

# Assessing the Impacts of Climate and Land Use Changes on the Water Quality of a Transboundary Balkan River

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**Abstract** The Mediterranean area is highly vulnerable to climate changes that combined with potential land use changes could influence its aquatic systems significantly. The Evros River is one of the most important surface water bodies in the Balkans with an ecologically significant delta that is protected by international legislation. The aim of this study is to analyze the impacts of climate and land use changes on Evros River water quality, for different climatic and socioeconomic scenarios. For this purpose, a hydrodynamic and advection-dispersion model was set up and calibrated, three IPCC climatic scenarios were applied, and the pollution loads of the catchment area were estimated. These scenarios involved river discharge decrease due to regional climate changes and socioeconomic and technological development that would lead to population growth and to the decrease of agricultural activities. The results indicated that in the case of discharge reduction only, the total nitrate and phosphate concentrations will be increased, while in case of combined land use and discharge changes, the concentration of nutrients will be decreased. Thus, a transboundary long-term management plan of the entire River is needed that would eliminate the pollution pressures and restore its good ecological status.

**Keywords** Climate change · Land use change · Hydrodynamic model · Water quality · Pollution loads · Evros River

## 1 Introduction

Despite the fact that inland water bodies represent only a small percentage of the total aquatic systems on earth, their significance is indisputable (Karpatne et al. 2016). Natural or artificial inland water bodies have always been linked to socioeconomic development and human prosperity, but also to biodiversity (Millennium Ecosystem Assessment 2005). The ecological condition of inland aquatic systems is dependent on the pressures applied on their entire catchment area, since they are the final recipients of the pollution loads (Revengea and Kura 2003). Inland aquatic systems are also very sensitive to changes concerning the hydrological cycle (Arnell 1998). Agricultural and industrial intensification in many countries worldwide, as well as human population growth has led to the increase of nitrate and phosphate concentrations in aquatic systems (Hadjikakou et al. 2011). These changes in the water bodies' quality cause significant environmental impacts and economic damages that often demand expensive and difficult to apply restoration measures (Camargo et al. 2005; WHO 2004).

During recent years, studies of climate change have led to the conclusion that due to enhanced greenhouse effect, the average surface temperature has gradually increased (IPCC 2007). Inland aquatic systems,

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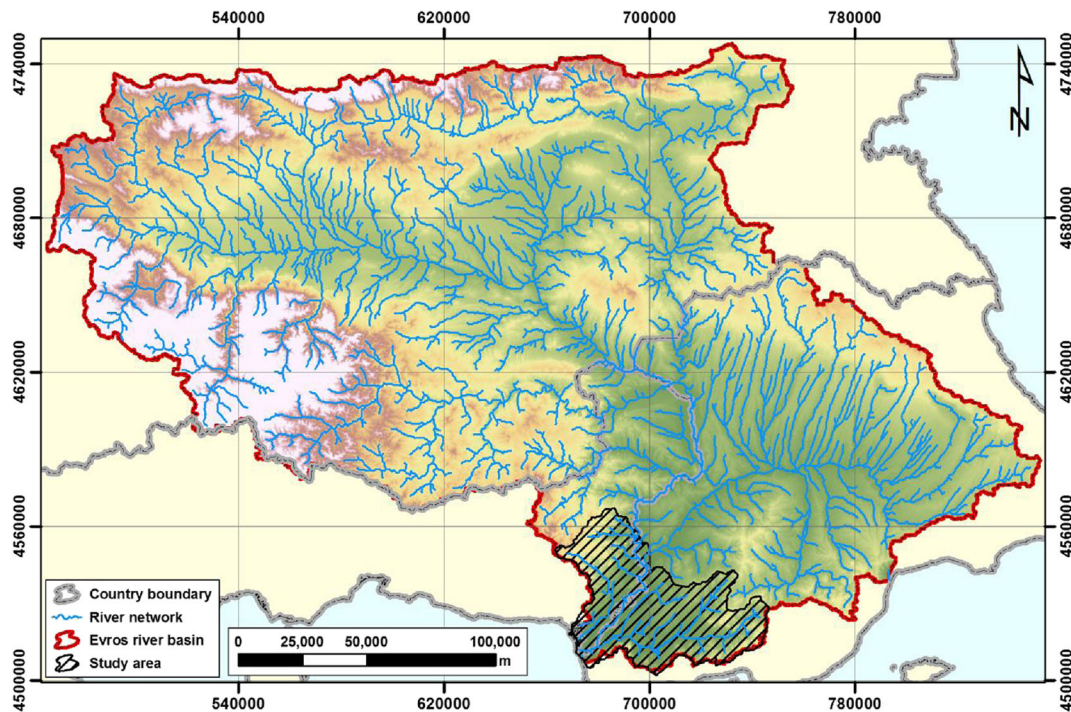
especially in semi-arid areas like the Mediterranean basin, are very sensitive and vulnerable to such impacts (Bonada and Resh 2013). Based on regional models, deterioration of the hydrologic regime of the particular area is expected. More specifically, most models foresee a temperature increase and precipitation decrease in the Mediterranean area, while the frequency and the intensity of extreme weather events may rise (Calbó 2010; Schröter et al. 2005). These phenomena combined with demographic, social, economic, and technological developments will change the status of the present environmental condition, while water resources are expected to be affected quantitatively and qualitatively (Alcama et al. 2007; Cooley et al. 2014; Mimikou et al. 2000).

The scope of this paper is to examine the effects of various climate and land use changes on the water quality of the transboundary Evros River due to potential, future economic and social alterations. In order to accomplish that, a hydrodynamic and water quality model of Evros River was set up and three climate change scenarios proposed by the Intergovernmental Panel on Climate Change (IPCC 2007) were examined with respect of the changes in the river's hydrology and nutrients' concentration. The main objective is to investigate the long-term dynamics amongst climate, land use

changes, and surface water quality and to propose management and mitigation measures, to minimize the possible adverse effects on the area's aquatic ecosystems. Moreover, the output of this study can be used for the accomplishment of a good ecological status in Evros River, facilitating the implementation of the Water Framework Directive (EU 2000).

## 2 Description of the Area

The Evros River is the second largest river in Southeastern Europe, flowing through Bulgaria, Greece, and Turkey and discharging significant quantities of water and sediment to the Aegean Sea (Skoulikidis et al. 2009). The total length of the river is 528 km, 310 km of which belong to Bulgaria and the remaining 218 km comprise the boundary between Greece and Turkey (Fig. 1). The catchment area is 53,000 km<sup>2</sup> while its annual average discharge fluctuates from 50 to 200 m<sup>3</sup>/s. The Evros River catchment is one of the most intensively cultivated areas in the Balkans and supports a population of 3.6 million people. Major pollution pressures comprise the mining industry in the Bulgarian part of the catchment area, industrial activities and domestic waste around the



**Fig. 1** Evros river catchment and the study area

town of Edirne in Turkey, and agricultural areas in the Greek territory of the Evros catchment (Skoulikidis et al. 2009). Over 1500 km<sup>3</sup> of cultivated area is located in the Greek part of the Evros River catchment and consists one of the most important agriculture regions of the Northern Greece.

