analysis because the major components of the water balance are the catchment's runoff, the lakes' precipitation/evaporation and the outflow of surface water.

3. Case study

3.1 Description of the study area

Lake Cheimaditida covers an area of 10 km^2 at its maximum water level (592 m a.m.s.l.). Its wider catchment (228 km^2) includes Lake Zazari, River Sklithros and other small torrents that drain the mountainous areas (Fig.1). River Sklithros constitutes the main source of surface water for lakes Zazari and Cheimaditida. Lake Zazari is located 2 km Northwest of Lake Cheimaditida and covers an area of 1.9 km^2 at its maximum water level (599.5 m a.m.s.l.), above which it overspills through a weir and a joining canal into the Lake Cheimaditida. The maximum water level of the later was 591.3 m since August 2009. Then a dyke was constructed at its northern shore to allow the increase of its mean depth and to protect the adjacent agricultural land from floods. Overspill from Cheimaditida (above 592 m a.m.s.l.) is partially stored for irrigation purposes in the main drainage canal just downstream the lake and the rest outflows to Lake Petron.

The economy in the catchment is mainly based on crop and livestock farming. The income from fishing is low. Agricultural land (about 2,200 ha) is shared among the farmers of the adjacent villages. It is extended mainly northeast to Cheimaditida and occupies the soils revealed after the lake's partial drainage. An area of 200 ha is cultivated almost every year by wheat (dry farming) while the remaining mainly by alfalfa, maize and sugar beets. The irrigation needs are covered by surface water coming from the lakes and groundwater (Table 2).

Table 2. Irrigated area and water source in Cheimaditida catchment

Water Source	Irrigated Area, ha	Irrigation Water Management
Lake Zazari	450	2 Collective irrigation schemes
Lake Zazari	50	Individual farmers
Lake Cheimaditida	100	Individual farmers
Overspill from Cheimaditida	500	Individual farmers
Return flows from the mine		
Groundwater (boreholes)	900	Individual farmers

Lake Kerkini is an artificial lake fed by Strymonas River (Fig. 2). It was constructed during 1933-36 mainly for protection against floods caused by Strymonas River. Soon after used as a reservoir for irrigation water. During recent decades a unique wetland ecosystem has been developed in its shores, which is protected by the Ramsar Convention and EU legislation. The lake covers an area of 73.2 km^2 at its highest elevation (35.8) and stores $345x10^6$ m^3 of water.

