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Influence of Land Use Changes on Alluviation of Volvi Lake Wetland (North Greece)

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Abstract

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The study deals with Volvi Lake, the second largest natural lake in Greece, where gradual alleviation and a land use change have taken place in the last 60 years. The aim of the study was to estimate the influence of land use changes of the area on sedimentation and alluviation rate. Due to the lack of sediment measurements the Gavrilovic model was used to calculate the mean annual erosion of the two main drainage basins of the Lake for 1945 and 2007. Field research, orthophotographs, and topographic maps dating from 1945, 1971, and 2007 were used to determine the evolution of the vegetation cover and lake shoreline, in order to compare and evaluate the Gavrilovic model results. An increase of 6% of the forested area in combination with the improvement of scrublands quality were enough to cause a 15% decrease of the mean annual sedimentation, according to the Gavrilovic model, as well as a 50% decrease in alluviation rate, according to delta change measurement, comparing the periods 1945–1971 and 1971–2007. The importance of vegetation for soil protection was clearly demonstrated, indicating that reducing the land use and enhancing the vegetation quality could slow down the erosion process.

Keywords: erosion; Gavrilovic model; GIS; sedimentation; soil

Erosion and sediment deposition processes are generally determined by four factors – land use, geology, climate, and morphology, which all interact with human interference. Vegetation is the basic factor that could be influenced by humans, either positively or negatively. This is a topic of great interest to scientists as well as local communities, and several studies on the land use and its influence have been conducted so far. Kosmas *et al.* (2000) evaluated the effect of a long-lasting land abandonment on soil properties and vegetation establishment and defined critical soil characteristics for changing the use of land from arable to an abandoned pasture for soils formed on different parent materials, in order to monitor the possible regeneration and concluded that there is a crucial soil depth, that determines the extent of vegetation regeneration. Therefore, the factor of land use is of great significance and can influence the erosion process in a positive or a negative way. Vacca *et al.* (2000) compared the runoff and soil erosion measurements of three hillslopes of different land use and concluded that land use has a significant influence on runoff and erosion rate.

The present research deals with Volvi Lake situated in central North Greece, which is the second largest natural lake in Greece. The lake is under the protection of "Ramsar" Convention and is considered to be one of the most significant wetlands in Greece. Volvi Lake is focused on mainly because of the observed and relatively intense alluviation during the last 60 years. The great significance of Volvi Lake for the local community and the international interest for this protected wetland of inestimable value make the clarification of the causes of the problem a matter of priority.

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Therefore, in an attempt to detect and clarify the causes of this phenomenon, the present work investigates the sedimentation rate, land use changes recorded within 1945–2007, while it correlates the land use changes with the erosion and sedimentation rates, as well as the process, taking into account also the meteorological data, relief, slopes, and geology of the area.

MATERIAL AND METHODS

Study area. Volvi Lake is the second largest natural lake in Greece (North Greece, Thessaloniki and Chalkidiki prefectures) and covers an area of 70.6 km^2. The height level of the lake surface is 37 m a.s.l, while the average and maximum depth is 13.5 m and 23.5 m, respectively. Maximum length of the lake is 21 km, it is 6 km wide, with the perimeter of 56 km.

The study area consists of two watersheds, Apollonia and Melissourgos. The main streams of these two watersheds flow directly into Volvi Lake. The exact area of Apollonia and Melissourgos watersheds is 245.39 km^2 and 195.35 km^2, respectively. The whole study area lies between 23°14'02'' to 23°43'15''E longitude and 40°27'22'' to 40°41'45''N latitude (Figure 1).

The elevation of the area ranges between 1080 m maximum and 60 m minimum, which lies at the outlet point of the basins. The relief of the area could be characterized as relatively steep with an average slope of 23%. The mean annual precipitation in the area is 590 mm, while the mean annual temperature is 11.5°C. The main geological formations of the area are sedimentary (limestone, clay, and marl), igneous (granite), and metamorphic (gneiss) rocks (Figure 2). The area is covered mainly by cropland and to a less extent by bushes and forest.