One of the most important tributaries of Evros River is Ergene, which flows entirely in the East Thrace region of Turkey and meets the Evros near the Turkish city of Ipsala and the Greek village of Tichero. Ergene has a drainage basin of 10,195 km<sup>2</sup>, about 264 km length and an average flow of 23.3 m<sup>3</sup>/s (Aksoy 2007). The Turkish part of Thrace supports a population of one million people, and it is intensively cultivated (wheat, sunflower, rice) and industrialized (textile, pharmacy, dairy, tanneries). Many municipalities and industrial plants discharge wastewater directly or indirectly to Ergene River, while landfill leachate and fertilizers from cultivated land drain towards the river (Güneş et al. 2008). An ecological assessment of the Ergene River concluded the severe toxicity on *Vibrio fischeri* and the high COD concentrations (over 300 mg/l). Therefore water quality of the river was classified as “bad,” based on the Turkish Water Quality Regulation (Nikolaou et al. 2008).

The area of interest is the downstream part of the Evros River basin, just below the junction between Evros and Ergene tributary (Fig. 1). The catchment area is 2778 km<sup>2</sup> and consists about 5.2 % of the total Evros river basin.

### 3 Methods

The approach of the probabilistic climate and land use change scenarios development based on IPCC data has been used in this study in order to identify and quantify the water pollution risk regarding TP and TN. This approach was preferred in relation to the use of input from General Circulation Models (GCMs) due to the large uncertainty involved with the use of such models for the particular purpose (Wilby et al. 2006) and the completely different modeling scale between the GCMs and the local 1D MIKE 11 model, which would impose significant difficulties and inconsistencies in downscaling the regional climate model output to the fine basin-specific scale required in the particular simulations.

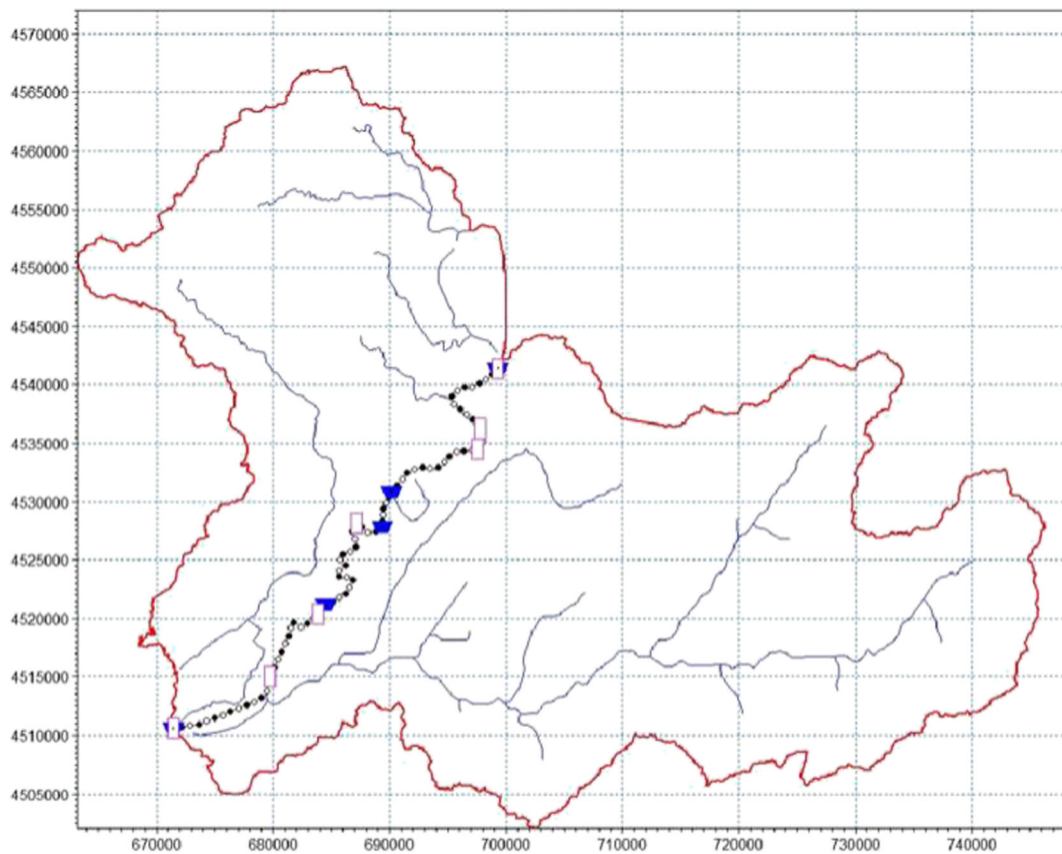
#### 3.1 Hydrodynamic Model Setup and Calibration

The hydrodynamic modeling tool used in the present effort for the simulation of Evros River and the transport and dispersion of conservative pollutants is MIKE 11. MIKE 11, developed by the Danish Hydraulic Institute of Water and the Environment (DHI 2007), is a one dimension, fully dynamic model that can simulate water flow, water quality, and sediment transport in rivers, irrigation canals, estuaries, and other inland water bodies. The particular modeling platform is flexible and can utilize various simulation approaches such as the complete dynamic wave formulation of the Saint Venant equations, diffusive wave approximation and kinematic wave approximation, Muskingum method and Muskingum-Cunge method for simplified channel routing, while many different modules can be used for pollutant advection-dispersion, sediment transport, erosion and deposition, water quality and ecology, and flood forecasting (DHI 2007).

The hydrodynamic model was first set up and calibrated for the period 22 February to 30 July 2011. Necessary inputs of the model are river network, cross sections, boundary conditions, and hydrodynamic parameters (Fig. 2). The model was set up only for the main branch of the river, while lateral flows from tributaries and irrigation channels were also taken into account. Due to lack of data concerning cross sections along Evros River, the open channel flow option was chosen for the simulation which adapts the simple shape of isosceles trapezoid to the few existing measurements of the river's geometric characteristics, as the dominant cross section pattern. The calibration of the model was achieved by a trial and error approach and the main calibration factors were lateral inflows, Manning number of the riverbed, and groundwater leakage. The model output (water level and discharge) was evaluated by statistical criteria, such as the coefficient of determination and the correlation coefficient between the modeled and measured variables, until satisfactory results were accomplished. The model was calibrated based on the daily average water level of the hydrometric station of Kipoi bridge (1961–1997, Ministry of Environment, Planning and Public Works).