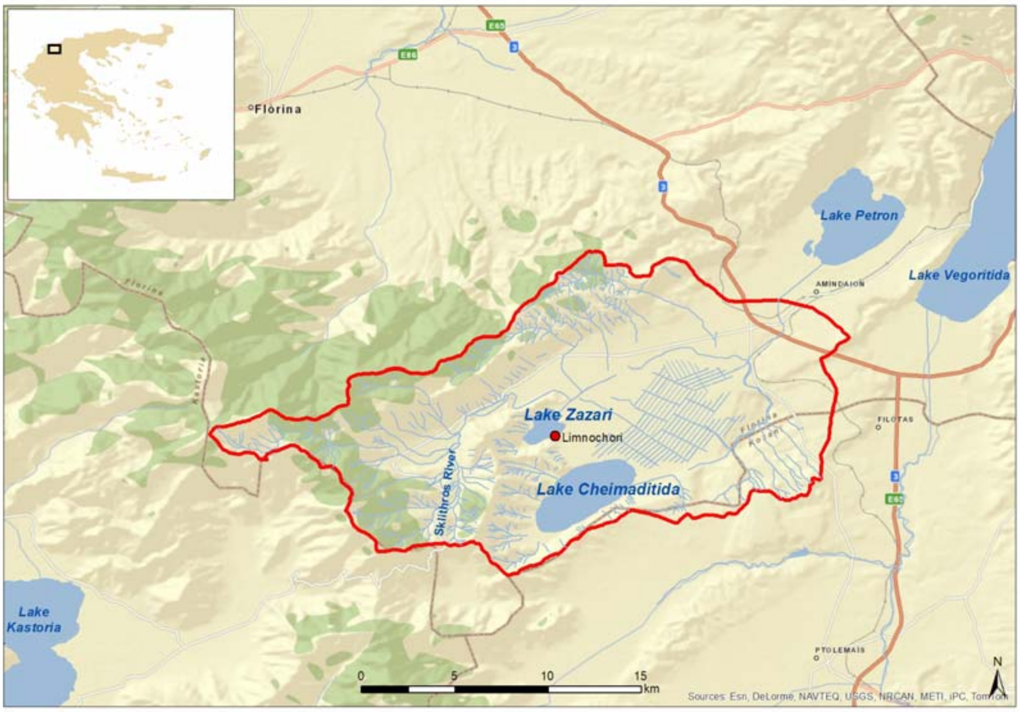

Fig 1. The wider catchment of Lake Cheimaditida

Fig 2. Lake Kerkini and Strymonas River catchment

Strymonas River and Lake Kerkini are the main surface water bodies in their catchment. From the 100.000 ha of arable land 84.500 ha are irrigated while 54.500 ha (64.5% of the total irrigated area) meet their irrigation needs directly from Strymonas River and Lake Kerkini. The remaining 30.000 ha are irrigated from streams and ground water (pumping wells).

The irrigation and drainage of this area is been elaborated through a dense network of irrigation canals and drainage ditches. The Land Reclamation Service of Serres – Greece (DEB-S) is responsible for the water resources management in the agricultural areas through its administrative and technical supervision of the General Land Reclamation Agency (G.L.R.A.) and of the 10 Local Land Reclamation Agencies (L.L.R.A.) (Fig. 3). These agencies are organizations of an agro-cooperative nature aiming at the management of land reclamation works and the distribution of irrigation water.

From autumn to spring the whole amount of Strymonas discharge after it crosses the Greek – Bulgarian border is stored into the lake. Its water level is controlled by four gates which also control the amount of water overspills in order to avoid floods to the areas downstream of the lake (nowadays the maximum conveyance of the river downstream of the lake has been reduced to 200 m^3/s). This in combination with the sedimentation of the lake, have resulted in a gradual increase of its mean water level causing undesirable alterations to the hydroperiod of its ecosystem.

During summer, 11 km after Strymonas crosses the Greek-Bulgarian borders, part of its discharge is diverted through the "Ypsilon 1 (Y1)" flow control structure into three irrigation networks (Fig. 3), while the remaining discharge, ends into the lake. Three more irrigation networks receive water directly from the lake through the "Ypsilon 2 (Y2)" and "Ypsilon 3 (Y3)" flow control structures. During this period, downstream of the lake there is no water flowing in Strymonas River up to its joint with Belitsa drainage ditch. Meanwhile the latter receives the drainage water from all the above irrigation networks (almost all the networks located eastern of Strymonas River) and supplies with water three more irrigation networks. The excess water of Belitsa, outflows again into Strymonas River which in turn is used from the remaining irrigation networks (Fig 3), to the south of the basin.

Runoff from the surrounding mountainous area of the plain drains through a number of small torrents either in Kerkini Lake and Strymonas River to the west or to the main drainage ditch of Belitsa to the east (Fig. 3).

