Science of the Total Environment 407 (2009) 2501–2516

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

The environmental state of rivers in the Balkans—A review within the DPSIR framework

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A R T I C L E I N F O

Article history:
Received 9 May 2008
Received in revised form 22 December 2008
Accepted 12 January 2009
Available online 15 February 2009

Keywords:
Balkan rivers
DPSIR
Hydrochemistry
Pollution
Hydrology
Sediment

A B S T R A C T

Fifteen major Balkan rivers with over 80% of the inflows in Eastern Mediterranean were examined for their environmental state within the DPSIR framework. Physicogeographic and hydrochemical conditions differ substantially among river basins, which may be roughly classified into three main zones. Despite strong fragmentation, most of the rivers are liable to flash floods and have low summer flow. Decreasing precipitation and (mis)management caused a dramatic discharge reduction over the last decades. Wars, political instability, economical crises over the past decades, combined with administrative and structural constraints, poor environmental planning and inspection and, frequently, a lack of environmental awareness imposed significant pressures on rivers. Large wetland areas were drained in favour of widespread intensive agriculture. The treatment of municipal wastewaters is barely adequate in Greece and insufficient elsewhere, while management and treatment of mining and industrial wastewaters is overall poor. In general, lowland river sections are hydro-morphologically modified and are at the greatest pollution risk, while upstream areas mostly retain their natural conditions. Nutrient concentrations in a number of central and eastern Balkan rivers often exceed quality standards, whereas pesticides and heavy metals, partly of geochemical origin, occasionally exceed quality standards. Reservoirs retain vast masses of sediments, thus adversely affecting delta evolution, while dam operation disturbs the seasonal hydrological and hydrochemical regimes. Almost all Balkan countries face daunting water resource challenges because of urgently needed investments in water supply, sanitation, irrigation, and hydroelectricity. International treaties and designations and European Union Directives have mobilized pollution mitigation and conservation efforts. However, the application of environmental legislation has proved in a number of cases inadequate. Constraints arise from long-standing top-down planning traditions, inadequate planning of national environmental policies, poor administrative capacities, and heavy investment requirements, often combined with a lack of environmental awareness.

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doi:10.1016/j.scitotenv.2009.01.026

1. Introduction

DPSIR (EEA, 2008) stands for Drivers-Pressures-State-Impacts-Response; the components of an analytical framework that links the socioeconomic factors (drivers) forcing anthropogenic activities (pressures), the resulting environmental conditions (state—e.g. concentration of pollutants, disturbance of hydrological regime), the environmental consequences resulting from these conditions (impacts—e.g. eutrophication, fish deaths, water unsuitable for drinking) and, finally, the measures taken to improve the environmental state (response) (Guidance Document Nr. 3, 2003). In the present article, since many of the impacts are not easily measurable, state and impacts were treated together.

Apart from a number of articles focusing on environmental issues of individual (predominately Greek) Balkan rivers and restricted publications summarizing hydrogeochemical and nutrient conditions in Greek rivers (Skoulikidis et al., 1998, 2006), or presenting the micropollutant status of major Greek rivers (Nikolaou et al., 2002; Lekkas et al., 2004; Konstantinou et al., 2006; Kotrikla et al., 2006), a review on the environmental state of rivers in the Balkans is missing.

This article contributes to the filling of this gap according to the analysis of numerous scientific publications, technical reports and data sets. It examines 15 river basins that cover 83% of the Balkan river outflows in eastern Mediterranean and largely encompass the physicogeographical diversity of the Balkan Peninsula. It outlines within a DPSIR framework the physicogeographical conditions of rivers and basins, the socioeconomic drivers and related pressures adversely affecting the hydromorphological and physico-chemical regimes, and summarizes management, conservation and restoration measures.

2. Data set and methods

Hydrological data were obtained from various data sources (see Table 2). Water quality data from Greek rivers are from the Hellenic Ministry of Rural Development and Food (HMRDF) and the Hellenic Ministry for the Environment Physical Planning and Public Works (HME) as well as from scientific publications and technical reports. For the other Balkan countries, such data are often not available or inaccessible. In addition, a number of technical reports and scientific publications are written in the native language. Hence, for the other Balkan rivers, the database of the European Environment Information and Observation Network (EIONET) and information derived from scientific publications and some technical reports were used. Sediment fluxes were obtained from the World River Sediment Yields Database of FAO, related reports and publications.

Hydrological data were analyzed to identify long-term discharge trends and to assess the impact of dam operation to the seasonal hydrological regime. Long-term discharge trends were estimated using linear equations of discharge versus time. The baseflow contribution to river runoff was roughly estimated using multiyear average discharge of June–September compared to the multiyear annual average. Similarly, for the estimation of rainfall contribution to river runoff, the time span between October and March was selected, whereas for snow contribution, April and May were used. For southern Balkan rivers (e.g. Evrotas) March and April were considered as snow melting months. Missing values in water quality time series were filled by interpolation using a formula developed for that purpose (Skoulikidis, 2002). A preliminary classification of nutrient status was carried out by using a respective system developed according to the demands of the WFD for Greek rivers (Skoulikidis et al., 2006).

3. Physicogeographic aspects

The Balkans lay south of the rivers Save, Drava and Danube and is surrounded by the Adriatic and Ionian Seas in the west, the Mediterranean Sea in the south, and the Aegean, Marmara and Black Seas in the east. The term Balkans is often connected with its spectacular mountainous topography. The impressive chain of the Rhodopes (with Mt. Rila, 2925 m) traverses the centre of the Peninsula, throwing out spurs towards the Black Sea and the Aegean. To the north, the high (2376 m at Botev peak) narrow, rounded mountain range of the Balkans (Stara Planina) runs from west to east across Bulgaria. The NNW-SSE running Dinarides–Hellenides mountain range (Dinaric Mts. to Mt. Orthrys in Greece) is the backbone of the western Balkans. Eastwards, Mt. Olympos peaks at 2917 m, the second highest point in the Peninsula.

Altitudinal gradients, diverse mountainous relief, and the influence of the Mediterranean and Black Seas create various climatic conditions in the Balkan Peninsula, ranging from Continental to typical Mediterranean. The climate is characterized by a distinct bimodal seasonality and a strong N–S and E–W gradient. The Adriatic and Ionian basins receive highest precipitation. In the Dinaric Mountains, precipitation may surpace 300 cm, and may reach 550 cm in SW Montenegro. Temperature increases and precipitation decreases dramatically towards the S-SE. This area suffers from prolonged droughts and many river stretches have intermittent flow regimes. The annual precipitation east of the Dinarides–Hellenides Range is 25 to 50 cm less than in the western peninsula and large areas of Bulgaria are characterized by a drought-prone climate (Alexandrov, 1995). The Mediterranean climate, typical for most Albania and Greece, is influenced by local orographic effects.

The area is geotectonically divided in External (zone 1) and Internal zones (zones 2 and 3) (Fig. 1). The External Balkanides extend along the Adriatic and Ionian coasts and are bound to the east by the Dinarides–Hellenides mountain range. They were dominated by the Alpine orogenesis and reveal a rather simple geotectonic structure made up of sedimentary sequences. The Internal Balkanides, east of this mountain range, were additionally affected by older orogenic movements and reveal a complex geotectonic structure dominated by metamorphic massifs, plutonic and volcanic intrusions, and ophiolite suture zones.

Due to its relatively young geology, the Peninsula is characterised by highly fragmented hydrographic networks. It is thus drained by many small and medium-sized mountainous rivers running through steep, narrow valleys, with flashy flow and sediment regimes, descending abruptly to the coast. However, there are a few larger low-gradient rivers crossing the Balkans along prevailing thrust belts and related rift valleys that form extensive flood and deltaic plains.

Of the examined rivers (Fig. 1), the Kamchia flows into the Black Sea, all others into the Mediterranean; eight rivers enter the Aegean Sea (Evros, Nestos, Strymon, Axios, Aliakmon, Pinios, Sperchios and Evrotas), three the Adriatic Sea (Neretva, Drin and Aoos), and three the Ionian Sea (Arachthos, Acheloos and Alfeios). Seven river basins are transboundary. The Drin (Drim), for its relatively small size one of the most international rivers worldwide, flows through Albania and drains parts of Serbia, Montenegro, FYR Macedonia, and Greece. The Neretva flows through Bosnia and Herzegovina (97.5% of its basin) and Croatia. The Evros (Maritsa, Meriç) basin is shared among Bulgaria (66.4%), Greece (27.2%) and Turkey (6.4%). The Strymon basin is mainly located in Bulgaria (50%) and in Greece (37%), with tributaries draining

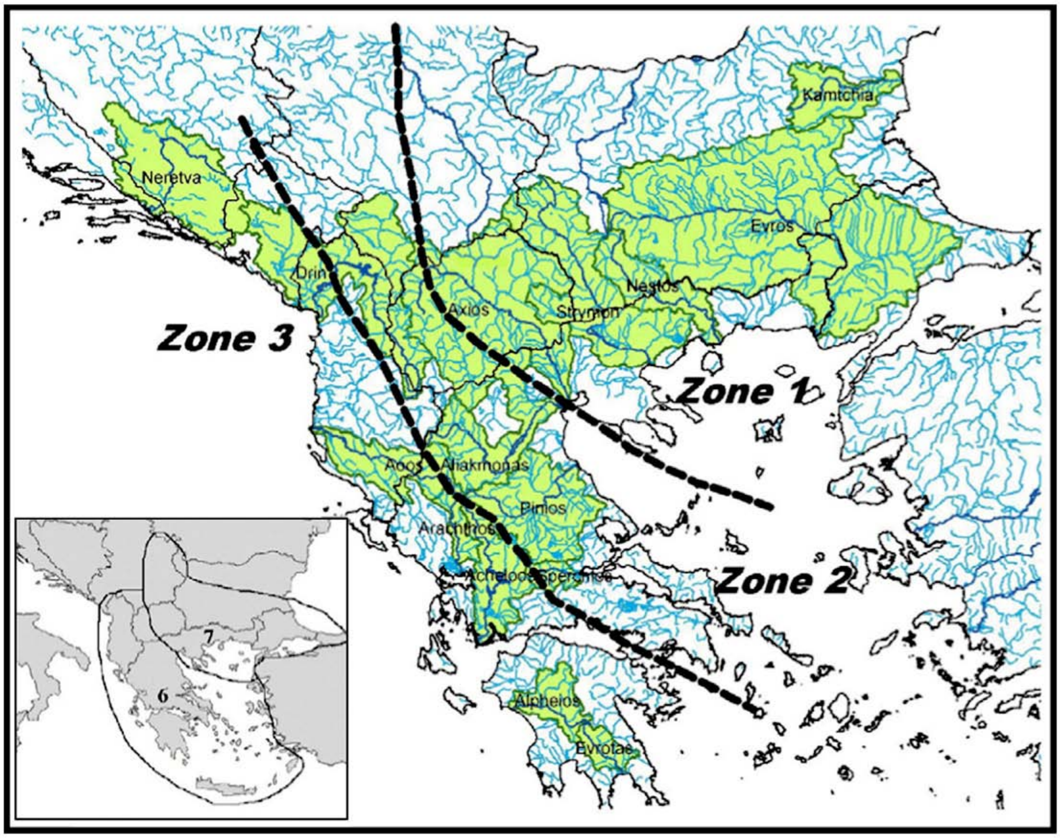

Fig. 1. Map of the examined Balkan rivers. The lines correspond to the borders of three hydrochemical zones. The small map presents the Balkan ecoregions after Illes (1967).

small parts of FYR Macedonia (9%) and Serbia (4%). The Nestos is shared between Bulgaria (60%) and Greece. The Axios (Vardar) enters Greece from FYR Macedonia (83%). Finally, the Aoos (Vjose) flows from Greece towards Albania (64%). The Kamchia is entirely located in Bulgaria, while the Aliakmon, Pinios, Sperchios, Arachthos, Acheloos, Alfeios and Evrotas rivers are entirely in Greece. The catchment area of all 15 rivers totals 182,637 km^2. Six river basins (Evros, Axios, Drin, Strymon, Neretva and Pinios) are considered as very large (>10,000 km^2) and 10 as large (1000–10,000 km^2). The Nestos, Drin, Neretva, Aoos, and Arachthos drain mountainous catchments with mean altitudes >800 m, while the remaining rivers drain mid-altitude (mean altitude: 200–800 m) catchments, with the Kamchia, Evros and Pinios having lowland river sections. Most Balkan rivers form deltaic plains and some of the basins host natural lakes and lagoons. The Narta lagoon is located in Aoos Delta. The lakes Mikri and Megali Prespa (shared between FYR Macedonia, Albania and Greece), Ohrid (shared between FYR Macedonia and Albania) and Shkodra (or Shkadar, the largest Balkan lake, transboundary between Albania and Montenegro) are placed in the Drin Basin. Lake Kastoria belongs to upper Aliakmon. Lakes Trichonis (the largest and deepest Greek lake), Lysimachia, Ozeros and Amvrakia are close to Acheloos Delta, where the Mesolonghi and Aetoliko lagoons are located. Lake Doirani (Dojran) (shared between FYR Macedonia and Greece) is in lower Axios. Finally, the Kerkini semi-natural lake is situated at the lower portion of Strymon basin. Most of these wetlands are of international importance (Section 7.1). Table 1 summarizes physiographic and socioeconomic characteristics of all catchments.