Gavrilovic model. Due to the lack of the sediment measurement station in the study area, the Gavrilovic model was used for the determination of the mean annual sediment yield (Gavrilovic 1988). It has been usedalso in many previous researches in Greece (Stefanidis *et al.* 1998; Emmanouloudis 2003; Myronidis & Arabatzis 2009) and the Mediterranean (Bazzoffi 1985; Globevnik *et al.* 2003; Mincev & Blinkov 2007; Tazioli 2008; Spalevic 2014), providing satisfying results (De Vente & Poesen 2005). In this model, coefficients depending on slope, vegetation, geology, climate, and erosion condition of the region are applied. The model was applied for the years 1945 and 2007, in respect of which sufficient data were available and possible land use changes were generally expected, due to the social-economic changes that took place in Greece during that period. The data were processed using the ArcGIS software. For each parameter of the model, a different GIS layer was created. In the Gavrilovic model, the mean annual soil loss is calculated by the following formulae (Kotoulas 2001):

$$W_{SP} = T \times H \times \pi \times Z^{1.5} \times F \quad (1)$$

$$T = (t/10 + 0.1)^{0.5} \quad (2)$$

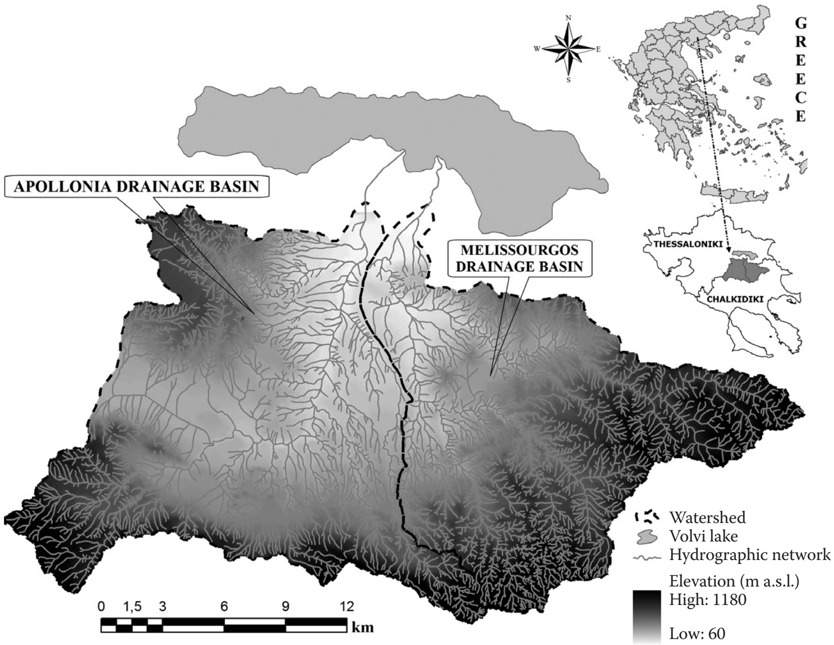

Figure 1. Exact location of the study area in central North Greece

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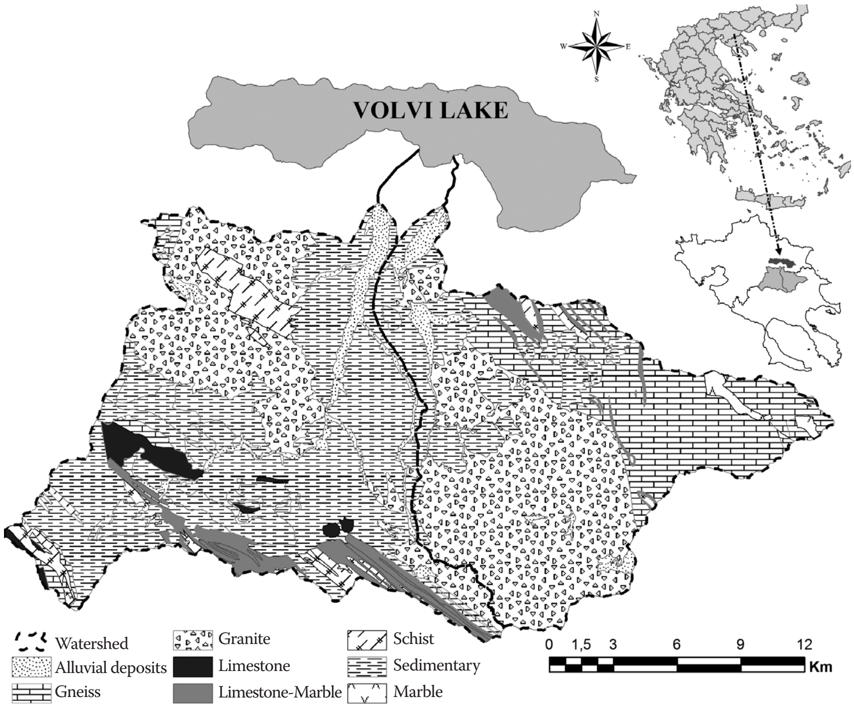