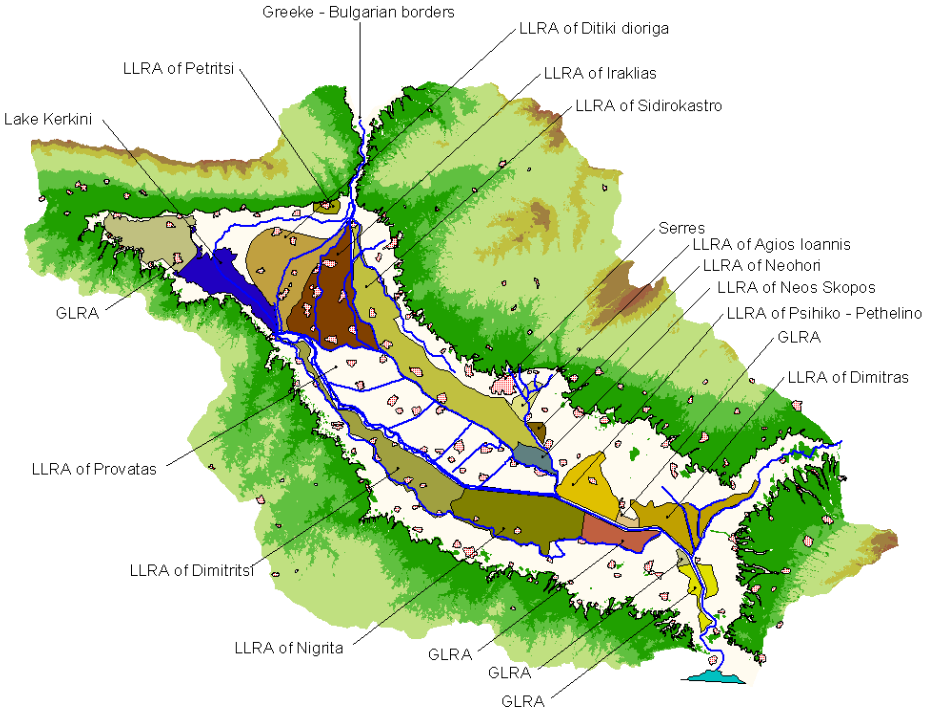

Fig 3. The Greek part of Strymonas River

3.2. Available data

Historical data on monthly temperature and precipitation were obtained from the station of Limnohori (January 1979 – December 1998) for Cheimaditida's catchment and from ten stations (January 2001 – December 2006) that are spread over in the catchment of Strymonas River.

Future monthly data of temperature and precipitation (2020 – 2050 for Emissions Scenarios A1B and 2070 – 2100 for Emissions Scenarios A1B, A2) for the two catchments were produced from the historical ones, which multiplied by their expected rates of change in the future [8] due to climate change (Table 3).

Table 3. Variations in rainfall and temperature in climate zone of West-Central Macedonia under Emissions Scenarios A1B and A2

Emissions Scenarios Time period	Season	Rainfall Rate of change (%)	Temperature Rate of change (%)
A1B 2020 – 2050	Spring	- 7.56	12.50
	Summer		9.73
	Autumn		13.50
	Winter		41.26
A1B 2070 – 2100	Spring	-16.90	29.96
	Summer		20.20
	Autumn		26.96
	Winter		89.66
A2 2070 - 2100	Spring	-16.5	39.86
	Summer		26.63
	Autumn		37.53
	Winter		144.30

For the historical and future time periods, the potential evapotranspiration was estimated using the method of Thornthwaite. Small water volumes have also been considered as infiltration from the lakes' bottom [14] and have been estimated to 3.6 and 5.1 mm/year for Zazari and Cheimaditida, respectively. The hypsographic curves (Elevation-Area and Elevation-Volume) of the lakes have been determined by the detailed Digital Elevation Model (DEM) of the lakes' bottom. The lakes' DEM have been constructed based on data from maps of Hellenic Military Geographical Service and on data derived from field works [10].

The water volume required to meet irrigation demands was taken into account to the lakes' water balance. The irrigation demands per ha has been estimated to 5,560 m^3/year for Cheimaditida catchment [10] and 11,247 m^3/year for Strymonas catchment [15]. Water demands of other uses (e.g. domestic, livestock etc) are not significant to water balance and have not been taken into account.

In both lakes a critical water level called "top of dead storage" represents the minimum level from which the users can withdraw water. Below that level only precipitation, evaporation and bottom infiltration can disturb the lake's water balance. Therefore, the "top of dead storage" can play the role of a safety margin to protect from an environmental point of view the lake's surface area and volume. This value has been set up considerable low in this study for the two lakes in order to see the consequences of climate change.

4. Results and discussion

4.1. Lake Cheimaditida

Fig. 4 and 5 show the monthly fluctuation of water level and surface area, respectively, in Lake Cheimaditida for the periods 1979-1998, 2020-2050 (scenario A1B) and 2070-2100 (scenarios A1B and A2). Using the historical meteorological data (1979-1998), the average value of water level is 591.2 m and the surface area is

8.96 km^2. The water level stands at 590.8, 590.45 and 590.35 m and the surface area shrinks to 7.14, 5.92 and 5.61 km^2, by adopting the scenarios A1B/2020-50, A1B/2070-100 and A2/2070-100, respectively.