4. Socio-economic drivers

Economic drivers differ among regions. Mining activity is extensive in Bulgaria and Albania, industry is developed in Serbia, Bulgaria, FYR Macedonia and Bosnia and Herzegovina, agriculture is widespread in Greece, Albania and Serbia and Montenegro (now separate states), while hydroelectricity is more important in Albania, Croatia, Bosnia and Herzegovina and Serbia and Montenegro. After the end of the communist era and due to the civil Yugoslav wars, Balkan countries experienced a major decline in mining, industrial and agricultural activities. However, more recently, political stability gradually leads to a reconstruction of these economic sectors.

In Greece, mining and industrial activities are limited. Heavy industry is concentrated mainly to large urban centres and seasonally operating food processing comprises the main industrial uses. The other Balkan countries have developed significant mining and industrial activities (e.g. metallurgical and chemical industries) during the communist era. The contribution of the industrial sector to GDP is as low as 20% in Greece, while in the other Balkan countries it ranges between 38% in Serbia and Montenegro and 25% in Bosnia and Herzegovina (World Bank, 2003). Moreover, in Croatia and Bulgaria, half of the water resources (53 and 45% respectively) supply industrial uses. Mining and industrial activities are particularly intense in the Evros, Axios and Drin basins and moderately developed in Nestos and Strymon basins.

During the last decades, rising overall trends in agricultural intensification are apparent in the plains, especially in Greece, with increasing agrochemical consumption, and extensification in mountainous areas (Caraveli, 2000). The agriculture sector's contribution to GDP is maximum in Albania (55%), followed by Serbia and Montenegro (25%), while it ranges between 10 and 17% in the other Balkan countries. Agriculture is by far the most important water consumer in Greece (89%), FYR Macedonia (80%), and Albania (72%) (World Bank, 2003). Today, about 40% of the examined river basins are cultivated. This corresponds to a total area of ~75,000 km^2. The Evros, Pinios Kamchia, Aliakmon and Alfeios drain the most intensively cultivated basins (Table 1).

In Albania, Croatia, Bosnia and Herzegovina and Serbia and Montenegro, hydroelectricity represents a substantial source of power

Table 1
Physicogeographic and socioeconomic characteristics of the Balkan river basins, modified from Skoulikidis et al. (2008)

	E m	CA km^2	L m	P cm	T °C	Q km^3	SQ l/skm2	F1	F2	Geol	Ur	Ar	Ps	For *	Gr-SpV	IW-W	Inh [a]10^3	AGDP [a]10^3
Neretva	848	13311	255	117.7	9.2	11.9	28.3	3	2	car	0.7	16.3	18.5	20.2	43.2	1.1	650	2.0
Aoos	849	6813	260	100.2	11.8	5.55	25.8	1	0	car	1.0	16.0	0.5	35.7	46.2	0.6	301.5	4.4
Arachthos	807	1907	105	91.2	12.9	2.08	34.6	1	0	car	0.6	19.3	20.0	24.7	33.9	1.5	53.5	9.3
Acheloos	744	6478	255	80.8	13.5	4.38	21.4	3	2	car	0.7	22.2	0.0	26.3	46.3	4.5	178	12.0
Alfeios	690	3637	112	76.2	13.9	2.1	18.3	0	2	car	0.8	38.6	0.9	17.2	42	0.5	95.3	10.8
Evrotas	654	2418	90	73.3	14.0	0.76	10.0	0	0	car	0.7	34.6	0.0	15.8	48.8	0.1	73	11.4
Drin	868	20585	285	105.3	8.9	11.4 (21.4)[b]	17.5 (26.3[b])	3	2	si	0.7	21.7	4.3	36.6	31.4	5.3	2011.3	2.6
Aliakmon	771	8880	310	67.1	10.6	2.7	9.6	1	1	si	1.1	39.3	0.4	30.4	27.0	1.8	317.2	13.2
Pinios	431	10743	257	72.0	13.3	2.55	7.5	0	1	si	2.1	51.1	1.6	10.9	34.0	0.3	576.1	12.3
Sperchios	685	1493	82	64.4	13.2	0.703	14.9	0	0	car	1.3	31.4	0.2	32.4	34.5	0.2	42.3	15.1
Axios	747	24604	380	62.9	9.9	3.62	6.7	0	2	si	1.4	34.0	8.1	32.1	23.7	0.7	2042	3.2
Kamchia	311	5338	245	57.7	11.1	0.607	5.2	1	1	si	4.5	40.6	3.4	44.7	5.8	1.0	255.7	1.8
Evros	400	53078	550	62.9	11.2	~7.0	~4.2	0	2	si	2.7	53.4	5.1	26.7	10.3	1.8	3643	2.9
Nestos	100	6265	246	64.8	9.6	2.08	10.5	2	2	si	1.2	18.2	0.8	56.4	21.9	1.5	205	6.7
Strymon	715	17087	410	60.8	10.1	4.31	8.0	2	1	si	2.4	34.5	2.0	35.8	24.2	1.1	975.4	6.6

E: mean catchment elevation, CA: catchment area, L: river length, P: mean annual precipitation, T: mean annual air temperature, Q: mean annual discharge, SQ: Specific discharge, F1: fragmentation, main channel (0–4), F2: fragmentation, tributaries (0–2) (for criteria see Dynesius and Nilsson, 1994), Geol: geology, si: silicate, car: carbonate, Ur: urban areas, Ar: arable land, Ps: pasture, For: forest, Gr-Sp: natural grassland–sparsely vegetation, IW–W: inland waters–wetlands, Inh: inhabitants. AGDP: Annual Gross Domestic Product ($ per person).

[a] Land use data are approximate values.

[b] With Buna.

(97, 62, 59 and 40%, respectively, of total energy production). In FYR Macedonia, the share of hydropower is about 20%, in Greece and Bulgaria ~10%. Dams along the Drin River supply major energy for Albania (about 90%, i.e. 1350 MW, of total power production; World Bank, 2003). Similarly, the Neretva River (installed capacity: 1120 MW) is a main energy source for Bosnia and Herzegovina (EIA, 2006). In Greece, the mean annual hydropower production is ~3000 MW (Power Public Corporation). Most reservoirs have multi-purpose functions (e.g. irrigation, urban water supply, cooling of thermoelectric plants, aquaculture and recreation) and around 30% of the usable volume of reservoirs is allocated for irrigation (Power Public Corporation).

Other economic activities comprise forestry in mountainous areas, a declining industry, fisheries in lakes, lagoons and estuaries, ecotourism and cultural tourism, extraction of salt from lagoons and inert material from river beds. The most important lakes for fisheries are Lakes Shkodra, Trichonis, Ohrid, Kerkini, and Prespa. Important lagoons for fisheries are the Mesolonghi lagoons in the Acheloos Delta and the Narta lagoon in the Aoos Delta. Salt is harvested from Mesolonghi and Narta lagoons. Protected areas, where the local economy was formerly based on agriculture and forestry, play an increasingly important role for ecotourism and recreation. For example, Lake Ohrid has been declared as a mixed cultural/natural heritage site by UNESCO, which stimulated the local tourist market (ILEKF, 2005). Other protected areas of major tourist interest include the Vikos-Aoos and Valia Kalda (Aoos) and the Pirin (Nestos) forest national parks, the Nestos Delta, the Amvrakikos wetlands (Arachthos-Louros Delta), and Lake Kerkini.

5. Environmental pressures

Up to the 19th century, when major shifts of settlements and land use ensued, many areas in the Balkans were considered a wilderness and were scarcely populated (Mazower, 2002). In the 1920–30s, massive land reclamation took place in Greece to create new land for people displaced from Asia Minor. Further, extensive wetland areas were drained in all Balkan countries to produce agricultural land. In the past 50 years, huge drainage and irrigation networks were established and inter-basin water transfer projects took place, e.g. from Trebisnjica River to the Neretva and from the Strymon and Nestos headwaters to the Iskar and Evros basins (Knight and Staneva, 1996).

In the 1950s, the first large dams were constructed. Nowadays, most rivers are "strongly fragmented" by dams and flow regulation (Table 1, for criteria see Dynesius and Nilsson, 1994). The Evros, Axios, Pinios, Alfeios and Aoos are "moderately fragmented", while only Sperchios and Evrotas are free-flowing. The most modified river is the Acheloos. In its headwater and middle sections, four large reservoirs exist and two more are under construction. These reservoirs will cover >150 km^2 with a total storage capacity of ~6.6 km^3, ~1.5 times the total annual discharge. Moreover, ~0.15 km^3/yr is transferred to the Pinios basin and additional 0.6 km^3/yr is planned to be transferred to the same basin. In the Evros basin, there are 21 large reservoirs, mainly along Bulgarian tributaries (four in Arda and three in Tundja) with a total storage capacity of about 3.4 km^3. The Drin has two hydropower plants in FYR Macedonia and three in Albania, of which Fierza, covering 97 km^2, is the largest in Albania. In the middle section of Aliakmon three reservoirs cover 81 km^2 and can store ~2.9 km^3. In the Neretva basin, five hydropower plants impound a total area of 36 km^2 and store ~1.1 km^3. In Nestos basin, there are six reservoirs in Bulgaria situated on river tributaries, whereas in Greece two large hydropower reservoirs (area 56 km^2, storage volume 0.8 km^3) (an additional one is under construction) and a small irrigation dam are found along the main stem. Two reservoirs situated at lower Arachthos cover 21 km^2 and can store ~0.8 km^3. 17 large dams for irrigation and flood control are located at Axios River tributaries in FYR Macedonia with a total storage capacity >0.5 km^3 and a small irrigation dam at its Delta. In the Kamchia basin there are three large reservoirs serving irrigation and drinking water supply. In the Bulgarian part of Strymon, 56 multipurpose reservoirs are placed with a total storage capacity of 0.14 km^3. In the Greek section, a dam for flood control transformed the former Kerkini wetlands into a large semi-natural lake. In Alfeios, there is a small multipurpose dam at the Ladon tributary and in the Aoos headwaters a small reservoir diverts ~10% of Aoos water towards the Arachthos basin.

