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River systems and their water and sediment fluxes towards the marine regions of the Mediterranean Sea and Black Sea earth system: An overview

Serafeim E. POULOS

Laboratory of Physical Geography, Section of Geography & Climatology, Department of Geology & Geoenvironment, National & Kapodistrian University of Athens, Panepistimioupolis-Zografou, 10584, Attiki

Corresponding author: poulos@geol.uoa.gr

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Abstract

A quantitative assessment of the riverine freshwater, suspended and dissolved sediment loads is provided for the watersheds of the four primary (Western Mediterranean-WMED, Central Mediterranean-CMED, Eastern Mediterranean-EMED and Black Sea-BLS) and eleven secondary marine regions of the Mediterranean and Black Sea Earth System (MBES). On the basis of measured values that cover spatially >65% and >84% of MED and BLS watersheds, respectively, water discharge of the MBES reaches annually almost the 1 million km^3, with Mediterranean Sea (including the Marmara Sea) providing 576 km^3 and the Black Sea (included the Azov Sea) 418 km^3. Among the watersheds of MED primary marine regions, the total water load is distributed as follows: WMED= 180 km^3; CMED= 209 km^3; and EMED= 187 km^3. The MBES could potentially provide annually some 894 10^6 t of suspended sediment load (SSL), prior to river damming, most of which (i.e., 708 10^6 t is attributed to MED). Between MED primary marine regions, CMED receives the highest amount of suspended sediment (287 10^6 t), followed by WMED (239 10^6 t) and EMED 182 10^6 t, while 185 10^6 t are delivered to BLS. The dissolved load (DL) of MBES is about 376 10^6 t, of which 215 10^6 t (~57%) is provided by the MED watershed. The large river systems (watershed>10^4 km^2) provide >85% of the water load, >80% of SSL and >60% of DL of both MED and BLS.

Keywords: Physical geography; water discharge; suspended sediment; dissolved sediment; hydrology; human intervention.

Introduction

Rivers play a key role in sustaining the coastal environment transferring water and sediment to the sea, with the former being associated with nutrient and/or pollutants concentrations in coastal waters, while the latter having implications for shelf sedimentation, coastline evolution, benthic ecosystem and the potential of burial of pollutants (e.g. Ludwig *et al.,* 2003; Syvitski *et al.,* 2005; Hill *et al.,* 2007; Karditsa & Poulos, 2013).

In the case of the Mediterranean and Black Sea semi-enclosed marine system, changes in riverine inputs are, therefore, potential drivers for long-term changes in coastal morphology (e.g., Poulos & Collins, 2002; CIESM, 2006; Syvitski & Saito, 2007; Syvitski *et al.,* 2009; Vörösmarty *et al.,* 2009) and marine ecosystems (e.g., Bianchi & Allison, 2009; Ludwig *et al.,* 2010; McCarney-Castle *et al.,* 2010). These changes have several demographic and socioeconomic implications, frequently accompanied by negative feedbacks on ecosystem services (e.g. Syvitski *et al.,* 2003; Vörösmarty *et al.,* 2009; Ludwig *et al.,* 2010).

On the basis of the highly variable morphological, lithological, pedological, climatic conditions and the associated vegetation land cover, the MBES watershed incorporates more than 3000 river systems with catchment size ranging from less than 50 km^2 to more than 10^5 km^2; furthermore, most of the rivers with catchments <200 km^2 present ephemeral, torrential flows draining mountainous coastal areas (Milliman & Syvitski 1992) undergone arid and semi-arid climatic conditions. Moreover, these temporary (non perennial) streams due to their complex and diverse flow regimes (Skoulikidis *et al.,* 2017) have not been studied systematically and, therefore, limited data is available.