The above data shows that the lake's water level will decline by 40 cm during the period 2020-50 and by 75-85 cm during the period 2070-100, assuming that climate change is the only altering factor in lake's water balance. Correspondingly, the lake's surface area will undergo a substantial decrease, initially by 20% during the period 2020-50 and later until 37% during the period 2070-100. The influence of climate change in lake's surface differs between the seasons (Table 4); a higher decrease will exist in autumn (25%-46%) and a lower decrease in spring (16%-30%).

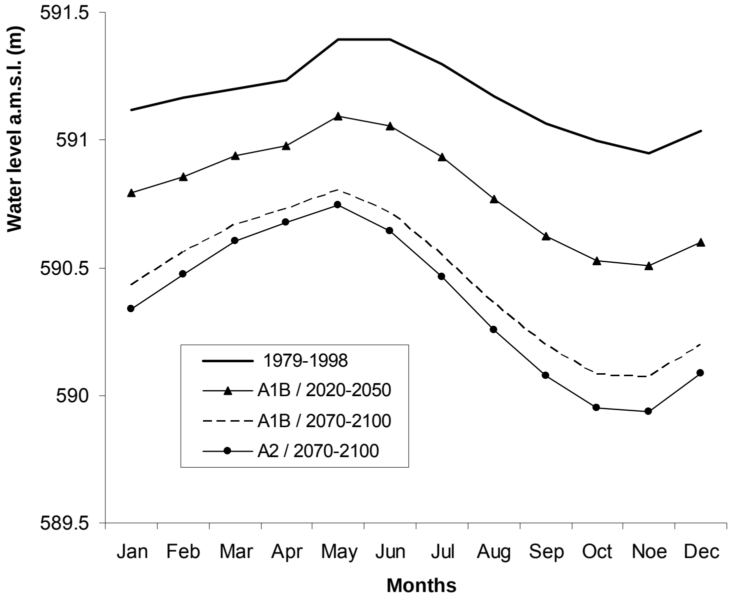

Fig 4. Water level fluctuation in Lake Cheimaditida under the scenarios A1B and A2

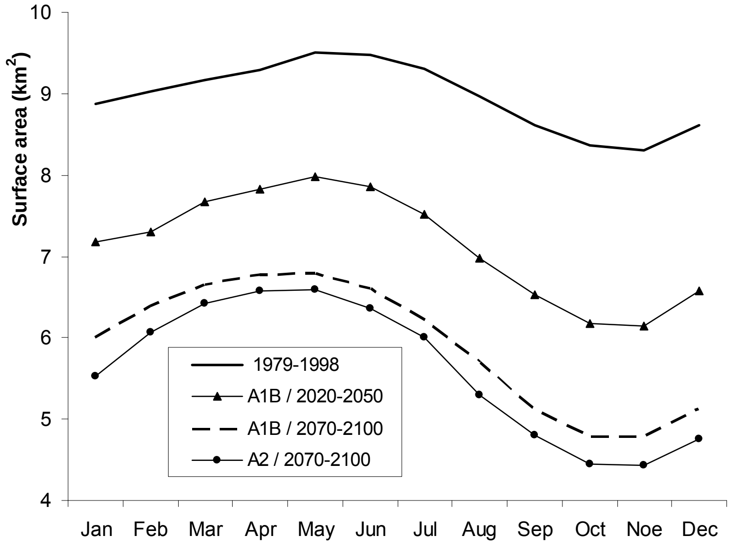

Fig 5. Surface area fluctuation in Lake Cheimaditida under the scenarios A1B and A2

Table 4. Seasonal variation of surface area in Lake Cheimaditida under the climate scenarios A1B and A2

Scenario/ Time period	**Season**	**Surface area**	
		(km^2)	(%)
1979-1998	Spring	9.32	
	Summer	9.25	
	Autumn	8.42	
	Winter	8.84	
	Annual	**8.96**	
A1B/2020-2050	Spring	7.82	-16
	Summer	7.45	-19
	Autumn	6.28	-25
	Winter	7.02	-21
	Annual	**7.14**	**-20**
A1B/2070-2100	Spring	6.74	-28
	Summer	6.18	-33
	Autumn	4.90	-42
	Winter	5.84	-34
	Annual	**5.92**	**-34**
A2/2070-2100	Spring	6.53	-30
	Summer	5.89	-36
	Autumn	4.56	-46
	Winter	5.45	-38
	Annual	**5.61**	**-37**