Since Greece joined the European Union in 1981, major efforts have been devoted to control municipal wastes. However, small villages still have simple sewage systems (permeable seep-tanks) and there is evidence of poorly functioning, or even not operating, Waste Water Treatment Plants (WWTPs) in the smaller towns. In the other Balkan countries, municipal waste water is rarely treated and even large towns are not served by sewerage systems. The treatment of mining and industrial wastewaters is overall poor, while all countries face substantial solid waste management problems and have a great number of illegal, uncontrolled landfills. A reduction in economic activities due to political instability resulted in an improvement of environmental conditions. Recently, potential polluting industries have been reactivated (e.g. Rastall et al., 2004), while those previously equipped with WWTPs have often not maintained their facilities.

With the exception of the Drin, where iron, chromium, nickel and copper mining and processing are intense, pollution pressures in the western Balkan basins are less extensive than in the central and eastern ones. The Neretva is moderately affected by untreated municipal and industrial wastewaters, i.e. metallurgy effluents and wastes from light industries. The Aoos, Arachthos and Acheloos catchments remain in a semi-natural state and only their downstream portions are affected by partly treated urban effluents and small-scale industries. In contrast, the Axios River is heavily affected by mostly untreated municipal wastewaters and effluents from metal and chemical industry in FYR Macedonia. The lower Aliakmon is densely populated and receives partly treated wastewaters from small agro-industrial units and the effluents from a long irrigation canal. Lignite combustion units in the city of Ptolemais (lying just outside the basin) are also a major source of air pollution (SO_2, heavy metals) for the entire area. The Pinios is affected by partly untreated municipal and agro-industrial wastes, e.g. sugar factories, paper mills, slaughterhouses, olive-presses and dairies. The Sperchios is dominated by semi-natural features, particularly in its upper and mid portions. Sewage of a number of small towns and villages, olive oil refineries and small manufacturing units remain untreated or partly treated. The Alfeios is mainly affected by the Megalopolis lignite power plant that causes high SO_2 emissions, whereas the Evrotas is mainly influenced from >90 olive oil presses. The Kamchia receives annually ~1.85 Mm^3 industrial and 15.3 Mm^3 municipal wastewaters (Mihailov et al., 2005). The Evros basin hosts 3.6 million people. In the Bulgarian part of the basin, mining activities are intense and mostly untreated effluents from heavy and light industry are released into the river. In Turkey, industrial activities are concentrated around Edirne, whilst the Greek part of the basin is less industrialized. Due to its rough relief, the Nestos basin has a low population density and contains relatively natural upland areas. Toxic industrial effluents come from timber industries and uranium mining at Eleshnitza, which is scheduled to cease (NATURNET, 2006). Industrial activity in the Bulgarian part of the Strymon basin is relatively intense (Mihailov et al., 2001). In the Greek part, partly treated industrial (mainly from food-processing industries) and municipal wastewaters are discharged into the river (HMD, 2003).

6. State and impacts

6.1. Hydromorphology

The total river runoff in the European Mediterranean region is ~330 km^3/yr (UNEP/MAP, 2003). All Balkan rivers contribute 85 km^3/yr. The rivers included in this study contribute 83% (70 km^3/yr) to the Balkan discharge, or ~21% to the European Mediterranean runoff. Because the eastern Balkan basins exhibit a semi-arid climate, specific discharge is low, ranging between 4 and 14.9 L s^{-1} km^{-2}. The western Balkan basins are characterised by high precipitation and specific discharge ranges from 18.3 to 34.6 L s^{-1} km^{-2}. The Drin and Neretva rank 3rd and 4th in total annual discharge of all rivers in the Mediterranean region after the Rhone and the Po Rivers.

The rivers' hydrological regime depends on the seasonal distribution and type of precipitation (rain or snow), as well as on hydrogeological features (e.g. karstic or alluvial aquifers, degree of surface/subsurface flow interactions). Table 2 presents the hydrological characteristics of

Table 2
Hydrological characteristics of the Balkan rivers in m^3/s, modified from Skoulikidis et al. (2008)

River	Station	Period	A (km^2)	NQ	MNQ	MQ	MHQ	HQ	MHQ/MNQ	MAX/MIN	Discharge trend % (period)	Source
Neretva+	Opuzen	1946–05	13,300	23	48.3	69.5	114	193	2.4	1.7		Croatian Meteorol. & Hydrol. Service
	Metcovic	1946–05	12,311	43	60.7	93.2	163	297	2.7	2.0		
Drin	Ura e Dodes	1976–84	5400	27	47.8	98.2	164	302	3.4	2.9	−31 (1965–84) at Kalimash	UNESCO
	Van Deze	1960–68	12,368	13	66.8	339	613	772	9.2	11.2		
Kamchia	Gzozdevo	1936–86	4857	0.09	3.74	21.8	69.5	191	18.6	8.0	−38 (1936–86)	
Aoos	Konitsa	1963–71	665		4*	27	58*			14.5	−24 (1964–87)	Therianos (1974)
	Dorze	1965–84	5420	21	36.1	146	260	595	7.2	7.7	−19 (1965–84)	
Evros	Plovdiv	1936–85	7931	2	14.2	51.6	123	258	8.7	5.0	+7.5 (1936–85)	UNESCO
	Harmanli	1965–79	19,693	1.6	20.4	113	272	516	13.3	3.2		
	Svilengrad	1936–85	35,165	0.7	27.1	110	299	911	11.0	5.1		
Nestos	Thisavros	1998–2005	3698	2.2	31	52.6	76	96.6	2.5	1.5		PPC
	Platanovrisi	2000–2006	4090	3.8	15.2	36.3	73.4	112	4.8	2.2		
	Temenos	1966–89	4394	2.7	9.7	44.5	111	199	11.4	6.5	−0.8 (1966–06)	GRDC
	Stavroupoli	1989–2000	5509	0	4.4	26.4	84.4	406	19.2	3.5		Darakas (2002)
Strymon	Radzavitza	1965–79	2171	1.5	3.5	11.7	30.5	41	8.7	4.2		UNESCO
	Krupnik	1965–79	6777	5	13.5	47	111	157	8.2	5.0		
	Roupel	1951–56/29–32	10,800		27*	110	228*			8.4		Therianos (1974)
Axios	Skopje	1978–90	4650	6.6	24.3	57.3	102	164	4.2	4.2		GRDC
	Axioupoli	1961–2000	20,200	3.4	29.7	115	275	949	9.2	6.4	−57 (1961–00)	EUROCAT
Aliakmon	Ilarion	1962–88	5505	2.1	4.57	48.3	138	369	30.1	16.6		PPC
	Polifito	1975–2006	5800	0	10.9	43.8	88.8	184	8.1	3.2	−12 (1963–06)	
	Sfikia	1986–2006	6030	15	59.5	80.8	125	196	2.1	2.0		
	Asomata	1986–2006	6180	0	8.6	58	89.6	191	10.4	3.1		
Arachthos	Tsimovo	1965–2003	640	0.250	3.51	18.2	51.1	97	14.6	13.9	−30 (1963–76, 1982–06) at Arta bridge	
	Pournari	1950–80	1778		11.5*	62	130.9*			11.4		
	Pournari I	1982–06	1778	0	4.9	45.5	129	235	26.4	8.0		
	Pournari II	1999–2006	1845	0	8.1	49	113	145	13.9	12.1		
Acheloos	Kremasta	1980–2006	3570	1.9	48.3	96.7	182	320	3.8	1.9	−12 (1980–06)	
	Kastraki	1980–2006	4118	13	60.7	116	244	1118	4.0	1.9		
Pinios	Giannouli	1903–11/32–42/51–56	8563		11*	81	171*			15.5		Therianos (1974)
Sperchios	Kobotades	1932–41/49–59	1165		12*	62	110*			9.2	−48 (1950–90)	
Alfeios	Alfeiousa	1949–56	3534		21*	67	145*			6.9		
Evrotas	Vrodamas	1974–04	2000	0	0	2.9	10.4	21.9	–	20.1	−84 (1974–06)	HMRDF

A: catchment area upstream of gauging station, NQ: lowest measured mean monthly discharge, MNQ: arithmetic mean of the lowest measured mean monthly discharge, MQ: arithmetic mean annual discharge, MHQ: arithmetic mean annual of highest mean monthly discharge, HQ: highest measured mean monthly discharge, + water level, * arithmetic mean of month with minimum/maximum discharge, MAX/MIN: ratio between the month with maximum discharge and the month with minimum discharge, PPC: Public Power Corporation, HMRDF: Hellenic Ministry of Rural Development and Food.

the examined rivers. They reveal a strong seasonal regime, mostly flashy in nature and with low summer flow. In regulated (Neretva, Nestos, Aliakmon, Acheloos) and karstic (Neretva, Acheloos, Alfeios and the Strymon-tributary Aggitis) rivers, as well as in the upper Strymon, the upper and middle Evros and the middle Drin, the seasonal variation between the long-term maximum and minimum monthly discharge is low to moderate, ranging between 1.5 and 7 (Table 2). In contrast, the lower parts of Drin, Strymon and Evros, the upper Aliakmon, the Kamchia, the Aoos, the Arachthos, the Pinios, the Sperchios and the Evrotas show high seasonal hydrological variation with ratios ranging between 8 and 20 and are prone to floods. Rock permeability also affects other runoff characteristics. For example, the Aoos and Arachthos basins reveal high stream density (>0.90 km/km^2), high runoff coefficient, low baseflow contribution in river runoff, and flashy flow due to the dominance of flysch. In contrast, the Neretva basin, despite a high annual precipitation, has a low stream density because water is 'lost' in karstic aquifers. The correlation between the ratio and the percentage contribution of rainfall and baseflow in river runoff shows that high baseflow and low rainfall contribution smoothes seasonal hydrological variations (Fig. 2).

Over the past 40–45 years, the Balkan rivers have undergone dramatic discharge reduction (Table 2—discharge trends), a common phenomenon for the entire Mediterranean region (UNEP/MAP, 2003), caused by climate variability and change, evaporation from reservoirs and extensive water abstraction for irrigation. Dry periods (e.g. at the end of 1980s–beginning 1990s) act cumultive creating major water shortages. After reservoir construction the annual flow of the Kamchia decreased from 0.87 to 0.61 km^3/yr (Jaoshvili, 2002). In Pinios basin, intensive use of water for agriculture deteriorated the water balance, which is strongly negative even in rainy years (Loukas et al., 2007) and resulted in lowering of the groundwater table by tens of meters (Marinos et al., 1997). In summer, river stretches in Pinios may dry out, and in Evrotas intermittent flow regime dominates vast portions of the rivernet, as a result of water abstraction for irrigation (Skoulikidis et al., 2008). Since the end of the 1990s, the water level of Lake Doirani has been receding as a result of drought and overexploitation for irrigation (Griffiths et al., 2002). Dam operation smoothes and modifies the hydrological regime downstream of reservoirs. Thus, Acheloos, Nestos and Aliakmon nowadays present high to maximum discharge in July due to peak hydropower production. In Acheloos, 30% of the annual flow occurs during summer (compared to 11% prior to dam construction). Finally, the Arachthos reservoirs diminish intra-annual flow variations but only slightly alter the relative seasonal flow regime.