Figure 2. Geological formations of the study area

where:
W_{SP} – annual average erosion (m^3/year)
T – coefficient of temperature
t – annual average temperature (°C)
h – mean annual rainfall (mm)
F – area of the watershed (km^2)
Z – erosion coefficient given by equation:

$$Z = X \times Y \times (\phi + J^{0.5}) \tag{3}$$

where:
X, Y, ϕ – coefficients that depend on vegetation, geology, and the erosion degree of the basin, respectively
J – average slope steepness of the watershed (%)

Z coefficient quantitative values are divided (Gavrilovic *et al.* 2008) into five erosion categories (Table 1).

W_{SP} gives the total yield of erosion process in a catchment. Nevertheless, the sediments generated in a watershed would not necessarily be drifted to the outlet point, but part of them would be deposited in various locations. Retention coefficient (*RU*) estimates this function of sedimentation (Zemlijc 1971):

$$RU = [(O \times D)^{1/2} \times (L + L_i)]/(L + 10) \times F \tag{4}$$

where:
O – perimeter of the drainage basin (km)
D – elevation difference between the mean and minimum elevation (km)
L – length of the main stream (km)
L_i – total length of secondary waterways (km)
F – basin area (km^2)

After the calculation of the *RU* coefficient, the spatial sediment rate (G_{SP}) is estimated using the following equation:

$$G_{SP} = W_{SP} \times RU \tag{5}$$

Table 1. Gavrilovic erosion coefficient (Z) and torrent categorization

Erosion and torrent category	Qualitative name of erosion category	Z	
		range	mean
I	excessive erosion – deep erosion process (gullies, rills, rockslides, etc.)	> 1	1.25
II	heavy or milder forms of excessive erosion	0.71–1	0.85
III	medium erosion	0.41–0.7	0.55
IV	slight erosion	0.2–0.4	0.30
V	very slight erosion	< 0.19	0.10

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Investigation of torrential delta. In order to evaluate and compare the results coming from the Gavrilovic model with the corresponding field measurement results, orthophotographs and maps of the study area were used. The orthophotographs and topographic maps corresponded to data from 1945, 1971, 2007 and according to these data, the change and development of Volvi Lake shoreline was compared and the alluviation rate in Volvi Lake (m^2/year) was evaluated.

Field work and data collection. To analyze hydrographic and morphological characteristics of the watersheds, also topographical maps (1:50 000 scale) were used. Vegetation was assessed based on high resolution orthophotographs dating from 1945 and 2007, on vegetation maps, and on the European Environment Agency data (CORINE land cover survey for 2000). Erosion condition and geology of the two watershedswas determined based on field investigation and geological maps (1:50 000 scale). The geology of the area was divided into five categories, according to its erosion susceptibility to precipitation (Stefanidis 2004). The precipitation and temperature data were provided by two meteorological stations in the region. One of them, Arnaia Meteorological Station is in 595 m a.s.l., located in 40°29'N–23°35'E and the precipitation data acquired from this station refer to the period between 1974 and 2008, while temperature data refer to the period between 1987 and 2008. The second one, Taxiarchis Meteorological Station is in 860 m a.s.l., located in 40°25'N–23°30'E and obtained data of both rainfall and temperature concern the period 1974–2007.

RESULTS

Retention coefficient and morphological characteristics. The Gavrilovic model was used to calculate the mean annual erosion of the two drainage basins.