Table 5 shows the average annual inflows (catchment runoff and precipitation in lake) and outflows (evaporation from lake, outflow to irrigation, downstream outflow) in Lake Cheimaditida for the periods 1979-1998, 2020-2050 (A1B) and 2070-2100 (A1B and A2). In comparison to the period 1979-1998, the lake's catchment runoff is decreased by 26% (2020-50) and 52% (2070-100) in scenario A1B, and 54% in scenario A2/2070-100. Catchment runoff represents 70 to 74% of the total inflow into Lake Cheimaditida and its monthly variation is given in Fig. 6. Evaporation is increased by 10.1%, 24.8% and 36.9% in scenarios A1B/2020-50, A1B/2070-100 and A2/2070-100, respectively, measured as water outflow per lake's surface (in mm), but the water volume lost by evaporation (in m^3) is decreased since the lake's surface is shrinking in climate change conditions.

Table 5. Annual water balance in Lake Cheimaditida under the climate scenarios A1B and A2

Scenario/ Time period	**Catchment runoff**	**Precipitation in lake**		**Evaporation from lake**		**Outflow to irrigation**	**Downstream outflow**	**Water volume change**
	10^6 m^3	10^6 m^3	*mm*	10^6 m^3	*mm*	10^6 m^3	10^6 m^3	10^6 m^3
1979-1998	13.08	4.62	*514*	6.48	*716*	0.674	10.51	0.045
A1B/2020-2050	9.62	3.53	*475*	5.65	*788*	0.669	6.80	0.035
A1B/2070-2100	6.29	2.64	*427*	5.21	*893*	0.601	3.40	-0.280
A2/2070-2100	6.03	2.53	*429*	5.40	*980*	0.580	2.93	-0.342

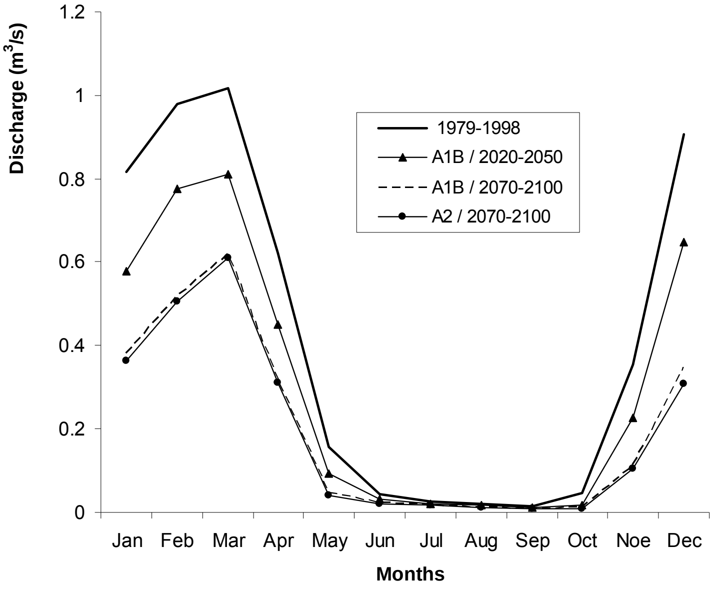

Fig 6. Catchment runoff into Lake Cheimaditida under the scenarios A1B and A2

4.2. Lake Kerkini

Fig. 7 and 8 show the monthly fluctuation of water level and surface area, respectively, in Lake Kerkini for the periods 2001-2006, 2020-2050 (scenario A1B) and 2070-2100 (scenarios A1B and A2). Using the historical meteorological data (2001-2006), the average value of water level is 32.6 m and the surface area is 55.44 km^2. The water level stands at 32.3, 31.9 and 31.8 m and the surface area reduced to 52.88, 48.9 and 47.69 km^2, by adopting the scenarios A1B/2020-50, A1B/2070-100 and A2/2070-100, respectively.

The average water level in Lake Kerkini will decline by 30 cm during the period 2020-50 and by 70-80 cm during the period 2070-100. Lake's surface area will decrease, initially by 5% during the period 2020-50 and later until 14% during the period 2070-100. As far as concerned the seasonal variation of lake's surface (Table 6), a higher decrease will exist during summer and autumn and a lower decrease in spring.