Agricultural development and reservoir construction resulted to dramatic morphological modifications in water bodies. Lakes Yiannitsa, Amatovou and Ardjan in lower Axios, Lake Achinos and the marshes of Philippi in Strymon area, Lake Karla in Pinios basin, the Agoulinitsa and Mouria lagoons at the Alfeios outflow, and extensive marshes related to river deltas, were drained out. Thus, Greece lost 60–70%, of its original wetlands (Tsiouris and Gerakis, 1991). Due to reservoir construction, the Neretva, Acheloos, Arachthos, Aliakmon, Nestos and Evros experienced dramatic reduction in sediment transport, deltaic and sand barrier erosion, upstream propagation of the sea, and salinization of aquifers and of coastal lagoons (Glamuzina et al., 2002; Mertzanis, 1997; Kapsimalis et al., 2005; Stournaras, 1998; Kanelopoulos et al., 2006). Flow regulation in the Kamchia has caused degradation of riparian vegetation and localized habitat loss. Other morphological alterations include river channel straightening and embankment The Neretva has been already channelled in the 1880s. The lower parts of Evros, Aoos, Acheloos, Sperchios and Evrotas and almost the entire Strymon River in Greece are straightened and embanked, whereas riparian vegetation has been removed (e.g. the Nestos Delta lost 80% of the virgin Kotza Orman forest, Ministry of Environment Baden-Württemberg 1990). Finally, extraction of inert material from riverbeds for construction material or for flood control (e.g. at Evrotas) favours bed incision (e.g. at Drin and lower Alfeios).

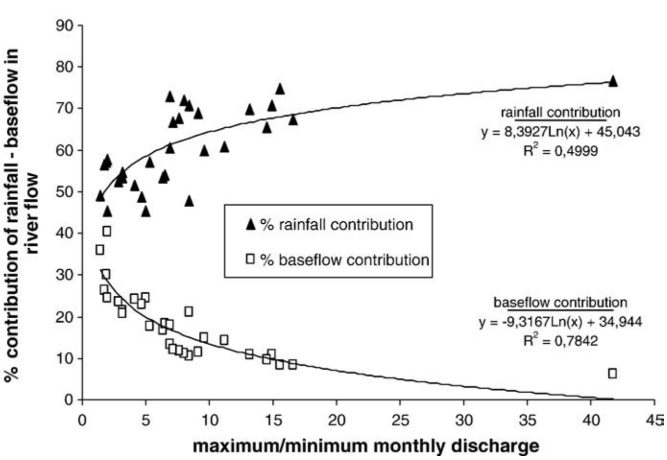

Fig. 2. Correlation between percentage contribution of rainfall—baseflow and the ratio maximum to minimum monthly discharge in major Balkan rivers.

6.2. Hydrogeochemistry

In Greece, medium and large rivers are being monitored for their chemical quality since the 1970s at monthly intervals (HMRDF and recently HME), while a number of studies focused on their hydrogeochemical regime and pollution status (Skoulikidis, 1993; Skoulikidis et al., 1998; Nikolaou et al., 2002; Lekkas et al., 2004; Konstantinou et al., 2006; Skoulikidis et al., 2006).

Geology and climate are the main controllers of the hydrochemical regime of southern Balkan rivers (Skoulikidis, 1993; Skoulikidis et al., 2006). Geochemical and hydrogeological variability as well as precipitation patterns affect water temperature and solute concentrations. Further, wastewater discharges, reservoir outflows and water abstractions locally affect chemical composition (e.g. Skoulikidis et al., 1998, 2006). The majority of the Balkan rivers belong to the calcium-carbonate hydrochemical type ($Ca>Mg>Na>K–HCO3>SO4>Cl$, in meq/l), similar to the average of rivers worldwide (Meybeck, 1981). The Aoos headwaters are of a magnesium carbonate type ($Mg>Ca$). In Evros, Acheloos and Kamchia, and in Nestos and Aliakmon headwaters, sodium is the second dominant ion while chloride is in Acheloos and Arachthos. The southern Balkan rivers belong to three hydrochemical zones (Fig. 1). Zone 1 basins (Evros, Nestos, Strymon and Axios) are of an acid silicate type with low air temperature. Zone 2 basins (Aliakmon, Pinios, and Sperchios) belong to a mafic silicate type, together with low precipitation. Zone 3 basins (Aoos, Acheloos, Arachthos, Alfeios and Evrotas) are of a carbonate type and with high precipitation and runoff to the north (Skoulikidis et al., 2006). Zones 1 and 2 correspond to Ille's ecoregions 6 and 7, while zones 2 and 3 correspond to the geologically (and hence geochemically) and climatically diverse Internal and External Hellenides. This hydrochemical zonation may be broadly applicable to the entire Balkan Peninsula. For example, the Kamchia basin lies in the extension of zone 1; the Drin belongs almost entirely in the extension of zone 2, while the extension of zone 3 covers the Neretva basin. Rivers in the northern part of zone 3 (Acheloos, Arachthos and Aoos) are only slightly mineralized due to high precipitation (causing dilution) and the dominance of poorly leached soils in their catchments (Skoulikidis, 1993). In the Peloponnese (Alfeios and Evrotas), mineralization increases southwards as climate becomes semi-arid. Evrotas, at the southern part of zone 3, exhibits the maximum mineralization of all examined Balkan rivers. Rivers in zone 2 (Aliakmon, Pinios, Sperchios and Aoos headwaters) present hard waters and are enriched with magnesium carbonate due to mafic rock weathering. In zone 1, the prevalence of magmatic and metamorphic rocks with sulfide ore dykes cause low (Nestos, Kamchia) to medium (Strymon, Axios)

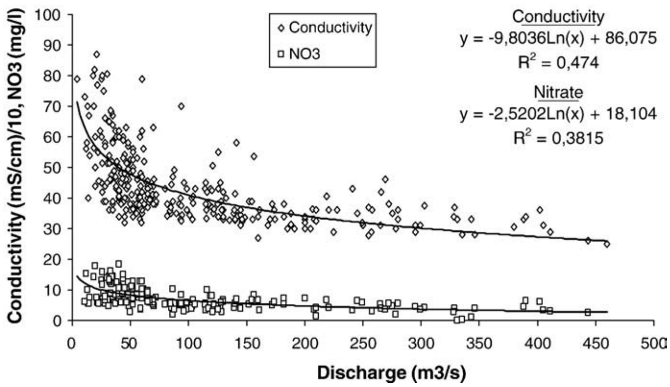

Fig. 3. Correlation between discharge and conductivity—nitrate in Axios River at Axioupoli (GR-FYROM border) (data HMRDF, 1971–96). Adapted from Skoulikidis et al. (2008).

mineralization associated with high alkali and sulfate ion percentages (Evros, Kamchia, Nestos, Strymon, Axios) and generally medium hardness. Despite its position within zone 1, Evros presents exceptionally high mineralization (caused by elevated sulfate concentration), as a result of human impact (mining, industrial and municipal wastewaters) (Skoulikidis, 1993). The Alfeios has the second highest sulfate concentration behind Evros due to gypsum dissolution and lignite mining and combustion (Skoulikidis et al., 2006). Increased chloride concentrations are caused by municipal wastes (Evros, Evrotas, and Axios), marine deposits (Sperchios), evapotranspiration (Lake Doirani), and/or marine aerosol (Acheloos, Arachthos).

Solute concentration increases downstream and is proportional to the percentage of recent (Neogene and Quaternary) sediments in the river basins. This is due to the downstream increase in surface/groundwater interaction, evapotranspiration and pollution, and to the high weathering and dissolution capacity of unconsolidated sediments (Skoulikidis, 1991, 1993). Most Balkan rivers reveal larger temporal than spatial hydrochemical variation governed by the factors drought, dilution, and flash flows (Skoulikidis and Kondylakis, 1997). In general, specific conductance peaks during base flow conditions and is lowest during spring (snowmelt) and winter (maximum rainfall). Thus, an inverse relationship between discharge and conductivity is commonly apparent (e.g. Fig. 3). Such rivers are of a "dilution type" (Skoulikidis, 1993). Floods are associated with salt flashing and may enhance solute concentrations. The Aliakmon, upstream of the reservoirs, is a characteristic "flash type" river showing maximum mineralization in winter. The Axios shows increased flashing in autumn. Karst dominated rivers with weak seasonal runoff fluctuations, such as the Neretva, Aggitis and Evrotas, show low seasonal solute variations. Regulated rivers reveal an artificial chemograph. For example, in Acheloos, mineralization is low in summer as a result of carbonate precipitation in upstream reservoirs and high in winter due to inputs of hypolimnion waters (Skoulikidis, 2002). The increase in solutes during the afforementioned dry period demonstrates the impact of climate variability on river hydrochemistry (Fig. 4). At that time, the conductivity in Axios rose by ~40% compared with previous years (Skoulikidis, 2000).

6.3. Water quality

6.3.1. General

Table 3 shows long-term average concentrations of dissolved oxygen and nutrients (also presented in Fig. 5) at national monitoring stations and illustrates an indicative nutrient quality status according to Skoulikidis et al. (2006). Existing data are sometimes restricted. For example, data from the Neretva, Drin, Kamchia and Aoos (in Greece and Albania) are annual averages (that include missing months) from 3 to 9 years, whereas for Sperchios and Evrotas are from one year measurements (Dassenakis et al., 2005; Nikolaidis et al., 2006). This fact may reduce the representativeness of a part of the data presented in Table 3 and Fig. 5. Data for the other rivers correspond to multiyear monthly measurements. To increase comparability among rivers, data from the lowermost monitoring stations were used.

In general, rivers located in zone 3, i.e. Aoos (Greek part), Neretva and Alfeios are at least polluted, while the Kamchia, the Evros and the Axios are probably the most polluted Balkan rivers (Skoulikidis, 1993; Dassenakis et al., 2006), along with the downstream of Drin. Of the entire Greek rivers, the Pinios shows maximum pollution and of the rivers entering Greece, Nestos is at least polluted (Fytianos et al., 1987; Skoulikidis, 1991).

Balkan rivers show satisfactory oxygenation with mean oxygen concentrations ranging from 10.5 (Sperchios) to 7.2 (Kamchia) mg/L. On average, minimum monthly values range from 9.5 (Aliakmon) to 5.8 (Evros) mg/L. Oxygen concentrations <5 mg/L are only sporadically recorded (e.g. Evros: 4.2% of all measurements).

The Drin exhibits the highest nitrate concentration (Table 3), followed by Evros, Pinios and Axios and score "bad" nitrate quality. Aoos (in Albania), Evrotas and Strymon exhibit "poor" nitrate status. Nestos, Kamchia, Alfeios, Acheloos, Aliakmon, Sperchios and Neretva present a "moderate" and Aoos (in Greece) a "good" status. Concerning nitrite, Evros, with a maximum concentration, has a "bad" status, followed by Aoos (in Albania), Axios, Kamchia and Evrotas which have "poor" status. The Drin, Strymon, Nestos, Pinios, Aoos (in Greece), Acheloos and Aliakmon are classified as "moderate", while the Neretva, Sperchios, Evrotas and Alfeios have "good" nitrite status. Maximum ammonia levels place Kamchia in "poor" status and Aliakmon, Evros, Axios, Nestos, Strymon, Pinios, Sperchios, Acheloos and Evrotas in "moderate" status, while the rest of the rivers (Alfeios, Evrotas, Aoos/Vjose, Drin and Neretva) have "good" status.