Table 2. Retention coefficient (*RU*) and basic characteristics of the two drainage basins

Characteristic	Apollonia	Melissourgos
Basin area (km^2)	245.39	195.35
Basin perimeter (km)	91.27	75.72
Basin length (km)	24	22
Basin elevation difference (m)	350	400
Basin mean slope (%)	20.29	26.93
Mean temperature (°C)	11.6	11.6
Mean annual precipitation (mm)	570	590
Temperature coefficient (*T*)	1.09	1.09
Retention coefficient (*RU*)	0.66	0.71

The first step in this direction was the estimation of the X, Y, ϕ, and J parameters, to calculate the erosion coefficient (Z). The basiccharacteristics of the two drainage basins were estimated (Table 2) and then used in order to estimate the erosion coefficient (Z) and the retention coefficient (RU).

Although the area of the Melissourgos drainage basin is quite smaller, if compared to the Apollonia basin, the values given in Table 3 and the results of the field research show that Melissourgos is characterized by very rugged relief and a higher RU value, which crucially affects the total amount of sediments transported into Volvi Lake.

Land use changes during the period 1945–2007. Independently of the year, the area of the forest land of the Apollonia basin is by approximately 33% smaller and its cropland is by 31% larger compared to the Melissourgos basin (Figure 3). In the Apollonia basin, where the agricultural land and bush-grass cover percentage is higher than in the Melissourgos basin, larger amounts of sediment material has been deposited.

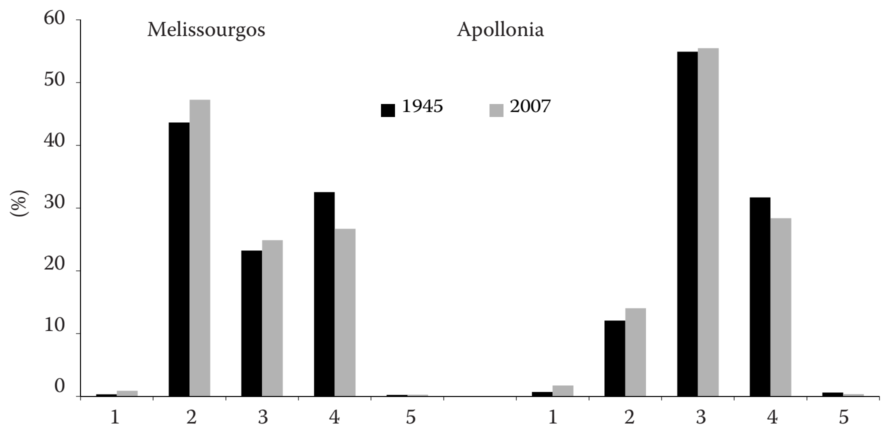

Figure 3. Configuration of the percentage of land uses during the years 1945 and 2007
1 – settlements, 2 – forest, 3 – agriculture land, 4 – bush-grass, 5 – bare soil

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Table 3. Land use (in km^2) and differences between the years 1945 and 2007

Land use	Watershed							
	Apollonia				Melissourgos			
	1945	2007	differences		1945	2007	differences	
			(km^2)	(%)			(km^2)	(%)
Settlements	1.72	4.23	2.51	1.02	0.66	1.71	1.05	0.54
Forest	29.63	34.44	4.81	1.96	85.29	92.34	7.05	3.61
Cropland	134.76	136.1	1.43	0.58	45.38	48.60	3.22	1.65
Bush-grass	77.8	69.69	–8.11	–3.30	63.58	52.17	–11.41	–5.84
Bare soil	1.48	0.84	–0.64	–0.26	0.44	0.53	0.09	0.05
X parameter	0.50	0.46	–	–	0.35	0.30	–	–

Despite the mentioned significant differences between the two basins, there is a remarkable homogeneity in the tendency of the land use changes during the 1945–2007 period. The forested area increased in both the basins, while a decrease in the bush-grass cover was noticed (Table 3). Furthermore, there was a slight increase in cropland area. Due to the gradual decrease of grazing activity in the study area, a part of the bush-grass vegetation area was naturally reforested and another part was converted into agricultural land. Worth mentioning is also the improvement of the remaining bush-grass area quality, while the percentage of the canopy cover and also its density increased.

Geology. The study area is dominated mainly by rocks extremely susceptible to erosion and as a result, great amounts of fine grained sediments have still been generated here. Almost 40% of the area consists of sedimentary rocks (limestone, marble, clay, sandstone, marl, and conglomerate), 30% of gneiss and alluvial deposits, and 30% of granite (Table 4). In general, more than 65% of the study area is formed of highly erodible rocks enhancing erosion and high rates of sedimentation, very frequent and intense phenomena here. Granite is the only rock of the area that is not susceptible to erosion.