Estimates of the annual surface freshwater influx provided by the Mediterranean watershed have been found to vary from 357±29 km^3 (Ludwig *et al.,* 2009) to 737 km^3 (Vörösmarty *et al.,* 1998), while an average value of 533 km^3 corresponds to the following published values (in km^3/year): 663 (Korzoun *et al.,* 1977); 737 (Vörösmarty *et al.,* 1998); 440 (UNEP, 1978); 517 (Margat & Treyer, 2004); 357±29 (Ludwig *et al.,* 2009) ; 447 (Thornes & Woodward, 2009) and 550 (Poulos, 2011). In the case of the Black Sea, freshwater fluxes (in km^3/year) account for 338 (Simonov & Atman, 1991) to 517 (Margat & Treyer, 2004), while a mean value of 401 is derived from the values given (in km^3/year) by: 473 (Korzoun *et al.,* 1977) ; 338 (Simonov *et al.,* 1991); 353 (Reshetnikov, 1992); 413 (Vörösmarty *et al.,* 1998); 365 (Jaoshvili, 2002); 517 (Margat & Treyer, 2004); 355 (Mikhailov & Mikhailova, 2008); 400±4 km^3 (Ludwig *et al.,* 2009); and, 395 (Poulos, 2011).

The MBES region encompasses a wider range of fluvial denudation rates than those recorded elsewhere on a global scale (Walling & Webb 1996; Milliman & Syvitski, 1992). Annual average denudation values for the MED catchment fluctuate from less than 250 t/km^2 to more 1000 t/km^2 (Woodward, 1995), having an average value of about 175 t/km^2; the latter value that is close to the global average increases to an average of about 580 t/km^2, which is very high compared to other regions of the world (Ludwig & Probst, 1998).

The suspended sediment loads provided by the MED watershed account from 670 10^6 t (Poulos & Collins, 2002) to 730 10^6 t (Ludwig *et al.,* 2003), while the BLS loads vary from 153 10^6 t (after Jahoshvili, 2002) to 172 10^6 t (after CIESM, 2006). These values are expected higher if both the dissolved and bed loads are included. In the case of the MED, dissolved and bed loads may represent around 30% of the total sediment load (Poulos & Collins, 2002), whilst in the case of the BLS this percentage could be much higher being, i.e. 45% (CIESM, 2006).

On the other hand, during the past decades, water and sediment fluxes have been modified following the regulation of river flows through dam construction for hydroelectric power and irrigation purposes. CIESM (2006) has referred that about 50% of MED catchment is dammed, causing an analogous reduction, primarily in sediment fluxes and secondarily to water discharge. For the MED catchment, Ludwig *et al.* (2003) have reported a continuous decrease in water discharge because of both climate change and anthropogenic water use, which in the case of the Black Sea was estimated to be about 10% (CIESM, 2006). Sediment fluxes for the Mediterranean Sea may have been reduced down to about ¼ (after Ludwig, 2003), when globally approximately 30% of the total potential global sediment flux has been estimated to be trapped behind large reservoirs (Syvitski *et al.,* 2005; Vörösmarty *et al.,* 1997).

The scope of this work is to provide estimates of the natural fluvial inputs in different spatial scales for the Mediterranean and Black Sea Earth System (MBES) in anticipation of future environmental changes such as climate change (e.g. Giorgi *et al.,* 2004; Giorgi & Lionello, 2008) and human interference (e.g. UNEP/MAP, 2012). Therefore, a quantitative assessment of the riverine freshwater, suspended and dissolved sediment loads is provided for the four primary and eleven secondary marine regions of the MBES, on the basis of measured values that cover spatially >85% of MED and about 90% of BLS total drainage basin. In addition, the interrelationships of the fluvial inputs of each marine region are elaborated statistically.

MBES marine regions and associated watersheds

The Mediterranean and Black seas constitute a semi-enclosed and connected to the Atlantic Ocean intercontinental marine system (Fig.1), having a total surface area of almost 3000 10^6 km^2 (excluding the Strait of Gibraltar) and a watershed of more than 7000 10^6 km^2 (Table 1). In terms of coastal morphology, the MBES

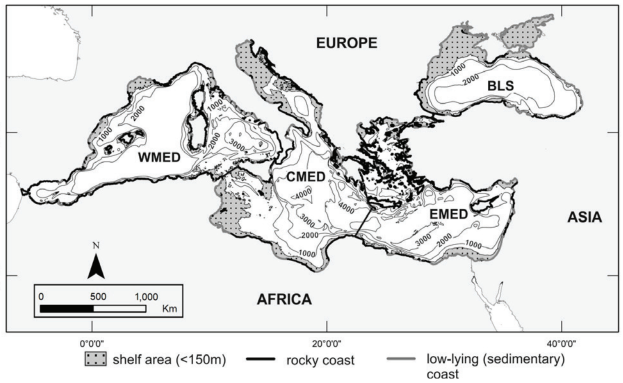

Fig. 1: Mediterranean and Black Sea bathymetry and their primary marine regions. [WMED: West Mediterranean; CMED: Central Mediterranean; EMED: East Mediterranean and BLS: Black Sea].