The ammonia share of DIN shows dramatic variations. In the Drin, minimum ammonia proportion is observed (0.7–1.1%). In Neretva, a 10-fold downstream ammonia concentration increase is evident (0.5%

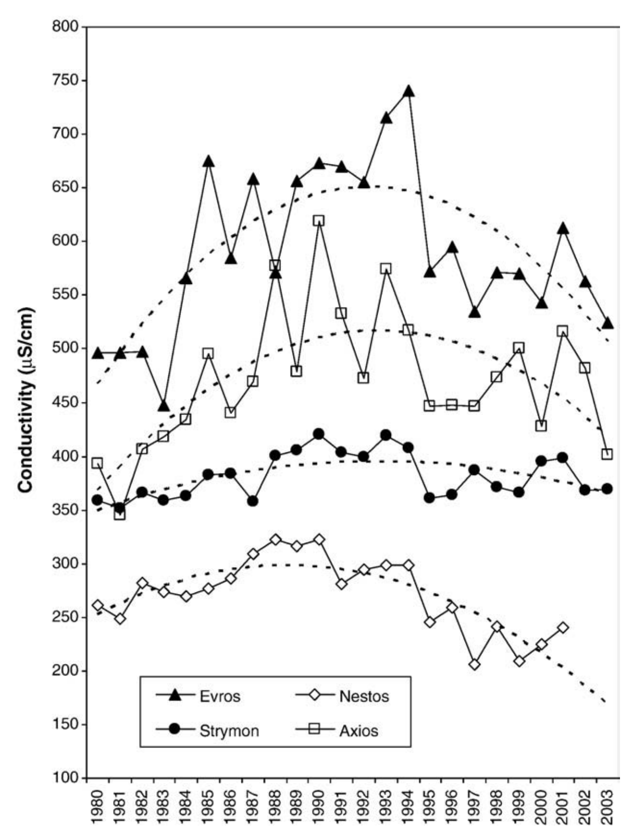

Fig. 4. Inter-annual variation of conductivity in transboundary Balkan rivers (data HMRDF).

Table 3
Water quality characteristics of the Balkan rivers and indicative nutrient quality status according to the classification system of Skoulikidis et al. (2006), modified from Skoulikidis et al. (2008)

River	Station		DO	N-NO_3	N-NO_2	N-NH_4	TP	Source, period (comments)
			mg/l	mg/l	µg/l	µg/l	µg/l	
Neretva	40159	Average	9.78	0.62	5.7	37	28.5	EIONET, 2003–05
	(near mouth)	Median	9.9	0.59	39	28	26.7	(from annual averages, N = 3)
		Range	5.1–12.1	0.27–1.01	2.5–20	5–160	0.005–0.08	
Drin	A1RV2	Average	8.6	4.60	16.3	37.75	175	EIONET, 1994–01
	(near L Shkodra)	Median	8.6	1.465	16.3	35.25	31	(from annual averages, N = 6)
		Range	2–12	0.035–12	1–65	10–80	9–90	
Vjose	A1RV20	Average	8.9	1.71	63.8	44.3	29.1	EIONET, 1995–05
	(near mouth)	Median	8.9	1.67	14.3	51.5	28.9	(from annual averages, N = 9)
		Range	6.1–10.4	0.01–6.8	1–1200	12–210	12–75	
Aoos	Konitsa	Average	10	< 0.22	10	< 36	19.6	HME, 1984–87
	bridge	Median	10.1	< 0.1	64	< 19		(from annual averages, N = 4)
		Range	6–15.2	< 0.1–2.20	< 0.3–47	<19–222		
Acheloos	Neochori	Average	11.1	0.82	27	87	66	HMRDF
	(near mouth)	Median	11.2	0.58	4.9	53	29	(interpolated data)
		Range	8.2–13.5	0.018–4.00	0.30–198	22–599	10–413	
		Count	65	94		54		
		Period			1989–01			
Alfeios	Floka dam	Average	10.1	0.69	< 5.5	< 54	< 16	HME, 1983–97
	(near mouth)	Median	10.1	0.70	< 3.6	< 19	< 10	(from annual averages, N = 15)
		Range	8–12.2	< 0.1–1.30	0.00–44	< 19–222	< 10–65	
Evrotas	Basin average	Average	8.9	1.21	21	65	< 21	Nikolaidis et al. (2006)
		Median	9.0	1.17	16	50	< 18	(May, September 2006)
		Range	6.6–11.8	0.43–2.26	5–75	30–172	< 10–71	
Axios	Bridge	Average	9.7	1.86	60	87	634	HMRDF
	Axioupoli	Median	10.0	1.62	6	44	506	(interpolated data)
	(near border)	Range	2.2–13.5	0.004–5.1	0.30–1704	1.9–1154	26–4359	
		Count	228	240		192		
		Period	1980–95	1980–00		1980–95		
Aliakmon	Ilarion	Average	10.9	0.68	8	140	20	HMRDF
		Median	11.0	0.49	5	23	10	(interpolated data)
		Range	6.0–14.5	0.005–3.64	0.09–137	2.3–13246	1–118	
		Count	192	240		180		
		Period	1980–95	1980–00		1980–94		
Pinios	Larisa	Average	10.5	1.92	13	63	77	
		Median	10.7	1.60	8	36	65	
		Range	1–14	0.08–12.1	0.30–213	6.2–709	2–340	
		Count	201	241		181		
		Period	1979–95	1979–00		1979–94		
Sperchios	Basin average			0.75	5.2	83.2	15.2*	Dassenakis et al. (2005)
Kamchia	28066	Average	7.15	1.23	49.5	737.7	337.5	EIONET, 1992–04
	(near mouth)	Median	7.56	1.03	44.1	484.5		(from annual averages, N = 3)
		Range	4.6–8.5	0.65–2.81	21.3–107	124–1480	0.80–4.40	
Evros	Dikea	Average	8.9	3.47	165	105	668	
	(near border)	Median	9.4	3.18	18	31	555	
		Range	1.2–12.5	0.02–22.4	0.30–3729	0.67–1675	65–2668	
		Count	78	91		91		
		Period	1980–95	1980–01		1980–94		
Nestos	Papades	Average	9.8	1.24	14	84	136	HMRDF
	(near border)	Median	10.0	1.04	5	36	111	(interpolated data)
		Range	3.1–13.2	0.02–5.78	0.30–164	3.9–1089	10–627	
		Count	220	250		190		
		Period	1977–95	1980–01		1980–95		
Strymon	Rupel	Average	10.0	1.46	16	63	144	
	(near border)	Median	10.2	1.30	2	33	114	
		Range	2.6–13.4	0.30–5.40	0.30–312	7.8–436	18–1255	
		Count	192	264		192		
		Period	1980–95	1980–01		1980–95		

high	good	moderate	poor	bad

N = number of measurements, *P-PO4.

in Bosnia and Herzegovina and 5.6% in Croatia). In the majority of Greek rivers (Evros, Nestos, Strymon, Axios, Pinios, Alfeios), the ammonia share of DIN ranges between 2 and 6%. The Acheloos, Aoos, Aliakmon and Sperchios show higher ammonia portions (10–17%). In Bulgarian river stretches, ammonia comprises even higher percentage (21–23% in Nestos, Strymon and Kamchia, 25–28% in Evros and its tributaries Tundja and Arda), indicating organic pollution. The Axios in FYR Macedonia shows the maximum ammonia portion (44%), reaching 75% and 89% downstream of Skopje and Veles, respectively. The organic fraction of dissolved nitrogen is 50% in the upper Aliakmon and 65% in the upper Drin, while in rivers with relatively higher impact of agriculture, compared to organic pollution, the organic fraction decreases; 40% in the lower Acheloos, 35% in lower Axios, 33% in T66 (a long irrigation ditch entering Aliakmon) and 11.5% in lower Strymon (data: Skoulikidis et al., 2001; Voutsa et al., 2001; Ovezikoglou et al., 2003; Borgvang et al., 2006).

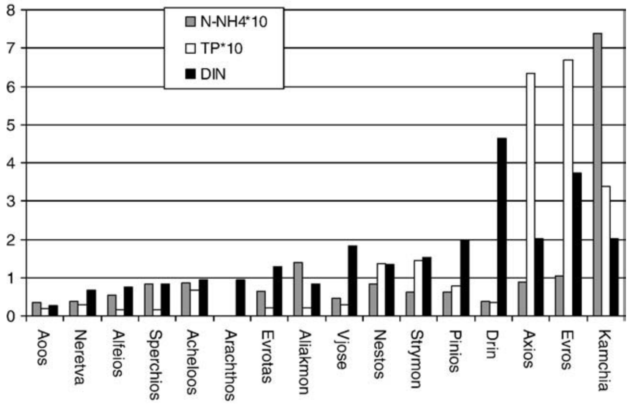

Fig. 5. Concentrations of dissolved inorganic nitrogen (DIN), ammonia and total phosphorus (TP) in major Balkan rivers (for data sources and period of measurements see Table 3). Adapted from Skoulikidis et al. (2008).

Rivers in zones 3 (Neretva, Drin, Aoos/Vjose, Acheloos, Alfeios and Evrotas) and 2 (Aliakmon, Pinios and Sperchios) have the lowest total phosphorus (TP) concentrations (Fig. 5) and reveal a "high" TP status. The carbonate matter of these basins may act as phosphorus sink. Strymon and Nestos have "good" TP status, Kamchia "poor", while Evros and Axios a "bad" status. The organic fraction of TP is high even in upstream river portions (e.g. 62%, 54% and 50% in the upper parts of Acheloos, Drin and Aliakmon, respectively) indicating natural enrichment. In the lower parts of the Acheloos, Aliakmon, Neretva and Drin, the organic fraction ranges between 57 and 75%, indicating additional organic inputs of upstream reservoirs, while the high portion in Evros (70%) is attributed to organic pollution (data: Skoulikidis et al., 2001, 2002; Voutsa et al., 2001; Ovezikoglou et al., 2003; Borgvang et al., 2006).

According to Lekkas et al. (2004), the pollution of Greek rivers from compounds of List II referred to in Directive 76/464/EC, and other toxic compounds, shows low concentrations of VOCs and insecticides, whereas the concentrations of herbicides and metals (despite high geochemical background) generally range around moderate levels. Regarding pesticides, the most polluted rivers are the lower portions of Axios and Aliakmon. *S*-triazines, amide herbicides, and organophosphorus insecticides are the most frequently detected, while organochlorine pesticides (banned in Greece in 1972) occur at very low concentrations (Konstantinou et al., 2006). The highest levels of organochlorines, occasionally exceeding the EC qualitative standards, were detected in interregional water bodies, especially near the borders (Evros, Nestos, Strymon, Axios, Small Prespa, Doirani) denoting transboundary pollution (Golfinopoulos et al., 2003; Lekkas et al., 2004; Papadopoulou-Mourkidou et al., 2004; Konstantinou et al., 2006). In Axios, lindane (phased out in Greece since 2002, according to Directive 2000/801/EC) was detected in 100% of the samples at the entrance of the river to Greece, demonstrating the impact of lindane manufacturing in Skopje (Konstantinou et al., 2006). Concerning insecticides, methyl parathion, parathion (withdrawn since 2003) and diazinon were compounds previously detected in most Greek rivers, followed by fenthion, carbofuran and malathion. The highest insecticide levels were recorded for the lower Axios (up to 2000 ng/L for malathion, parathion, and pyrazophos, 362 ng/L for parathion methyl and 7300 ng/L for carbofuran), while fenthion's maximum was observed in Evrotas (Konstantinou et al., 2006). Several organophosphorus insecticides were detected, mainly in the Evros, Nestos, Strymon, Aliakmon, Acheloos, Pinios, Alfeios and Lake Prespa. Regarding herbicides, atrazine, simazine (withdrawn in Greece since 2004), metolachlor, alachlor and prometryne were most frequently detected (Lekkas et al., 2004; Konstantinou et al., 2006; Kotrikla et al., 2006). The highest concentrations of simazine (117 ng/L) and cyanazine (63 ng/L) were found in Strymon (Lekkas et al., 2004), of prometryne in Aliakmon (6100 ng/L) and of propanil in lower Axios (20,600 ng/L) (Konstantinou et al., 2006). Captafol, captan, chlorothalonil, metalaxyl, flutriafol and vinclozolin were the fungicides found in the Axios, Aliakmon, Nestos and Evrotas (Konstantinou et al., 2006). Concerning VOCs, hexachlorobutadiene exceeded the quality target level (0.1 μg/L) in the Axios, Strymon, Nestos and Pinios. In the transboundary rivers, a number of VOCs presented elevated concentrations near the border (e.g. 4-chlorotoluene and napthalene in Strymon, 1,1,2-trichloroethane in Nestos) denoting transboundary pollution, while others (e.g. 1,3-dichlorobenzene in Strymon) were attributed to Greek sources (Nikolaou et al., 2002).