#### 3.2 Water Quality Model Setup and Calibration

After the calibration of the hydrodynamic model MIKE 11 of Evros River during the period 22 February to 30 July



**Fig. 2** River network (blue line), cross sections (blue trapezoid), boundaries and lateral inflows (pink rectangles), and computational grid points (white circles, h-points; black circles, Q-points) of the hydrodynamic model

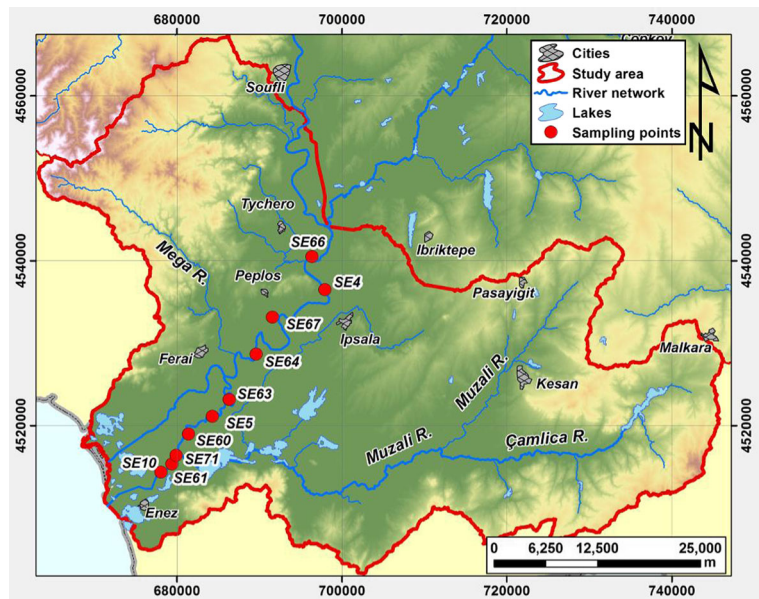
2011, the water quality model MIKE 11 AD (advection-dispersion) was setup and calibrated for the period 10 May to 20 May 2011, when a water quality sampling campaign took place. During this procedure, the advection-dispersion of the total nitrogen and total phosphate concentrations along Evros River was simulated. Lateral pollution loads from tributaries to the main river branch, the dispersion factor/coefficient, and decay constants were the main calibration factors. The pollution loads were initially estimated for each municipality in the study area based on the potential TN and TP production per socioeconomic sector (agriculture, urban, and livestock breeding) by using well-established methods (WHO 1982; Bertahas et al. 2006; Metcalf 1991; OECD 2000) that are analytically described below. The actual pollution load inflows from the main tributaries were though a calibration factor, applied as a fine tuning process by using the aforementioned TN and TP estimations, trial and error approaches, and the respective water quality measurements. The water quality model was

calibrated based on the results of the sampling campaign conducted in May 2011 that consisted of 10 sampling points between the junction of Evros with Ergene River and Evros delta. In this part of the river, flow velocity decreases significantly (twofold or more), due to the deltaic nature of the river, marshes begin to appear along the river and sea intrusion phenomena take place occasionally (Fig. 3). From this hydrochemical survey, the nutrient concentrations (total nitrogen and total phosphate) were used to calibrate the model.

### 3.3 Scenarios Applied

Most of the climate change scenarios for the Mediterranean basin suggest a long-term increase of the surface temperature and a tendency of the precipitation to decrease. As a consequence, annual average runoff in southern Europe (south of 47°N) is expected to decrease by 6 to 36 % up to the 2070s (IPCC 2007), while in some rivers summer

**Fig. 3** Sampling points along Evros River (Kipoi bridge gauging station is at SE4 point; sampling date, 18 May 2011)



flow is expected to decrease by 80 % (Santos et al. 2002). Furthermore, socioeconomic and technological development of this area is expected to lead to population growth, although the aspects of this demographic growth vary significantly amongst the different scenarios and spatial scales.

In order to examine the influence of these changes on Evros River water quality, the IPCC (2007) A2 and B2 scenarios were both examined and compared to the current situation in Evros River. The A2 “pessimistic” scenario is characterized by a continuously increasing population with regionally oriented, more fragmented and slower economic development, while the “optimistic” B2 scenario is characterized by a continuously increasing population (but at slower rate than in A2) with intermediate levels of economic development and emphasis to economic, social, and environmental sustainability (IPCC 2007). Based on these scenarios, the area of agricultural land for food production in the Mediterranean is expected to decrease, while a small increase is expected in bioenergy production, forests (Kankaanpää and Carter 2004) and urban and protected areas. These changes in scenario A2 are due to technological development, while in scenario B2 are caused by new agriculture policies that encourage extensification and organic production (Rounsevell et al. 2005).

Based on the above assumptions, the following model scenarios were applied on the water quality model of Evros River (Table 1):

- Sc1 scenario (–): Runoff decrease by 6 to 36 % up to the 2070s.
- Sc2 scenario (A2): Runoff decrease by 6 to 36 and 33 % population increase up to the 2070s. The agriculture area in Greece is expected to decrease by 47 %, while livestock is expected to decrease by 63 % (Rounsevell et al. 2005).
- Sc3 scenario (B2): Runoff decrease by 6 to 36 and 3.8 % population increase up to the 2070s. The agriculture area in Greece is expected to decrease by 33 %. Livestock is expected to decrease by 49 % (Rounsevell et al. 2005).

These land use and socioeconomic scenarios are based on specific political and economic growth trends that may be altered during the course of time since they depend on many unpredictable parameters (stakeholders lobbying, social movements’ pressure, economic status, etc.). Nevertheless, IPCC has formulated the particular scenarios, according to the dominant socioeconomic and political conditions worldwide, in order to test the impacts from climate change scenarios on the society and vice versa. In the study area, the principle assumptions of these scenarios are still valid since the Common Agricultural Policy of European Union attempts to

**Table 1** Scenarios applied on the study area

a/a	Scenario	IPCC	Discharge	Population	Agriculture	Livestock
1	Sc1	–	–6 to –36 %	–	–	–
2	Sc2	A2	–6 to –36 %	+33 %	–47 %	–63 %
3	Sc3	B2	–6 to –36 %	+3.8 %	–33 %	–49 %

establish environmentally friendly agricultural practices, by reducing the amount of chemicals used and promoting organic farming. Moreover, the current policies attempt to transform the type of agriculture from intensive to extensive with high quality products in order to decrease the environmental impacts from this activity and reduce the high water irrigation demands. Thus, it is probable that in the semi-arid area of Northern Mediterranean, the agricultural sector will be reduced in size and transformed to an environmentally friendly economic activity.

### 3.4 Pollution Loads

In order to estimate the modified pollution pressures on Evros River for given land use changes, the present situation in the catchment must be assessed. The estimation of non point pollution pressures on the study area was based on relevant Greek and Turkish bibliographical data, in situ observations at a municipal level, and statistical data (Hellenic Statistical Authority; Turkish Statistical Institute) regarding the pollution sources (cultivations, livestock and urban wastes) of the area. The estimation followed the methodology suggested by the World Health Organization (WHO 1982) which is based on empirical relationships between the pollution sources and the

respective loads produced. This methodology has been widely used in the past by the international scientific community while in this study, it is applied in order to estimate the differences in the potential pollution loads at the study area between the various land use scenarios (Table 1) and incorporate them in the water quality model.