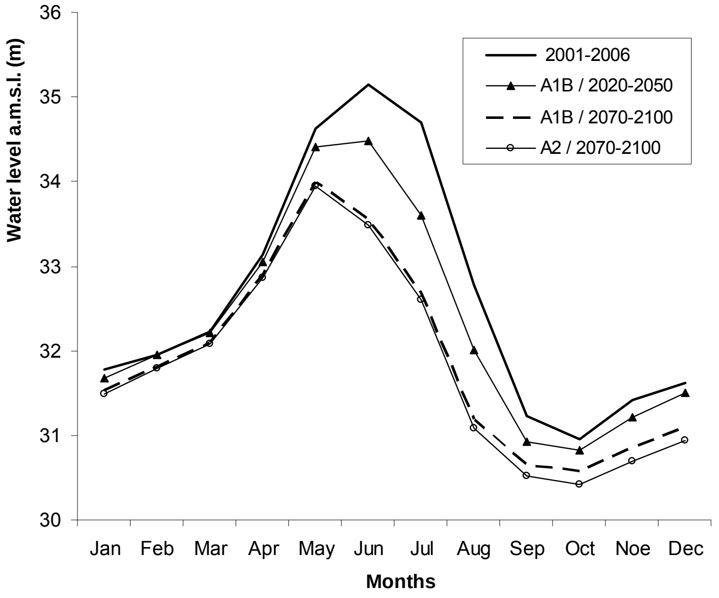

Fig 7. Water level fluctuation in Lake Kerkini under the climate scenarios A1B and A2

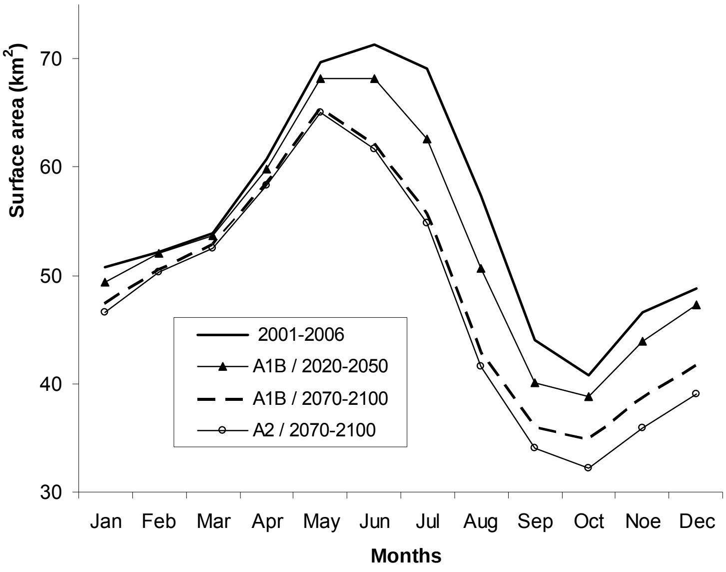

Fig 8. Surface area fluctuation in Lake Kerkini under the scenarios A1B and A2

Table 6. Seasonal variation of surface area in Lake Kerkini under the scenarios A1B and A2

Scenario/Time period	**Season**	**Surface area**	
		(km^2)	(%)
2001-2006	Spring	61.45	
	Summer	65.93	
	Autumn	43.83	
	Winter	50.54	
	Annual	**55.44**	
A1B/2020-2050	Spring	60.53	-1
	Summer	60.46	-8
	Autumn	40.96	-7
	Winter	49.58	-2
	Annual	**52.88**	**-5**
A1B/2070-2100	Spring	58.91	-4
	Summer	53.56	-19
	Autumn	36.55	-17
	Winter	46.56	-8
	Annual	**48.90**	**-12**
A2/2070-2100	Spring	58.62	-5
	Summer	52.72	-20
	Autumn	34.09	-22
	Winter	45.31	-10
	Annual	**47.69**	**-14**

Table 7 shows the average annual inflows (catchment runoff and precipitation in lake) and outflows (evaporation from lake, outflow to irrigation, downstream outflow) in Lake Kerkini for the periods 2001-2006, 2020-2050 (A1B) and 2070-2100 (A1B and A2). In comparison to the period 2001-2006, the lake's catchment runoff is decreased by 25.1% (2020-50) and 47.8% (2070-100) in scenario A1B, and 48.1% in scenario A2/2070-100. Catchment runoff represents 97 to 98% of the total inflow into Lake Kerkini and its monthly variation is given in Fig. 9. Agriculture receives water from Lake Kerkini when the water level in lake is above

31 m, and consequently a substantial decrease of water outflow to irrigation exists during the future climate change.