Dissolved heavy metal levels were compared with world averages and background levels (Hart and Hiness, 1995). The Axios is possibly the most polluted river due to geochemical (ophiolite ores and mixed sulfides), mining and industrial sources (Levkov and Krstic, 2002; Milovanovic, 2007). In the Greek part of the catchment, the river is also enriched in metals (Karageorgis et al., 2003), while high K-40 levels in plants were attributed to the dominance of igneous rocks in the basin (Sawidis et al., 1995). According to Lekkas et al. (2004) and Karamanis et al. (2006), highest toxic metal concentrations are present in the Strymon (6.39 μg/L As), Evros (9.17 μg/L Pb; world average 1 μg/L), Axios (43.6 μg/L Zn; world average 30 μg/L and 1.15 mg/L Al), Aliakmon (5.3 μg/L Pb, 224.8 μg/L Zn and 15.1 μg/L Cu; world average 10 μg/L), Pinios (40.3 μg/L Cr, 51.1 μg/L Ni; world average 2.2 μg/L, 4.0 μg/L Pb, 57.9 μg/L Zn, 5.35 μg/L Co and 23.7 μg/L Cu) and in L. Doirani, which generally shows elevated geogenic heavy metal concentrations, especially for As (51.5 μg/l). The Alfeios has high Fe and Mn levels (5.7 and 0.26 mg/L, respectively). The lower portion of the Drin is affected by high geochemical background for Cr, Cu, Fe, Ni, and mining activity, resulting in elevated heavy metal concentrations in sediments (Neziri and Gössler, 2004). Moreover, in the Neretva, agrochemicals cause relative high concentrations of Hg in freshwater fish (Has-Schön et al., 2006). Core sediments of the Axios and Aliakmon reveal high anthropogenic Cd flux in recent decades (Samanidou et al., 1991). Finally, Sawidis (1996), who studied the levels of radioactive contamination in eleven rivers and lakes of northern Greece, found that the Axios, the Pinios and L. Prespa were most contaminated with Cs-137 and Cs-134 as a result of the Chernobil accident (1986), while high Ra-226 and Ra-228 levels in lakes Polifito (Aliakmon-reservoir) and Prespa were caused by lignite combustion.

6.3.2. Spatial variations

In general, nutrients exhibit a downstream increase in their concentrations caused by a cumulative increase in human pressures, with some exceptions due to the contribution of local point pollution sources. For example, the Axios exhibits dramatic ammonia and phosphorus increase downstream Veles and, especially, downstream Skopje (Fig. 6) as a result of municipal and industrial inputs. The

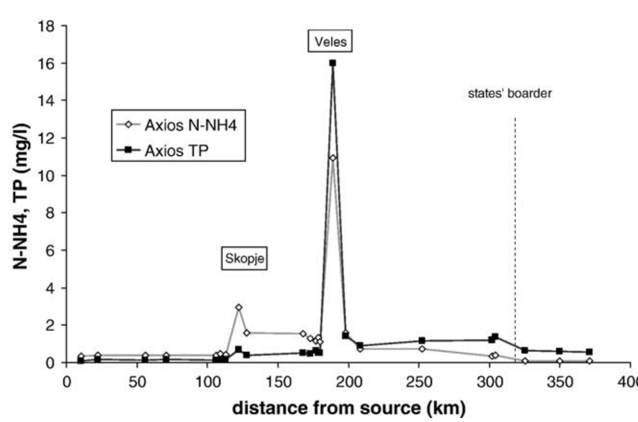

Fig. 6. Ammonia and TP variation along Axios river (period: 1997–1999; Karageorgis et al., 2005).

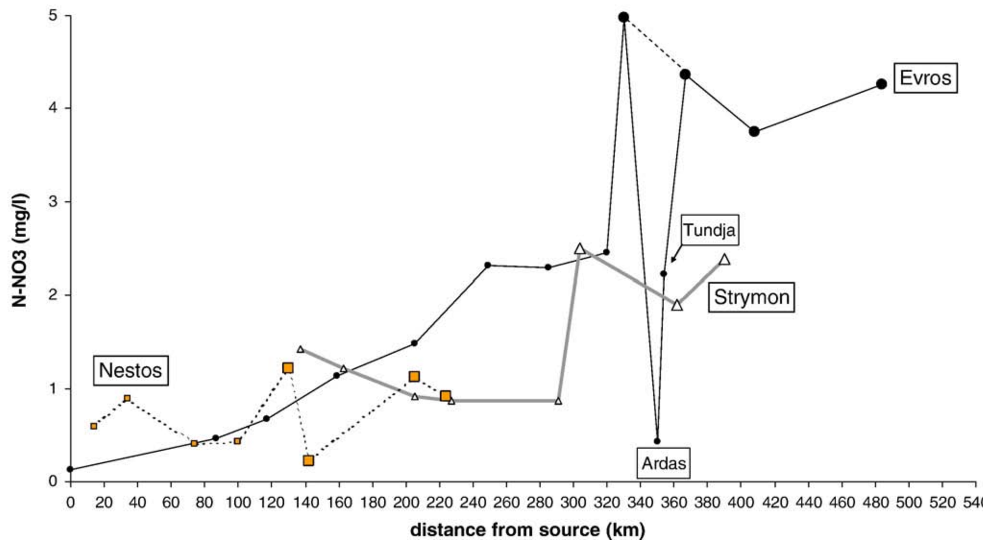

Fig. 7. Nitrate variation along Evros (2002), Nestos (2003) and Strymon (average 2003–04) rivers (data: EIONET, HMRDF). Bigger symbols refer to the Greek monitoring sites.

Neretva shows a TP maximum at Jablanica (115 Rkm) due to the impact of municipal wastewaters. Moreover, the Drin tributaries in the area of Lakes Prespa and Ohrid show relatively high nutrient concentrations, ranging between 0.18 and 3.2 mg/L for DIN and between 57 and 257 μg/L for TP due to municipal wastewater inflows (Borgvang et al., 2006). However, most of the river headwaters reveal "pristine" nutrient levels. For example, in the headwaters of the Aoos the DIN and $P\text{-}PO_4$ levels are as low as 0.03 mg/L and 5 μg/L (Chatzinikolaou et al., 2008). In rivers entering Greece from Bulgaria and FYR Macedonia, there is a steep increase in nitrate associated with a decrease in ammonium at the Greek border stations (Fig. 7). Since nitrate pollution sources between the border stations are insignificant and because it is unlikely that ammonia nitrification alone can account for the observed differences, it seems probable that diverse techniques and methodologies are employed in the different states for the determination of these constituents.

6.3.3. Intra-annual variations

Minimum oxygen concentrations occur in summer. In Axios, Aliakmon (upstream of the dams) and Strymon, the correlation coefficient (r^2) between monthly water temperature and dissolved oxygen range from 0.78 to 0.91 indicating that oxygen concentration is mainly physically driven. In Pinios, Nestos (upstream of the Greek reservoirs) and Acheloos (downstream of the reservoirs), the coefficient varies between 0.63 and 0.45, suggesting a higher biological influence, while in Evros no correlation exists between water temperature and oxygen. In fact, Evros, Nestos and Acheloos have high oxygen concentrations in summer as a consequence of increased photosynthesis, in-stream (Evros, Nestos) or in upstream reservoirs (Acheloos).

In general, Balkan rivers are enriched with nitrate in winter (December–February) as a result of arable land flashing (in Aliakmon mainly in autumn), while dilution during spring and insignificant nitrate inputs in summer keep nitrate concentrations low (Skoulikidis and Kondylakis, 1997). In contrast, in Acheloos, nitrate levels reach maximum in summer as a result of the input of nutrient-laden hypolymnion waters from upstream reservoirs. If nitrate concentration is correlated against discharge, some rivers (e.g. Evros, Strymon and Aliakmon) show an increase in nitrate concentration with discharge, indicating the prevalence of agricultural land flashing, while others (e.g. Axios and Nestos) show a nitrate decrease with discharge, indicating the prevalence of dilution processes (see Fig. 3). TP exhibits maximum levels at the rising limb of the hydrograph (mainly October) due to initial flashing. Ammonia peaks that occur in winter or spring may be attributed to organic matter mineralization. Increased TP and ammonia levels during low flow originate from municipal and industrial (e.g. seasonal food processing industries) effluents, although

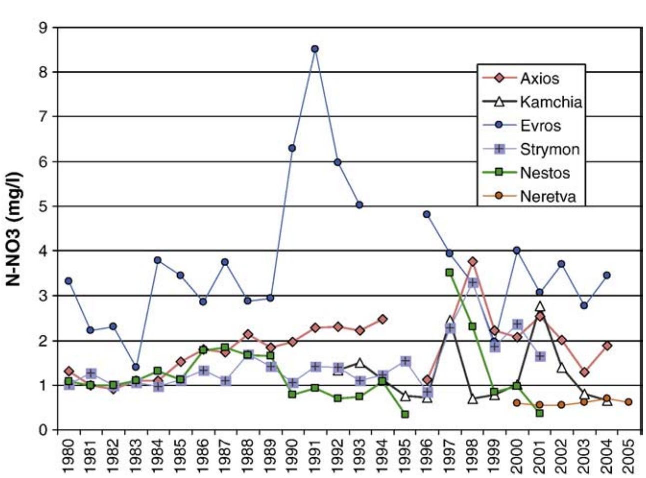

Fig. 8. Long-term variation of nitrate concentration in major Balkan rivers (data: EIONET, HMRDF). Adapted from Skoulikidis et al. (2008).

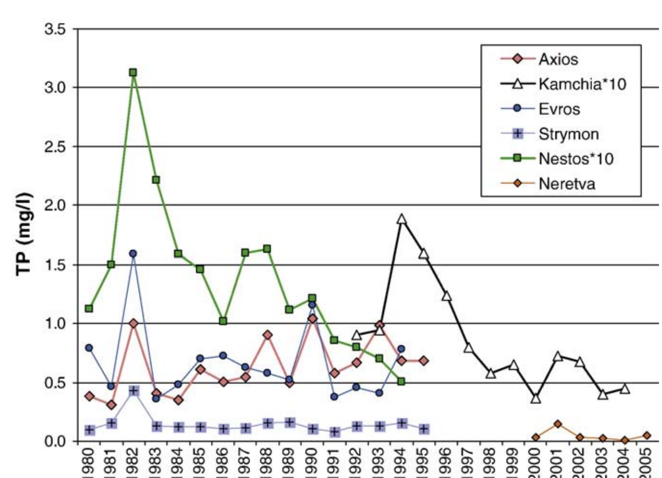

Fig. 9. Long-term variation of total phosphorus concentration in major Balkan rivers (data: EIONET, HMRDF). Adapted from Skoulikidis et al. (2008).

for ammonia denitrification processes (e.g. in the Pinios by standing waters) cannot be excluded.