### 3.5 Agriculture

In order to estimate the pollution loads from agricultural activities, the amount of fertilizers proposed by local agricultural engineers for the area's crop types and the extent of cultivations per crop type were used (same methodology as in Bertahas et al. 2006). The amount of the fertilizers per crop type (Table 2) are referred on the packaging in kilogram/1000 m<sup>2</sup> for the components N-P (P<sub>2</sub>O<sub>5</sub>) -K (K<sub>2</sub>O). Each nutrient is referred in kilogram per 100 kg of fertilizer, e.g., 11-15-15 means 11 kg N, 15 kg P<sub>2</sub>O<sub>5</sub>, and 15 kg K<sub>2</sub>O in 100 kg of compound fertilizer. The rest could be other elements in small amount, e.g., Fe, B, Mg, while it mainly consists of inert substances, e.g., apatite.

It must be noted that it is possible the amount of the fertilizers used can be greater than the proposed because of different cultivation tactics from each farmer. For this purpose, a 20 % surcharge in the application of fertilizers has been assumed in the calculations, in order to

**Table 2** Fertilizers proposed by agricultural engineers for the cultivations of the study area

	Cultivation	Fertilizer kg/1000 m <sup>2</sup>	kg N-P-K/100 kg fertilizer
1	Annual crops	25 kg	20-10-0
2	Tree crops	35 kg	11-15-15
		10 kg	20-20-20
		10 kg Ca(NO <sub>3</sub> ) <sub>2</sub>	26-0-0
3	Vineyards	25 kg (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	21-0-0
4	Grassland and pasture	10 kg (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	21-0-0
5	Vegetable gardens	100 kg basic fertilization	12-12-17
		30 kg	20-20-20
		15 kg Ca(NO <sub>3</sub> ) <sub>2</sub>	26-0-0

evaluate the total amount of N, P, and K used in agriculture (Table 3).

### 3.6 Livestock

In order to calculate the pollution load produced from livestock (Table 4), the relevant data regarding the number of breeding animals per municipality and the specifications of livestock waste production proposed by WHO (1982) were used.

### 3.7 Urban Waste

An important pollution pressure on the study area is urban waste, mainly because of the lack of sewer system and its uncontrolled disposal. Urban wastes consist of suspended and dissolved inorganic and organic substances, and the exact composition depends on living conditions and daily water consumption. The typical composition of urban wastes that has been used in the particular study was based on the findings of Metcalf (1991), while the daily water consumption per person is estimated to be 150 L/day/person in this area (OECD 2000).

## 4 Results and Discussion

### 4.1 Pollution Loads Today

Based on the results, the greatest amount of pollution loads due to agriculture activities (Fig. 4a, b), livestock (Fig. 4c, d), or urban wastes (Fig. 4e, f) are produced in the Turkish part of the study area (municipalities of Malkara, Kesan, and Ipsala). This is consistent with the fact that the Turkish part of the catchment is more intensively cultivated, livestock breeding is also more developed than in the Greek part of the catchment, and the human population is significantly higher.

**Table 3** Total annual amount of nitrate, phosphate, and potassium

Total amount (kg/1000 m <sup>2</sup> )	Cultivation (*1000 m <sup>2</sup> )				
	Annual crops	Tree crops	Vineyards	Grassland and pasture	Vegetable gardens
N	6	10.14	6.3	2.52	13.14
P	3	8.7	0	0	10.8
K	0	8.7	0	0	13.8

Based on the aforementioned estimations, the daily total nitrogen and phosphate pollution load from all the pressures applied (livestock, agricultural activities, and urban waste) in the study area has been calculated per municipality (Fig. 5). A correction factor accounting for the percentage of each Municipal area that is located inside the catchment area was applied. Based on the results, the main pollution source of the area is agricultural activities, while urban wastes contribute the least.

Depending on the land use change scenarios in Evros river catchment, the pollution pressures have been recalculated for each scenario, following the aforementioned methodology. The pollution loads applied on the catchment area, in comparison to the present pollution loads, were estimated to decrease by 53.8 % (total nitrogen) and 47.2 % (total phosphate) for scenario Sc2 and by 40.5 % (total nitrogen) and 33.7 % (total phosphate) for scenario Sc3 (Fig. 6). These reductions can be attributed to the decrease of the agricultural areas that is suggested by both tested scenarios due to technological development and changes in the relevant policies while the predicted human population increase led to increased production of total nitrogen (TN) and total phosphorus (TP) due to urban waste disposal. Nevertheless, the alterations in the agricultural sector overcome any potential changes in the human population and therefore the overall predicted changes in TN and TP indicate a significant reduction.

### 4.2 Hydrodynamic Model

Based on the results of Evros River hydrodynamic model, the calibration of the model is satisfactory, since there is a quite good agreement between the observed and simulated water level at Kipoi Bridge while a correlation coefficient ( $R$ ) of 0.981 and a Nash-Sutcliffe coefficient ( $R^2$ ) of 0.963 were achieved (Table 5, Fig. 7). This good calibration outcome is partially due to the relatively low variability in the hydrologic regime, of the

**Table 4** Characteristics of live-stock waste (WHO 1982)

	Waste production per ton weight					
	Cattles kg/day	Pigs	Sheep and goats	Poultres	Equines	Rabbits
Waste volume	46	51	36	66	23	66
BOD <sub>5</sub>	1.3	2.2	0.9	3.6	0.65	3.6
COD	7.4	7.3	11.5	15.5	3.7	15.5
Total solids	7.9	6.9	10.7	16.8	3.95	16.8
Nitrogen	1.55	0.39	0.43	0.99	0.775	0.99
Phosphate	0.035	0.075	0.066	0.34	0.0175	0.34
Potassium	0.108	0.083	0.26	0.29	0.054	0.29
Equivalent pop.	24	41	16.7	67	12	67
					(WHO, 1982)	
Adult weight (kg)	350	70	30	1.8	250	1.8

particular river section, since no significant exchanges of water exist in this area. The water level of the river lowers progressively by approximately 1.05 to 1.22 m, during the period February 2011 to July 2011 mainly due to dry weather conditions and water abstractions in the upstream part of the catchment. The positive value of mean error (ME) indicates that the model slightly under-predicts the water level (Table 5, Fig. 7a).