Table 4. Geological formation contribution of the two drainage basins

Geological formations	Watershed			
	Apollonia		Melissourgos	
	(km^2)	(%)	(km^2)	(%)
Alluvial deposits	12.20	4.97	7.46	3.82
Gneiss	8.25	3.36	59.32	30.37
Granite	58.18	23.71	88.67	45.39
Limestone	14.90	6.07	–	–
Limestone-marble	7.30	2.97	8.12	4.16
Schist	15.45	6.30	1.66	0.85
Sedimentary	129.11	52.61	30.12	15.42
Total	245.39	100.00	195.35	100.00
Y parameter	0.81		0.66	

The above-given facts are reflected in substantial differences in the two watersheds concerning sedimenation. In the Apollonia basin there prevail sedimentary rocks, while the Melissourgos basin is dominated by granite rocks. The difference in the geological composition of the two watersheds is also projected into the Y parameter of the Gavrilovic model (Table 5).

Gavrilovic model. In Table 5, a significant decrease of the Z value is evident for the years 1945 and 2007, caused mainly by the land use change. This value was decreased in the Apollonia drainage basin, though it still remained in the category of heavy erosion. On the other hand, the decreased Z value in the Melissourgos basin belongs to a moderate erosion category. The great difference in the Z value between the two basins and the spatial distribution is evidenced in Figure 4.

Within 1945–2007, a significant decrease in annual soil loss (W_{SP}) was recorded in both basins,

Table 5. Coefficient of erosion and sediment yield (Z) of the years 1945 and 2007

	Watershed			
	Apollonia		Melissourgos	
	1945	2007	1945	2007
Z	1.13	1.02	0.54	0.45

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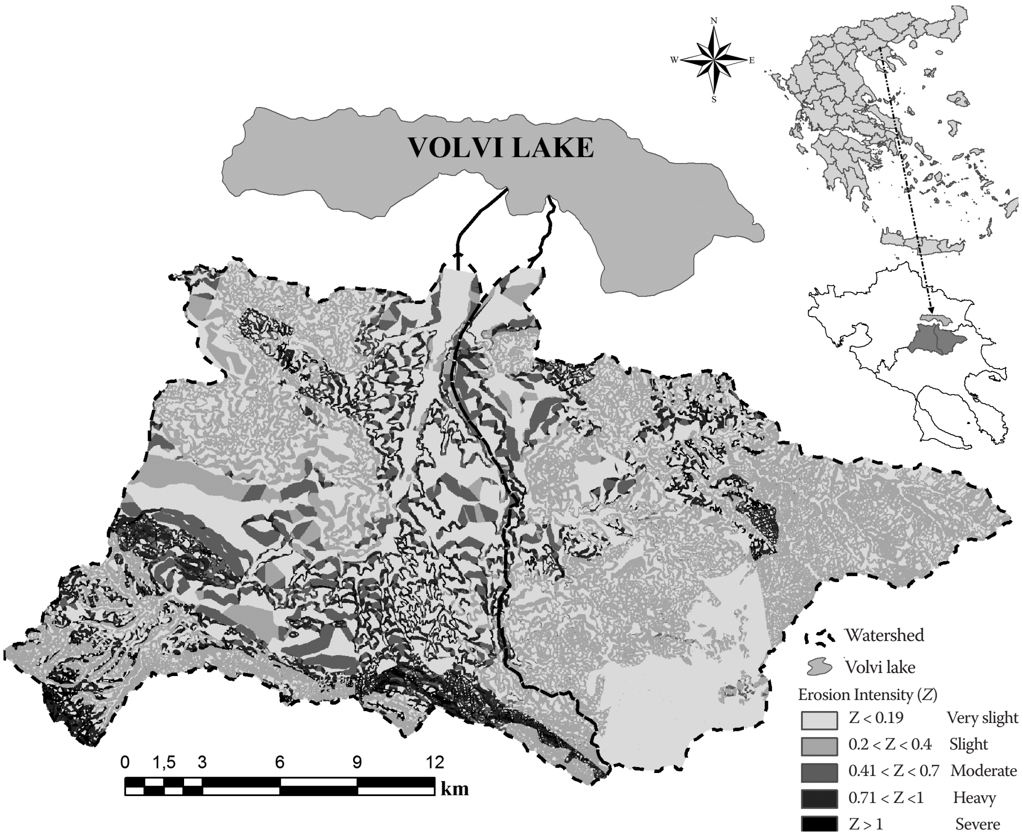