6.3.4. Inter-annual variations

Regarding long-term nutrient variation (Figs. 8 and 9), during the initial period of measurements, the Evros, Nestos, Strymon, Axios and Pinios show a, more or less, gradual increase in nitrate concentration reflecting agricultural intensification. These rivers, together with Aliakmon and Acheloos, show substantial concentration increases in the dry period (end of the 1980s–beginning of the 1990s). In the Evros, a decreasing trend is evident after 1991. In the Nestos, Strymon, Axios, Aliakmon, Pinios and Acheloos after a subsequent decrease, nitrate increased again to reach the multi-year maximum in 1997–98 and since then gradually diminishes (not in Aliakmon). The Kamchia shows peak nitrate values in 1997 and 2001. All rivers show high to maximum TP concentration in 1982 (the Acheloos in 1981). In the Evros, Axios and Acheloos, a second peak appears in 1990 that coincides with minimum discharge. After the 1982 peak, TP shows a clear decrease in the Nestos, a slight decrease in the Strymon, an increase in Axios and Pinios and no clear trend in the Evros, Aliakmon and Acheloos. In the Kamchia, TP concentration increased in 1995–97 and thereafter gradually decreased, with a peak in 2001, being also evident in the Neretva.

6.4. Sediment transport

Table 4 presents sediment transport data of the rivers examined. Many of the data are approximations due to inadequate monitoring. Most reliable are data upstream of reservoirs, where sediments were regularly monitored for long periods prior to dam construction.

Balkan rivers tend to have naturally high sediment fluxes due to high relief ratios, high seasonal climatic variation, easily erodible rock formations, and sparse vegetation. Fluxes have further increased by massive deforestation, fire, grazing, and mining (e.g. in Ardas River). The estimated total natural sediment flux of all rivers examined is 115 Mt/yr (UNEP/MAP, 2003; Eurosion, 2004). In the western Balkans (Arachthos, Aoos, Acheloos, Drin, and Neretva basins), high precipitation in combination with flysch bedrock cause specific sediment yields of 1000 to 16,000 $\mathrm{tkm}^{-2}\ \mathrm{yr}^{-1}$. In autumn, heavy initial rains on desiccated soils often cause landslides causing 50 to 95% of the annual sediment transport (Poulos et al., 1996). In the eastern basins, where magmatic and metamorphic rocks prevail (Kamchia, Evros, Tundja, Nestos, Strymon and Axios) and sediment transport mainly peaks during

Table 4
Sediment transport by the major Balkan rivers

River Tributary	Site	Area km^2	Sediment flux Mt/yr	Sediment yield t/km^2 yr	Source	Period—Comments
Neretva	~Mouth	12,429	13.58	1093	Eurosion (2004)	2000
Drin	Kukes	4956	2.93	591	FAO (2006)	1960–63—natural
	Can Deje	12,368	14.72	1190	FAO (2006)	1960–63—natural
		14,200	16.66	1173	UNEP/MAP (2003)	natural
Aoos	Konitsa	666	0.62	938	Poulos and Alexandrakis (2005)	1963–83—natural
		706	1.52	2151	Zarris et al. (2006)	~1965–80—natural
	Mouth	6700	8.38	1251	UNEP/MAP (2003)	natural
Kamchia	Mouth	5358	1.12	209	Jaoshvili (2002)	natural
			0.46	86	Jaoshvili (2002)	regulated
L. Kamchia	Beronovo	590	0.18	108.8	Gergov (1996)	1952–89
G. Kamchia	Preslav	1004	0.15	148.8	Gergov (1996)	1951–89
Evros	Belovo	741	0.06	80	Gergov (1996)	1936–89
	Parvomay	12,728	0.60	47	Gergov (1996)	1936–89
	Mouth	52,900	26.52	501	Poulos and Chronis (1997)	Calculated (discharge-corrected[a])
Arda	Vechtino	858	1.32	1535	Gergov (1996)	1956–89
Tunja	Banja	2240	0.11	47	Gergov (1996)	1951–89
Nestos	M. Kula	1511	0.31	202	Gergov (1996)	1937–89
	Border	3584	0.65	181	Paraskevopoulos-Georgiadis (2001)	
	Temenos	4394	0.69	157.4	Poulos and Alexandrakis (2005)	1965–82 (natural)
	Mouth	6100	0.98	160	UNEP/MAP (2003)	Prior dam construction
	Mouth	6265	0.49	78	Paraskevopoulos-Georgiadis (2001)	
Strymon	Rajavitsa	2171	0.34	158	Gergov (1996)	1936–89
	Kerkini	11,457	4.1	358	Calculated considering lake sedimentation for the period: 1932–1977 (data: Criveli et al., 1995)	
	Mouth	16,885	3.97	235	Eurosion (2004)	In 2000—regulated
Axios	Mouth	24,497	29.89	1220	UNEP/MAP (2003)	Prior dam construction
Aliakmon	Gevena bridge	847	0.07	81	Zarris et al. (2006)	~1965–80 (natural)
	Siatista	2724	0.64	233	Zarris et al. (2006)	~1965–80 (natural)
	Ilarion	5005	2.08	415	Zarris et al. (2006)	~1965–80 (natural)
			2.35	471	Poulos and Alexandrakis (2005)	1962–76 (natural)
	Mouth	9210	4.25	461	UNEP/MAP (2003)	Prior dam construction
Pinios	Downstream	7281	4.40	604	Poulos and Chronis (1997)	Natural
	Mouth	10,850	5.9	641	Poulos et al. (1996)	Calculated (natural)
Sperchios	Downstream	1158	0.97–2.1	838–1813	Poulos (1997)	Calculated (natural)
Acheloos	Avlaki	1355	2.31	1706	Zarris et al. (2006)	~1965–80 (natural)
	Kremasta	1733	2.05	1185	Zarris et al. (2006)	~1965–80 (regulated)
	Downstream	5500	3.38	614	UNEP/MAP (2003)	prior dam construction
Agrafiotis		320	0.65	2035	Zarris et al. (2006)	~1965–80 (natural)
Tavropos		1239	0.61	489	Zarris et al. (2006)	~1965–80 (natural)
Arachthos	Gogo bridge	203	3.23	15921	Zarris et al. (2006)	~1965–80 (natural)
	Tsimovo	640	0.67	1050	Zarris et al. (2006)	~1965–80 (natural)
	Plaka bridge	970	1.21	1249	Zarris et al. (2006)	~1965–80 (natural)
	Arta brige	1855	9.23	4976	Poulos and Alexandrakis (2005)	1962–82 (prior dam construction)
	Mouth	1907	4.68	2454	Mertzanis (1997)	Prior dam construction
			7.49	3941	UNEP/MAP (2003)	Prior dam construction

[a] According to recent discharge data.

snow melt, yields are low and range between 9 and 200 $tkm^{-2}yr^{-1}$. Basins formed by a mixture of bedrock types (Sperchios, Aliakmon and Pinios) exhibit intermediate sediment yields (460–1000 $tkm^{-2}yr^{-1}$). The organic fraction of suspended sediments transferred by major Balkan rivers is low (on average 2.83% POC, 1.69% PN). More than 50% of the inorganic fraction consists of muscovite–illite (~27%) and silica (~25%) (Skoulikidis, 1989).

In general, the natural sediment flux increases with catchment area that controls runoff. Hence, the total load of large basins (Evros, Axios, Drin, and Neretva) surpasses 13 Mt/yr. High sediment transport also occurs in small narrow mountainous basins with predominance of flysch, such as the Aoos and Arachthos with 8.4 and 7.3 Mt/yr, respectively. The Acheloos, Aliakmon, Pinios and Strymon have similar fluxes (between 4 and 6 Mt/yr), followed by Sperchios (~2 Mt/yr), while the flat Kamchia basin transports only 1.12 Mt/yr (Jaoshvili, 2002) and the Nestos, flowing through resistant rocks, about 1 Mt/yr. The Axios together with the adjacent Loudias and Gallikos Rivers form the most extensive deltaic area in Greece (600 km^2), followed by the Nestos Delta (434 km^2). The Arachthos creates together with Louros River a large double delta of 350 km^2. The Evros Delta extends over 188 km^2 and the Alfeios Delta covers 113 km^2. The Pinios and Strymon Rivers provide an exception. The Pinios has a relatively small delta (69 km^2) due to its low gradient and cyclic basin shape that retains most sediment. Similarly, Strymon has a surprisingly small deltaic area (9 km^2) as a consequence of sediment trapping in the former Achinos Lake. In contrast, the Sperchios, despite relative low sediment transport, has a dynamically expanding delta of 196 km^2 since it outflows in the shallow and of low wave energy Maliakos Gulf. The Sperchios delta lies just north of the famous Thermopylae battle field where the Greek fought against the Persians in 480 BC. The narrow Thermopylae pass was of strategic importance controlling the transition between the sea and the coastal mountains. During the past 2500 years the delta expanded by 100 km^2 (average: 4.1 ha/yr). This average rate increased during the past century to 13 ha/yr, mainly as a consequence of deforestation (Zamani and Maroukian, 1980), reaching 23.6 ha/yr in the period 1943–71 (Kotoulas, 1988). This rate surpasses 6 times the Nestos delta expansion rate (3.7 ha/yr in the last 30 years; Stefouli et al., 2005).

The long-term decline in river runoff, in combination with significant sediment retention in reservoirs, has resulted in a dramatic reduction in sediment fluxes during the past 50 years. For example, the sediment transport in the Strymon River has decreased from 6.5 Mt/yr (1932–1962) to 2.2 Mt/yr (1963–1977) and to 1.3 Mt/yr (1984–1990) (Criveli et al., 1995; Psilovikos et al., 1994). The Drin experienced a 13-fold sediment reduction compared to pre-industrial rates (REAP, 2006), while sedimentation rates near the Evros mouth have reduced by more than 50% since the 1950s (Kanelopoulos et al., 2006). Today, the proportion of the annual sediment flux trapped in reservoirs is over 80% for Acheloos, Nestos, Aliakmon, and Arachthos, and 60% for Kamchia (Piper and Panagos, 1981; Mertzanis, 1997; Paraskevopoulos-Georgiadis, 2001; Jaoshvili, 2002; Kapsimalis et al., 2005). Consequently, deltaic areas of dammed rivers are not expanding (Poulos et al., 1996) or have even started to decrease in size (Stournaras, 1998). It is predicted that the sandy beaches and island barriers of the Acheloos delta will gradually erode and coastal lagoons will be intruded by sea water (Bouzos et al., 1994). Global sea level rise will further accelerate the destruction of many deltaic areas of the Balkans.

7. Response

7.1. Environmental conservation and restoration

Wars and political instability over the past centuries and decades have created difficulties for research, management and conservation in the Balkans. With the exception of Greece, which is an old EU Member State, and Bulgaria, who jointed EU recently (2007), all other Balkan countries are in the process of integration. Greece has adopted the EU environmental policies and rules including the Water Framework Directive (WFD) and the other Balkan countries gradually adopt EU environmental legislation. International treaties and EU Directives enforce pollution abatement and environmental conservation. However, in all Balkan countries economic, political and structural constraints impose considerable impediments on the application of the EU environmental legislation. A major problem remains the administrative complexity on issues of environmental conservation, management, and enforcement of legislation. Additional problems arise from the lack of a national cadastre, institutional ineffectiveness, financial restraints, legal problems, deficiency of public involvement, and limited political commitment to conservation (Kassioumis, 1990; Handrinos and Akriotis, 1997). In Greece for example, the application of environmental legislation was proved in a number of cases inadequate. Even in protected areas, and despite national and international legislation, environmental protection has been often neglected in favour of large-scale development projects. Environmental Impact Assessments have so far been applied often in inappropriate and ineffective ways (Handrinos and Akriotis, 1997).