Table 7. Annual water balance in Lake Kerkini under the scenarios A1B and A2

Scenario/ Time period	Catch-ment runoff	Precipitation in lake		Evaporation from lake		Outflow to irrigation	Down-stream outflow	Water volume change
	10^6 m^3	10^6 m^3	*mm*	10^6 m^3	*mm*	10^6 m^3	10^6 m^3	10^6 m^3
1979-1998	1,565	29.3	*529*	52.2	*879*	374	1,163	5.6
A1B/2020-2050	1,172	26.0	*489*	56.7	*1033*	306	830	5.6
A1B/2070-2100	817	21.6	*440*	64.3	*1309*	221	547	5.6
A2/2070-2100	812	21.2	*442*	75.1	*1581*	213	540	5.6

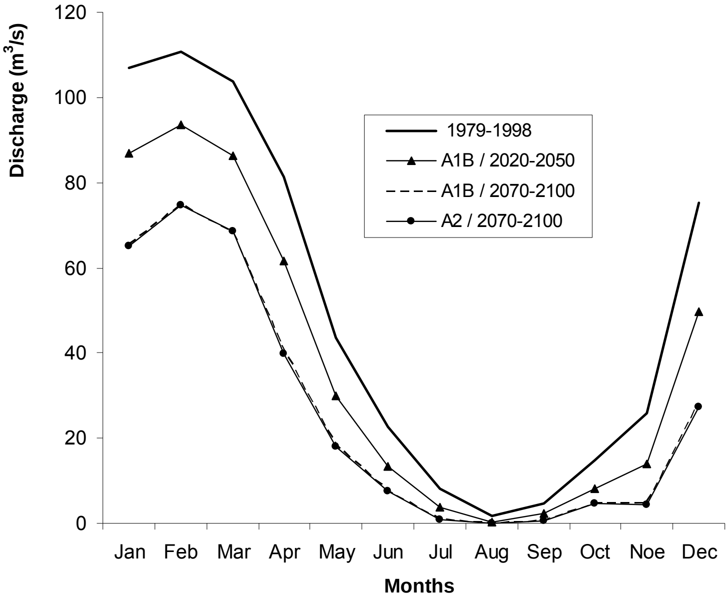

Fig 9. Catchment runoff into Lake Kerkini under the climate scenarios A1B and A2

5. Conclusions

This study examines the impact of climate change on the hydroperiod of two wetlands in Greece, Lake Cheimaditida and Lake Kerkini, by simulating their water balance using historical climate data and climate data produced under the emissions scenarios A1B for the period 2020-2050 and A1B and A2 for the period 2070-2100. The simulation of water balance was based on the assessment of water inputs and outputs in lakes using monthly time step; catchment runoff into the lakes was assessed by a rainfall-runoff model. Climate scenarios data were provided in the context of the study of Climate Change Impacts Study Committee.

Climate change is going to disturb the water balance in both lakes, by increasing losses due to evaporation and decreasing water gain from precipitation and lake's catchment runoff. Runoff represents a considerable amount of the water inflow into the lakes and is decreased by one fourth during the period 2020-50 and by half during the period 2070-100, in comparison to the historical period. In addition, the water volume of the lakes should serve the irrigation requirements of crops. Consequently, the surface area of Lake Cheimaditida will undergo a substantial decrease, initially by 20% during the period 2020-50 and later until 37% during the period 2070-2100. In Lake Kerkini, the surface area will decrease, initially by 5% during the period 2020-2050 and later until 14% during the period 2070-2100. In conclusion, climate change is anticipated to impact the hydroperiod of the two wetlands and the sustainable water management is essential to prevent the wetland's biodiversity loss. The consequences to biodiversity and the delivery of ecosystem goods and services should be the focus of further research.

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