Figure 4. Erosion intensity map of the study area

being higher in the Melissourgos compared to the Apollonia basin (Table 6). Noticeable is the fact that an average increase of about 6% of forest vegetation and a general quality improvement of bush-grass vegetation that took place were enough to decrease the sedimentation rate of both the watersheds by approximately 15%.

The sediment retention role of vegetation is indeed of great significance for the soil protection, but the role of geology of the area is also important. Comparing the spatial sediment soil loss rate (w_{sp}) values of the two drainage basins (Table 6), it was found out that there was by almost 53% higher mean annual sedimentation in the Apollonia than in the Melissourgos basin. This significant difference in sedimentation can be attributed not only to the differences in vegetation of the basins, but also to the highly susceptible geological formations of the Apollonia basin.

Changes in the torrent delta during the periods 1945–1971 and 1971–2007. In order to check and confirm the results coming from the Gavrilovic model, sediment transport measurements were necessary. Due to the lack of data referring to the study area, confirmation of the model was achieved through the measurement of the torrent delta and detection of its evolution for both watersheds. For the accurate determination of the delta evolution, orthophotographs

Table 6. Annual soil loss (W_{SP}), spatial soil loss rate (w_{sp}), and the respective values after the calculation of retention coefficient (G_{SP}, g_{sp})

	Watershed					
	Apollonia			Melissourgos		
	1945	2007	difference (%)	1945	2007	difference (%)
W_{SP} (m^3/year)	576 799	492 988	–14.5	213 322	177 768	–16.7
G_{SP} (m^3/year)	380 687	325 372		151 458	126 215	
w_{sp} (m^3/km^2/year)	2 341	2 009		1 092	910	
g_{sp} (m^3/km^2/year)	1 545	1 326		775	646	

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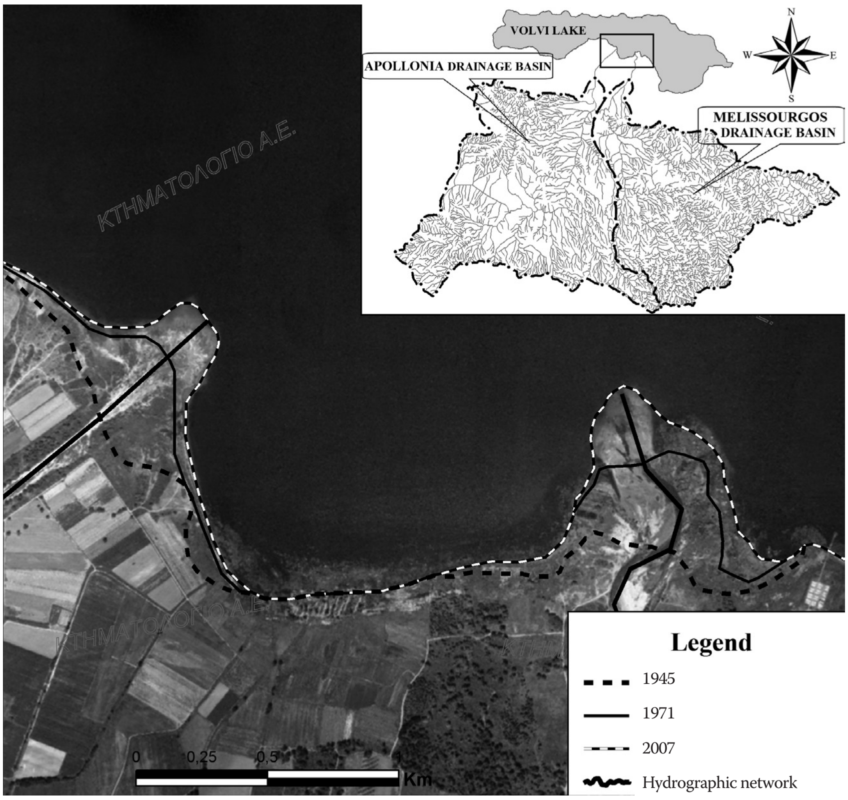