One of the most important steps in promoting the conservation of aquatic habitats was the signing of the Ramsar Convention (1975). In Greece, there are 8 sites in the examined basins (Evros Delta, Nestos Delta and associated lagoons, Kerkini Lake, Axios-Loudias-Aliakmon Deltas, Lake Mikri Prespa, the Amvrakikos Gulf including the Arachthos Delta, and Mesolonghi lagoons at Acheloos Delta). In FYR Macedonia, there is one Ramsar site at Lake Megali Prespa. Lake Shkodra and River Buna (Drin system) are Ramsar sites in Albania and Montenegro. The Neretva Delta is also protected by the Ramsar Convention. The Habitats Directive (92/43/EEC) also contributed to the designation of protected areas within the Natura 2000 conservation scheme. The Greek Natura sites include a number of riverine gorges, almost all the major river deltas and associated lagoons, and a number of lakes that maintain a present or past connection with large rivers, such as the Acheloos lakes, Kerkini, Prespa and Kastoria (Aliakmon system). In Bulgaria, assistance from the EU has helped important site inventory processes. The management of natural areas in the former Yugoslav Republics is still in a transitional stage.

In contrast to the other Balkan countries, where the establishment of WWTPs is insufficient, in Greece >90% of the human population is connected to WWTPs (with 2/3 primary and 1/3 secondary treatments) (NCE, 2003). There is however evidence of inadequate plant operation connected with inoperative environmental inspection. To combat nitrate pollution, the plains of Serres (Strymon basin), Thessaloniki (lower parts of Axios and Aliakmon basins), Thessaly (Pinios basin), and Arta (lower Arachthos basin) have been designated as Nitrogen Vulnerable Zones (Directive 91/676/EEC). Recently, a number of national projects test mitigation measures.

Ecological restoration efforts have traditionally concentrated on conservation actions for endangered species and protected-area habitat enhancement. Most projects are carried out at a local scale such as riparian tree planting. European Union funding (LIFE-NATURE and INTERREG programmes and EU-Structural Funds) has been instrumental for promoting this type of restoration. Active river restoration has not been extensively implemented and there is a major lack of post evaluation or project monitoring (Theocharis et al., 2004). A current large wetland restoration project concerns the partial re-establishment of former Lake Karla (Kettunen and ten Brink, 2006). Another ongoing project concerns the restoration of 2.8 km^2 riparian forests in the Nestos Delta. Additional restoration activities have been undertaken for the Evros riparian forest in Bulgaria and in the Kamchia delta.

7.2. River basin management

Almost all Balkan countries face daunting water resource challenges because of urgently required investments in water supply, sanitation, irrigation, and hydroelectricity. At the same time, water quality deteriorates (e.g. Evros, Axios, Kamchia, Drin and Pinios), water exploitation for irrigation increases dramatically (e.g. in the Thracian, Serres, Thessaly and Laconian plains), fragmentation by large dams comprise a major pressure for downstream habitats (e.g. Drin, Neretva, Acheloos, Nestos and Aliakmon), flooding remains a major threat (e.g. Evros, Drin, Aoos, Sperchios and Neretva) and droughts increasingly exhaust water resources (e.g. Pinios and Evrotas).

In Greece, a number of water resources management studies have been implemented in selected river basins and water districts. In addition, four large Master Plans for the management of the country's water resources are in the phase of completion. However, most of these studies are broad and barely cover ecological aspects. Simultaneously, despite a reorganization of public sectors to order with the demands of the WFD, structural complexity and ineffectiveness, top-down approaches, in combination with individual practices driven by personal interests, tackle integrated water resources management schemes. As a result, irrational one-sided water management approaches are still under way. The Acheloos Water Transfer Project is an outstanding example for one-sided decision making that neglects integrated inter-basin water management approaches. This is a mega-project which planned to divert a large portion of the waters of the Acheloos (today in a reduced rate of 0.6 km^3/yr) towards the Pinios basin to serve irrigation, drinking water supply, hydropower production, and to improve surface and groundwater quality of the Thessaly plain. The project has been on-going and has stirred debate and controversy for over 30 years. Similar examples are the planned water transfers from the Nestos towards the Strymon and Evros basins in Bulgaria.

For the other Balkan countries, constraints in integrated water management arise from long-standing sectorial planning traditions, heavy investment requirements (e.g. in sanitation and waste treatment infrastructure), poor administrative capacities and little experience of dealing with multidisciplinary issues. Additional difficulties arise from the deteriorating government services and public infrastructure following severe civil conflicts that recently affected the economies of these countries. Hence, policies and strategies for water use and management evolved on different principles, reflecting the long duration of the previous period of central planning culture and practice. In accordance with the prevailing political and administrative structures, management followed a top-down approach based primarily on sectorial planning, in which different sectors and services were separated and handled by different ministries and agencies. Bulgaria and Croatia, as a candidate country, made progress in establishing appropriate legislative and institutional framework for a decentralized integrated management on a river basin district scale compliant with the demands of the WFD. In Bulgaria, preliminary river basin management plans have been elaborated (BMEW, 2005). In the constituent republics of the state union Serbia and Montenegro the water legislation has several shortcomings hampering the effective management of water resources including lack of a clear institutional framework (World Bank, 2003). In Bosnia and Herzegovina, geopolitical and administrative boundaries in the Neretva basin make the optimal management of the river basin, delta and coastal zone complex and difficult. In FYR Macedonia and Albania, despite the adaptation of WFD principles in respective water laws, there is a clear lack in implementing a modern water resource management into reality (Speck, 2006). The speed of legal and institutional reforms required for the implementation of the WFD is generally slow in all countries, including Greece.

Concerning the management of shared basins, one-sided exploitation of water resources and pollution impact by upstream parties cause critical deficiencies of water quantity and quality to downstream countries, including surface and groundwaters and wetlands. The Neretva, Evros, Tundja, Nestos, Strymon, and Prespa and Doirani Lakes are examples of shared waterbodies where such situations are encountered (GWP, 2005). To face the transboundary nature of water supply and sanitation issues, the Balkan countries adopted the Water Convention of the United Nations Economic Commission for Europe, which entered into force in 1996. The provisions of the WFD and the Water Convention include the design and implementation of joint plans, joint river authorities, transboundary river basin units and coordinated national measures at a basin scale, and provide the platform for the management of shared water basins between member states and non EU countries. Today, joint international management is either insufficient or completely missing for the majority of shared rivers and lakes, although agreements, protocols and treaties have been signed for the rivers Neretva (not fully in power), Drin (only between Albania and FYR Macedonia), Aoos, Axios, Evros (only between Greece/Bulgaria and Greece/Turkey) and Nestos, and for the lakes Shkodra, Ohrid, Prespa and Doirani (GWP, 2005). In the majority of cases, political obstacles, lack of resources or inefficient collaboration in a technocratic level (Kallioras et al., 2006), have not allowed proper implementation (GWP, 2005). An example of poor transboundary cooperation is the case of the Evros basin, where major problems are connected with floods and water quality. Moreover, the Axios basin has been at the heart of numerous conflicts between Greece and FYR Macedonia for decades (GWP, 2005), despite agreements on water management that date since 1959. In contrast, the case of Prespa Lake is an excellent example of how transboundary environmental issues can encourage international cooperation among neighbouring nations (Greece, FYR Macedonia, and Albania). Lake Ohrid provides another example of effective measures being taken for cooperative management of transboundary lakes. Moreover, after years of disputes, a bilateral treaty regulating the amount of Nestos water entering Greece has been signed, while cooperation exists between the two countries in the framework of several joint research projects (GWP, 2005; UNESCO, 2006). Overall, the Balkans represents one of the most important areas for potential transboundary co-operation in protected area management worldwide. Indeed, at least 50% of the sites of international importance in the region are transboundary, including all the large lakes (Shkodra, Ohrid, Prespa and Doirani) and many large rivers and important deltas (e.g. Evros River, Buna Delta). Moreover, in the IUCN Strategic Plan for South Eastern Europe, 37 priority sites have been identified for a transboundary co-operation in protected areas development.

8. Conclusions and outlook

The water resources in the Balkan Peninsula are unevenly distributed temporally and spatially among and within countries. Some countries face localized water shortages, while most major rivers and lakes are transboundary, creating conflicts of interest. Large-scale wetland drainage has caused major hydromorphological modifications. Other hydromorphological alterations, such as embanking, straightening and reservoir building, inhibited or reversed the evolution of deltas, deteriorated associated wetlands, and reduced the recharge of groundwater aquifers, which are affected by sea water intrusion. Most of the examined rivers are strongly fragmented. Hydropower generation creates heavily modified river courses, with unnatural seasonal hydrological and hydrochemical regimes, and degrades river habitats and biotic quality. The implementation of ecological flow requirements downstream of reservoirs and water abstraction projects is thus urgently needed. In most Balkan countries there are major demands for further hydropower development, reflecting the expected strong economic growth in this region. There is also the obligation for EU and EU-perspective countries to increase the share of energy from renewable resources to the total energy production. On the other hand, unregulated river sections are prone to floods, and widespread deforestation and wildfires enhance erosion. Over the past decades, river runoff has declined dramatically due to overexploitation of water resources for agriculture and industry, in combination with semi-arid conditions and climate-change. Thus, former perennial rivers stretches are now temporary.

Pollution from municipal, industrial, and agrochemical sources remains a major threat to Balkan freshwater ecosystems. Mining effluents mainly affect Bulgarian and Albanian rivers, industrial pollution is important in Bulgaria, FYR Macedonia and Bosnia and Herzegovina, agricultural pollution is widespread in Greece, Bulgaria and Albania, while municipal waste water pollution prevails in all countries except Greece. Lowland river sections are at greatest risk due to lack of national cadastres, changes in agricultural practices, industrialization, (illegal) building and tourism, while headwaters mostly retain their natural conditions. Heavy metal and organic micropollutant concentrations occasionally exceed EC standards, with highest levels most commonly occurring in transboundary rivers entering Greece. Regarding nutrients, most headwater reaches maintain 'high' status. The majority of the rivers situated in the western Balkans reveal 'good' nutrient status whereas the central and eastern Balkan rivers are prone to nutrient pollution and most of them will need restoration in the framework of WFD-compliant river basin management plans.

The Balkan region, except Greece, is under strong economic development pressure, and the need to improve the living standards is leading to the growing exploitation of natural resources and environmental impact. Environmental policies and institutions have suffered a long period of eclipse and are now being rebuilt, although in a slow rate and with varying results. While in the other Balkan countries progress in environmental aspects is mainly tackled by administrative, structural and economic restrictions, Greece mainly suffers from poor planning of an effective national environmental policy together with insufficient implementation of environmental legislation. The public sector is prone to corruption and Balkan countries rank at the top of respective lists (e.g. GCB, 2007). Personal interests, frequently combined with a lack of environmental awareness, often overshadow public welfare. As a result, environmental protection has often been neglected in favour of development projects even in protected areas. Overall, environmental inspection is commonly inoperative and thus pollution abatement infrastructure is sometimes missing and, where it exists, is often barely operating.

Overall, oncoming integrated river basin management is tackled with a major lack of hydrological, physico-chemical and biological data. The development of operational monitoring networks has a pivotal priority. The situation becomes even more complex in transboundary river basins where the establishment of an appropriate administrative and institutional scientific framework is essential. Efforts should be devoted to standardizing and calibrating monitoring techniques among countries sharing river basins. The WFD demands a reduction of human impact to establish a 'good' water status. At present however the Directive begun to be implemented only in Greece and Bulgaria with notable delays. In all Balkan countries, the speed of legal and institutional reforms required for the implementation of the WFD should be accelerated. Today, there is a chance for Balkan countries to take advantage of EC and UN assistance in order to manage, protect and restore their watercourses efficiently. The obligation to apply the Directive in combination with the great number of internationally important sites in Balkan river basins and, principally, the need to change attitudes and raise environmental planning and awareness may push the procedure forward.

Acknowledgements

This article is based on the book chapter: Skoulikidis NTh, Economou AN, Gritzalis KC, Zogaris S. Rivers of the Balkans. In: Tockner K, Uehlinger U, Robinson CT, editors. Rivers of Europe, Elsevier (in press). A. Economou and S. Zogaris contributed to Section 7.

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