Based on the in situ measurements and on the results of the model, the maximum positive difference between simulated and observed values is 0.20 m and the maximum negative difference is -0.55 m (Fig. 7b). The total measured volume is approximately 4,073,400 m<sup>3</sup> and the total modeled volume is 2,633,700 m<sup>3</sup> which means a volume error of -35 %. Also the peak observed value is 1.43 m and the peak simulated value is 1.22 m which indicates a peak error of approximately -14 % (Table 5). In Fig. 7c, the best-fit line for the plotted timeseries and the perfect calibration best-fit line are plotted in a scatter graph, showing that there are not big discrepancies in the model outputs. Additionally, in Fig. 7d, the difference between observed and simulated timeseries is plotted on the y-axis and the average of observed and simulated timeseries is plotted on the x-axis, indicating a rather consistent behavior of the model. However, it should be mentioned that the estimated average river discharge compared with respective values from other time periods and studies can illustrate significant differences. Nevertheless, these variations can be caused by either natural variability in rainfall or (mostly) anthropogenic impacts relevant to the local water management

regime. Particularly, the construction of new dams, the changes in the electricity demands and the hydroelectric production, the land use, and cropland alterations, can be responsible for most of the interannual variations in the river's discharge values.

#### 4.3 Water Quality Model

The results of the water quality simulation, regarding total nitrogen and phosphorus advection and dispersion, along Evros River are relatively satisfactory (Fig. 8, Table 6), since the correlation coefficient (*R*) reached 0.793 for TN and 0.766 for TP. Moreover, Nash-Sutcliffe coefficient was slightly lower (0.535 for TN and 0.586 for TP), while the model was usually over-predicting the TN and TP values which was expected since these pollutants are tackled as conservative ones by the model and therefore natural removal mechanisms (biogeochemical processes) are not well represented in the model (Table 6). The spatial fluctuations of TN and TP in the study period were relatively low since they ranged approximately from 2 to 2.5 mg/l for TN and from 0.2 to 0.29 for TP. These variations followed the spatial distribution of the pollution sources in the study area and were caused by the input and output of pollution loads through impacted tributaries and natural attenuation processes, respectively. It is evident that the general spatial trend for both TN and TP is decreasing along the river towards its delta which indicates the important pollution reduction mechanisms of the natural system and particularly of the lowest part or the river



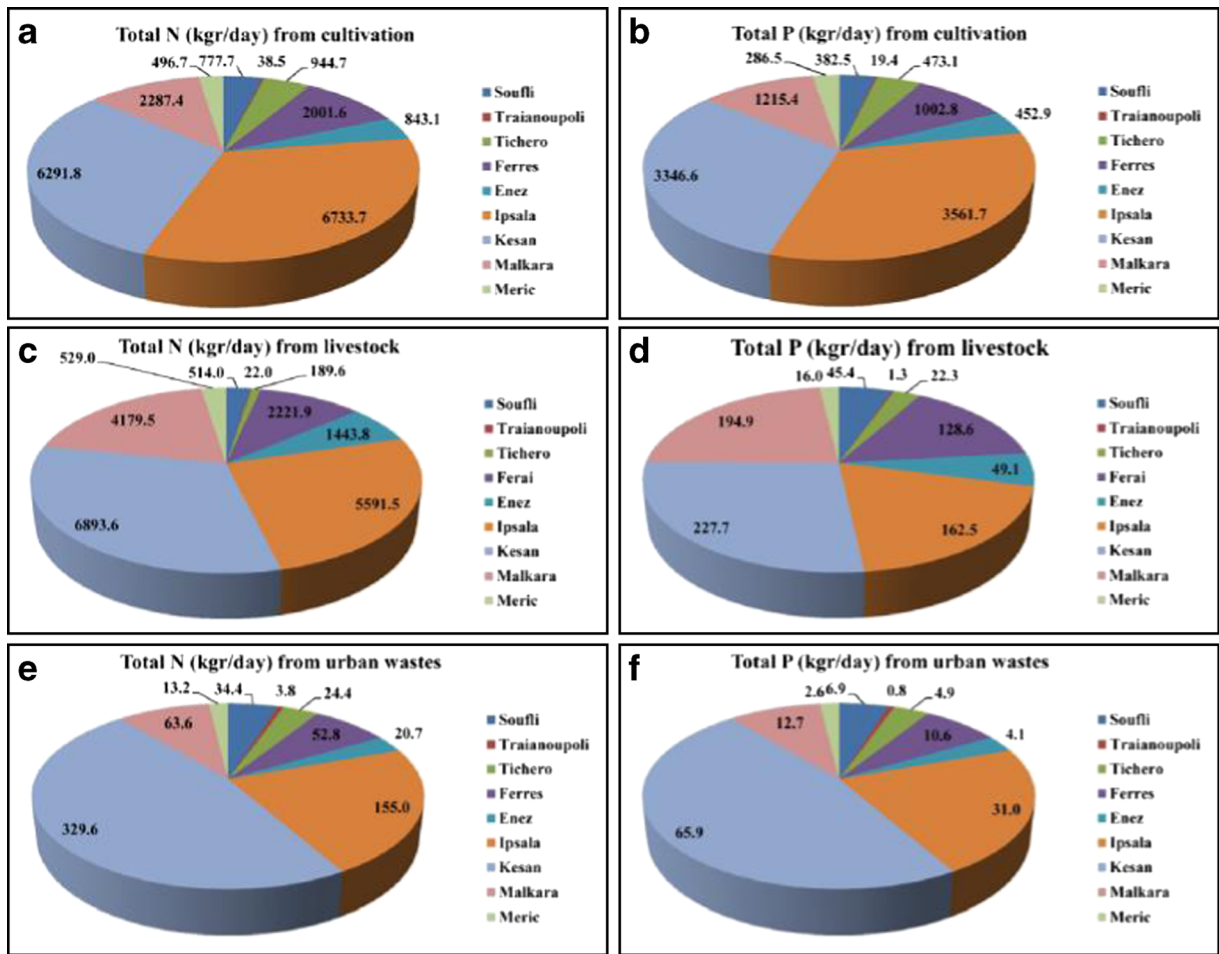


Fig. 4 Estimation of Total N and P produced from cultivation (a, b), from livestock (c, d), and urban wastes (e, f) per municipality (2000)

(deltaic wetlands, Fig. 8). The TN and TP concentration peaks in Fig. 8 illustrate the significant introduction of agrochemicals and urban waste in the river from the tributaries of Evros (Mega and Muzali rivers) while the highest peak in TP (0.3 mg/l) coincides with the location of Ipsala City.