Figure 5. Torrent deltas evolution of the drainage basins

and topographic maps of the years 1945–1971–2007 were used (Figure 5). It is necessary to mention that almost 1% of the Volvi Lake area has been shrunk, due to the alluviation in the last 60 years, and that the corresponding watered area lost during this period was 67.5 ha, referring only to the two studied catchments sedimentation. Moreover, the results of this process revealed a significant decrease in the delta area growth between the periods 1945–1971 and 1971–2007 (Table 7), suggesting that the alluviation rate was decreased.

Remarkable is the fact that the alluviation rate (m^2/year) in the first period 1945–1971 (26 years) was double, compared to the second period 1971–2007 (36 years). It is evident that the gradual land use changes significantly contributed to the sedimentation decrease.

DISCUSSION

The Gavrilovic model showed that during the period 1945–2007 mean annual sedimentation was significantly reduced in both drainage basins. The decrease in the alluviation rate is supported also by the comparison of the torrent delta of both watersheds for the same period. This significant decrease in the alleviation rate was correlated with the land use changes, (increase in forested area) that took place during the last 60 years. The land use changes were caused by the population movement from rural areas to urban centres mainly during the periods 1940–1949 (Second World War, in Greece followed by the civil war) and 1960–1970 (unemployment in rural areas). This movement affected the extent and nature of human activities in the study area,

Table 7. Torrent delta area values during the periods 1945–1971 and 1971–2007

	Watershed					
	Apollonia			Melissourgos		
	1945–1971	1971–2007	difference (%)	1945–1971	1971–2007	difference (%)
Torrent delta area (m^2)	208 240	109 700	–47	222 900	134 000	–42
Alluviation rate (m^2/year)	8 009	3 047	–61.9	8 573	3 622	–57.7

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especially grazing, and gradually the land use was altered, and this fact undoubtedly strongly impacted the sedimentation rate in the area.

Similar findings concerning the impact of land use changes on the sedimentation yield have been mentioned also in previous studies. Zorn *et al.* (2007) mentioned a decrease of 13.5% in sedimentation yield following a small decrease of 5% in cropland area. Yasouri *et al.* (2012) reported on a two-fold increase in sedimentation yield after the rangeland reduction by 13%. After a particular land use/cover alteration (cropland to forest), Solaimani *et al.* (2009) found a sedimentation yield decrease of 89.24%. According to Wayne *et al.* (2002), cultivated basins produced by almost 50% more sediments than the forest/woodland basins. Finally, Haghizadeh *et al.* (2009) suggested that the role of the vegetation cover is especially crucial in the case of areas susceptible to erosion.

Comparing the results stemming from the Gavrilovic model to those from the investigation of torrents delta evolution, some differences emerged. The Gavrilovic model calculated a higher decrease in sedimentation of the Melissourgos watershed, although shoreline measurements indicated a higher decrease in the Apollonia watershed. This difference could be probably explained by the moderate morphology and larger floodplain of the Apollonia watershed, which provided more deposition locations if compared to the Melissourgos basin. Moreover, lake shoreline measurements revealed an approximately 60% decrease of the sedimentation rate, while the Gavrilovic model estimated this decrease to be approximately 15%. In this case, the difference could be attributed to the possible deficient estimation of the density and canopy of scrublands in the years 1945 and 2007, and also to the possible precipitation changes not taken into account in the Gavrilovic model. Nevertheless, the decrease of alluviation rate recorded in the present study is very positive and hopeful for the preservation and the future of Volvi Lake.

CONCLUSION

The results of the present research demonstrated the significant role of vegetation and geological conditions of an area in protection of such invaluable wetlands like Volvi Lake. A relatively low natural enlargement of aforested area and quality enhancement of scrublands can cause an important decrease of sedimentation yield. The present results combined with those from previous researches indicate that drainage basin management plans should be implemented, especially in basins outletting into reservoirs. Reforestation and improvement of scrublands and grasslands quality could be the first step in reducing sediment generation rate and water velocity and thus in decreasing sediment load of reservoirs.

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