#### 4.4 Climate and Land Use Changes Scenarios in Water Quality

After the calibration of the water quality model of Evros River for the present climate conditions and land uses, the three scenarios mentioned above were applied to the

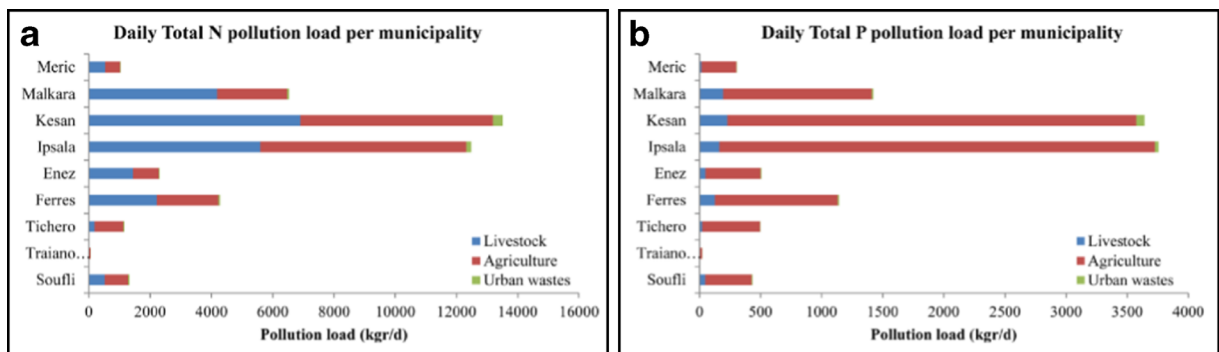
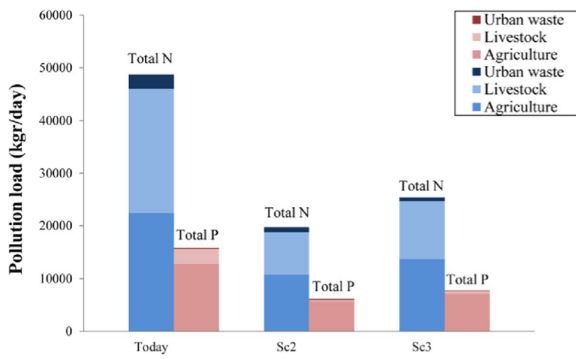


Fig. 5 Estimation of daily Total N (a) and Total P (b) pollution load per municipality



**Fig. 6** Estimation of daily Total N and Total P pollution load per municipality for 2000 and the two scenarios applied (Sc2 and Sc3)

model. The estimated future concentrations of TN and TP will be within the shaded area of each graph in Fig. 9.

For the scenario Sc1, where Evros discharge would decrease at a range between 6 and 36 %, according to the model, the total nitrogen and phosphorus concentrations will be significantly altered (Fig. 9a, b). Particularly, if the discharge of Evros River will decrease by 6 % in relation to the today's values, the concentrations of TN and TP will slightly be increased by up to 8 % for TN and 7 % for TP. Moreover, if the discharge will be reduced by 36 %, in Scenario 1, the concentrations of both parameters will significantly increase by up to 48 % for TN and 71 % for TP, in the upstream section of the study area (Fig. 9a, b).

The modeled changes along the river show the similar to the current situation decreasing trend towards the mouth of the river which is probably due to the natural attenuation mechanisms of the river that become more

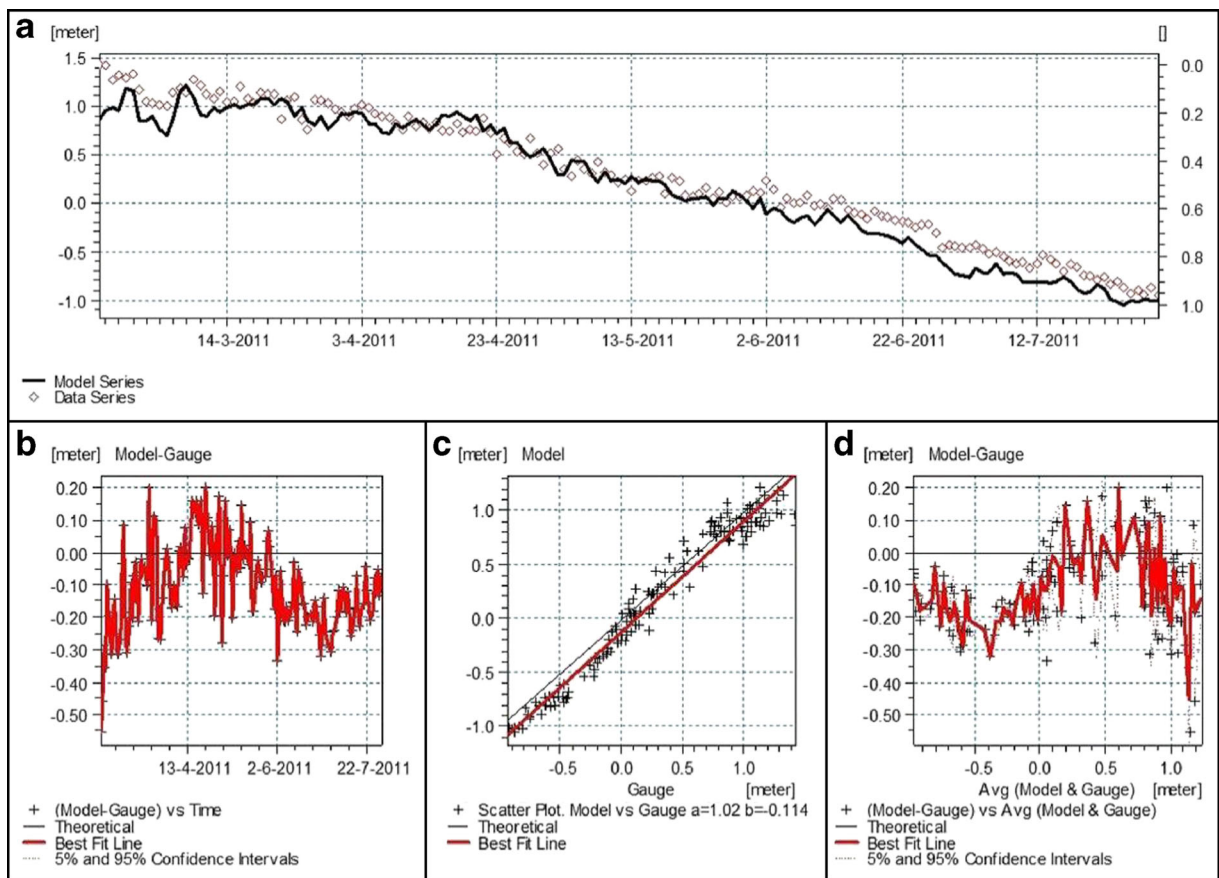
efficient and intense closer to the deltaic area (Figs. 9 and 10). Moreover, the main pollution sources are also located in the upstream part of the study area.

In scenarios Sc2 and Sc3, where land use and population changes were also taken into account, the concentrations of nutrients were decreased in all cases. In the pessimistic scenario Sc2, the decrease of total nitrogen concentrations fluctuates between 41.2 and 51.8 % (Fig. 9c), in relation to the today's (2000) values while in the optimistic scenario Sc3 between 24.3 and 37.9 % (Fig. 9e). Regarding the total phosphorus concentrations, in scenario Sc2 the decrease fluctuates between 32.8 and 44.9 % (Fig. 9d) and in scenario Sc3 between 15.5 and 30.7 % (Fig. 9f). These potential future trends in TN and TP of scenarios Sc2 and Sc3 indicate the significant impacts of agriculture and livestock in the study area since even though the human population increases (up to 33 % in Sc2) the TN and TP values decrease substantially due to the important reductions in these economic activities. Moreover, the TP behavior between Sc2 and Sc3 scenarios (Fig. 9d, f) illustrate the large difference in the impacts caused by livestock and urban waste production in the study area. Particularly, even though human population increases approx. 30 % more in Sc2 than in Sc3, TP decreases a lot more in Sc2 as a result of the higher decrease (by 14 %) of livestock in this scenario compared to Sc3.

It must be noted that in scenario 1, assuming that the discharge at Evros River is decreased by 36 % in comparison to the present conditions, the changes in the hydrologic regime are so large that the dispersion capability of the river gets significantly lower and thus the TN and TP are consequently increased. However, when the decrease of the river discharge is lower (6 %), the main factor that affects water quality is land uses, while the hydrologic changes have a substantially lower impact on the modeled nutrient concentrations (Fig. 10). This explains the significant reduction in the estimated nutrient concentrations of scenarios 2 and 3 when the discharge is lowered by 6 % in relation to the today's values (Fig. 10). These patterns also accredit the conclusion of the greatest impacts originating from agriculture and livestock in comparison to the human population as mentioned above. In particular, even with a 36 % reduction in the river discharge combined, with a 33 % increase in human population (scenario Sc2), the TN and TP levels do not overcome the current situation due to the decrease in agriculture and livestock activities (Fig. 10b, d).

**Table 5** Error statistics of the hydrodynamic model

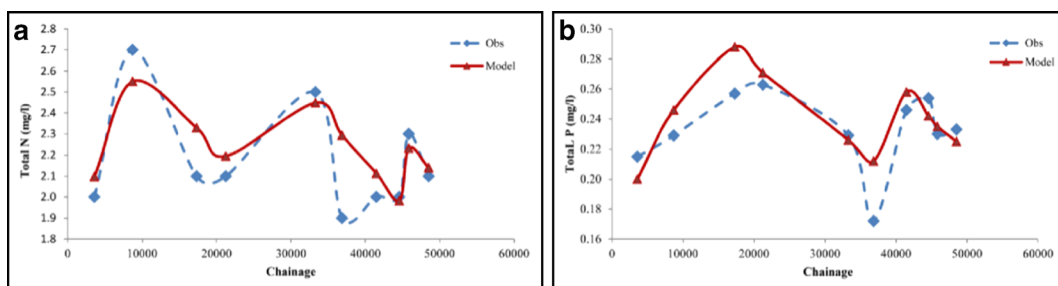
Correlation coefficient $R$	0.981	–
Nash-Sutcliffe coefficient $R^2$	0.963	–
Mean error ME	0.107	m
Mean absolute error MAE	0.029	m
Root mean square error RMSE	0.171	m
Max. positive difference	0.202	meter
Max. negative difference	–0.555	meter
Volume observed	4073368	m <sup>2</sup>
Volume modeled	2633681	m <sup>2</sup>
Volume error	–35.344	%
Peak observed value	1.427	meter
Peak modeled value	1.217	meter
Peak error	–14.71	%



**Fig. 7** Simulated and observed water level at Evros River (Kipoi Bridge). Statistical analysis

The particular land use scenarios will also have significant economic impacts in the study area which demand a thorough economic analysis and specialized models in order to be estimated. Nevertheless, a rather simplistic approach for the Greek part of the catchment would suggest that a 47 % reduction of the primary sector under Sc2 could result to a respective decrease on the annual turnover from local agricultural activities

which reaches a value of 77 million EUR (163 million EUR was the regional annual turnover from primary sector in 2005—9.4 % of the regional GDP, Greek Statistical Service, 2005). Similarly, following Sc3, a reduction of the primary sector by 33 % could lead to a loss of 54 million EUR annually, which corresponds to the 3 % of the regional GDP. However, the economic changes are always dynamic and follow the social



**Fig. 8** Simulated and observed total nitrogen and total phosphate concentrations along Evros River

**Table 6** Statistic calculations of water quality model

	Total N	Total P
Correlation coefficient <i>R</i>	0.793	0.766
Nash-Sutcliffe coefficient <i>R</i> <sup>2</sup>	0.535	0.586
Mean error ME	-4.41	-0.47
Mean absolute error MAE	4.41	0.47
Root mean square error RMSE	4.43	0.48

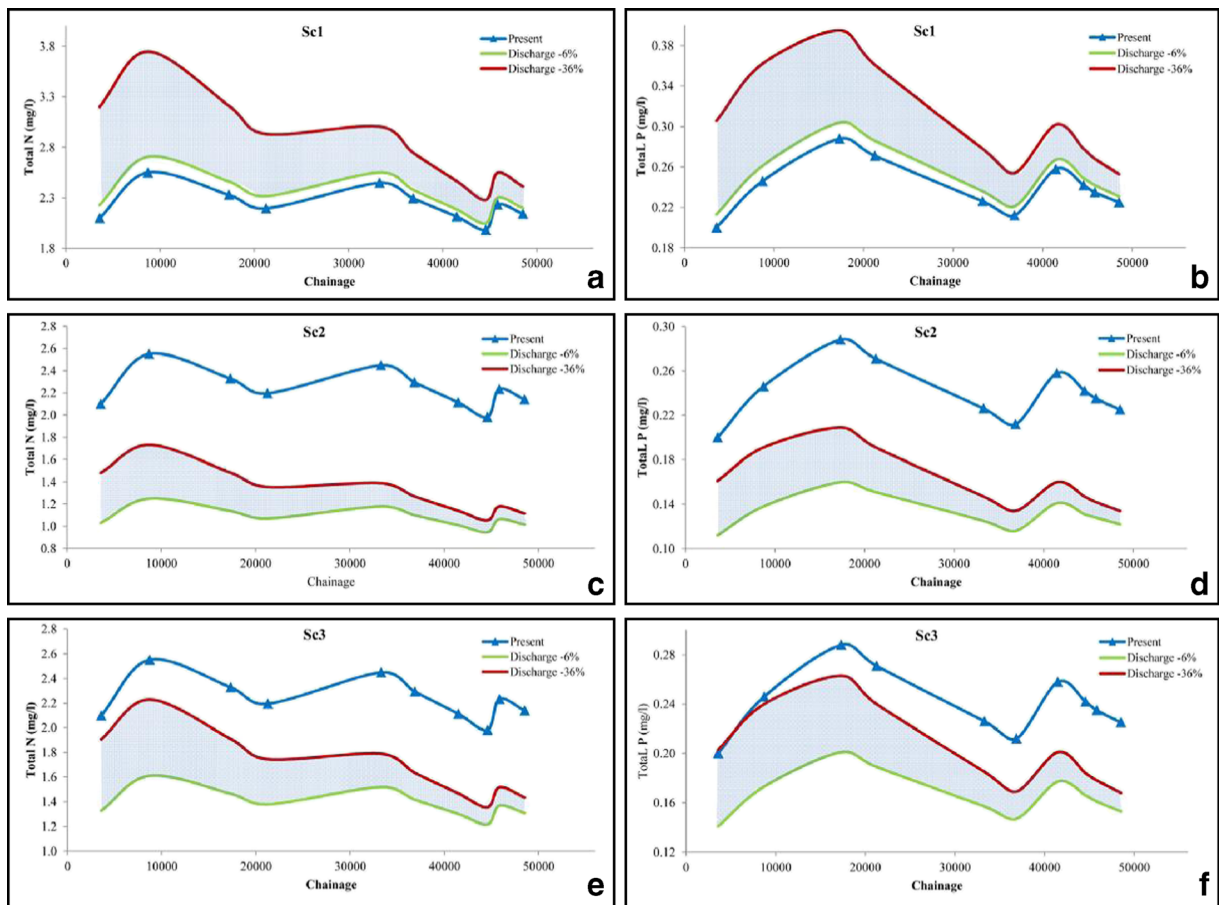
changes with the necessary adjustments and reforms which can result to the elimination of the cost of the aforementioned land use changes.

### 5 Conclusions

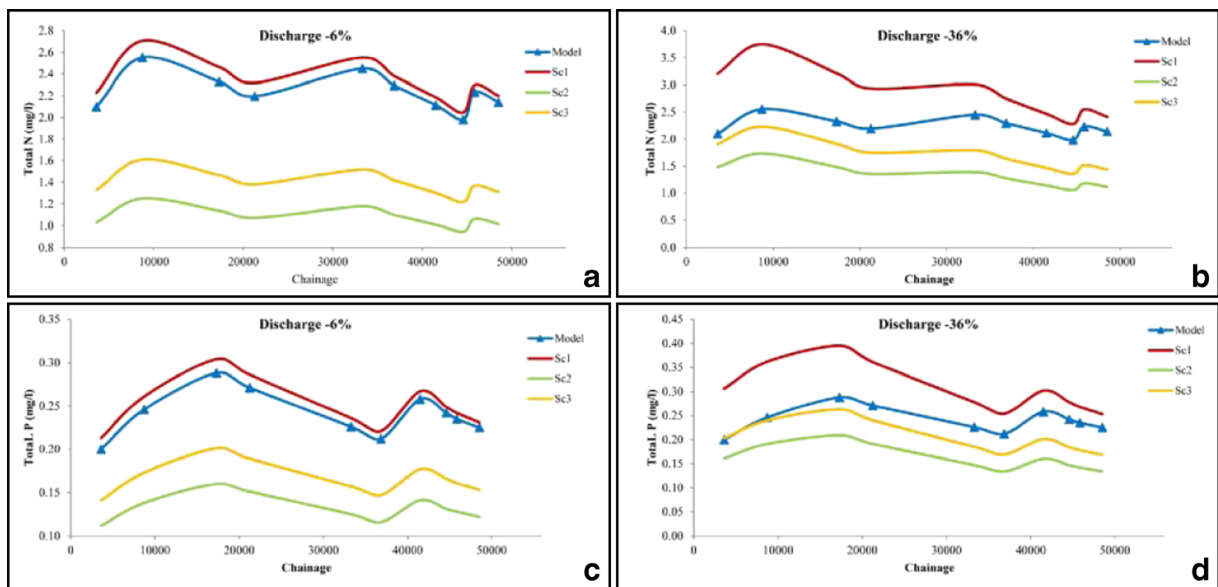
In this effort, MIKE 11, one dimension, fully dynamic model was used to simulate the hydrodynamic and

water quality of Evros River, at the area between the junction of Ergene River and Evros delta. The results of the model calibration showed a relatively satisfactory correlation between the observed and the simulated data regarding water level and nutrients concentrations (total nitrogen and total phosphate).

Three IPCC scenarios (IPCC 2000) were applied on the model, concerning discharge and land use changes in the particular catchment. Based on scenario Sc1 (decrease of discharge between 6 and 36 %), the total nitrogen and total phosphate concentrations will be increased by a rate of 4.4 to 27.2 %. On the contrary, in scenario Sc2 (pessimistic), the total nitrogen and total phosphate concentrations will decrease by 41.2 to 51.8 and 32.8 to 44.9 % respectively (depending on the discharge changes—6 to 36 %). In scenario Sc3 (optimistic), the TN and TP concentrations will be reduced by 24.3 to 37.9 and 15.5 to 30.7 %, respectively. This decrease is due to the land use policies that are expected



**Fig. 9** Total nitrogen and total phosphate concentrations along Evros River for simulated present conditions and for Sc1, Sc2, and Sc3 scenarios



**Fig. 10** Total nitrogen and total phosphate concentrations along Evros River for simulated present conditions and Sc1, Sc2, and Sc3 scenarios for different river discharges

to be applied in the specific area, in the future, that will progressively lead to the decrease of agriculture areas and livestock operations, which are the main pollution sources in Evros river catchment. It must be noted that although the population in the study area is expected to be increased, the contribution of urban wastes to total pollution load is relatively small.

Similar studies in Greece (Mimikou et al. 2000) indicated a significant increase in  $\text{NH}_4$  concentrations in Pineios River (Central Greece) as a result of 15 to 18 % mean annual runoff decrease due to climate change. Bouraoui et al. (2004) illustrated a 3 % decrease in the average annual runoff of a Finnish catchment during the period 1965–1998, which is accompanied by an increase of 3 % in the TN and 2 % in the TP, at the studied area. Hadjikakou et al. (2011) estimated a doubling of nitrate concentrations in a Turkish River during the period 2069–2098 as a result of climate change while measures such as the installations of wastewater treatment plants, the creation of meadows, and the control in agricultural practices could maintain the nitrate concentrations close to the 1961–1990 baseline period. Tu (2009) illustrated that climate change and land use changes decrease the streamflow in summer months and increase nitrogen loads during winter without affecting significantly the annual average respective values. Tong et al. (2012) found that water flow and nutrients will increase by 2050, in an Ohio

State watershed as a combined effect of climate change and land use change scenarios which is in accordance with Andersen et al. (2006) findings that revealed a 8 % increase in mean annual TN.

Evros River is one of the most important aquatic systems in the Balkans, while in the river's delta a biotope of international importance exists. Based on the results of the scenarios applied in the downstream part of Evros River, this system is extremely vulnerable to discharge and pollution loads alterations, due to climate and socioeconomic changes that are expected to occur in the next 50 years. In order to protect and preserve this area of high ecological importance, the cooperation between Greece, Bulgaria, and Turkey is essential. A coordinated long-term management plan for the entire catchment of Evros River based on the specifications and requirements of the EU Water Framework Directive (EU 2000) should be developed and implemented. Moreover, environmentally friendly land use policies should be established at an international level, which could offer considerable perspectives for the sustainable development of the area. Agroenvironmental measures, biological farming, wastewater treatment facilities, and eco-friendly industrial technologies could provide the means to protect the hydrologic regime of this region and eliminate the dominant pollution pressures.

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