Table 1. Sea surface area (SSA) and catchment area (CA) for all the marine regions of the MBES (for acronyms see text).

	SSA (km^2)	CA (km^2)
ALB	54,173	90,000
WEST_N	*258,300*	*303,000*
WEST_S	*316,727*	*185,000*
WEST	575,027	488,000
TYR	212,500	74,000
WMED	841,700	652,000
ADR	140,320	229,000
ION	197,980	70,400
CEN	**573,990**	306,000
CMED	912,290	605,400
LEV_S	*420,000*	*3,045,000*
LEV_N	*140,588*	*114,600*
LEV	560,588	3,159,600
AEG	**192,026**	240,000
MAR	**11,887**	40,000
EMED	764,501	3,439,600
MED	**2,518,491**	**4,697,000**
BLA_E	*161,340*	*83,615*
BLA_W	*260,895*	*1,724,385*
BLA	**422,235**	1,808,000
AZOV	**41,274**	590,000
BLS	**463,509**	**2,398,000**
MBES	**2,982,000**	**7,095,000**

comprises mostly of rocky coasts (~52%) with the remaining proportion (~48%) representing coasts whose development is associated with fluvial sediment delivery and accumulation. For the MED, the aforementioned proportions slightly change with the rocky coasts accounting for ~54% (Fulrani *et al.,* 2014; UNEP, 2010), while for the BLS (including the Azov Sea) it accounts only for ~39% (Panin, 2007).

The MBES comprises four major marine basins named as Western Mediterranean (WMED), Central Mediterranean (CMED), Eastern Mediterranean (EMED) and Black Sea (BLS). These primary marine regions have been further divided by the scientific community (e.g., Cruzado, 1985; UNEP/MAP/MEDPOL, 2005; Ludwig *et al.,* 2009; Ludwig *et al.,* 2010; UNEP, 2012) into a number of domains (secondary regions) (Fig. 2), for the requirements of regional physiographic, oceanographic and environmental investigations. For the aforementioned division the sea limits provided by the IOH (1953 and its revised edition in 2002) have been adopted. The only sea limit not introduced by IHO is the limit between the two sub-regions, central and Levantine, for which the geological/morphological boundary provided by Carter *et al.* (1972) has been adopted. Thus, the WMED includes the Alboran (ALB), WestMED (WEST) and Tyrrhenian (TYR) seas, the CMED consists of the Adriatic (ADR), Ionian (ION) and CentralMED (CEN) seas, the EMED comprises the Levantine (LEV), Aegean (AEG) and Marmara (MAR) seas and, finally, the BLS additionally to the major basinal area of Black Sea (BLA) incorporates the Azov Sea (AZOV) (Fig. 4). Furthermore, the marine regions WEST, LEV and BLA may be divided further into WEST_N/WEST_S, LEV_N/LEV_S, and BLA_W/BLA_E sub-regions. In Table 1 their sea surface area together with their corresponding catchment areas are listed.

The climate of the MBES (in both the marine and coastal sectors), due to its geographical location (from 30° N to 46° N), belongs to the temperate zone of the northern hemisphere. However, the climatic conditions fluctuate substantially within the MBES drainage basin, which covers an area expanding from 2° S to 56° N. According to the Koppen-Geiger classification (Geiger, 1961), the climatic zones vary from hot desert (BWh) in Africa to humid continental (Dfb) in northern Europe, whilst in some mountainous areas (for example in Pontides) the climate is continental with dry and hot summers (Dsa), and humid continental with cool summers (Dfc) and/or even tundra (ET) in localised areas in the Carpathians, Balkanides and Alps. Moreover, within the Nile River catchment, south of the northern hot desert zone (BWh), the climate type of hot steppe (BSh), the tropical types of rainforest (Af), monsoon (Am) and savanna (Aw), and those of dry-winter humid subtropical (Cwa) and dry-winter temperate maritime (Cwb) are also present. In Figure 3 the spatial distribution of the mean annual precipitation (1970-2000) is shown for the MBES watershed.

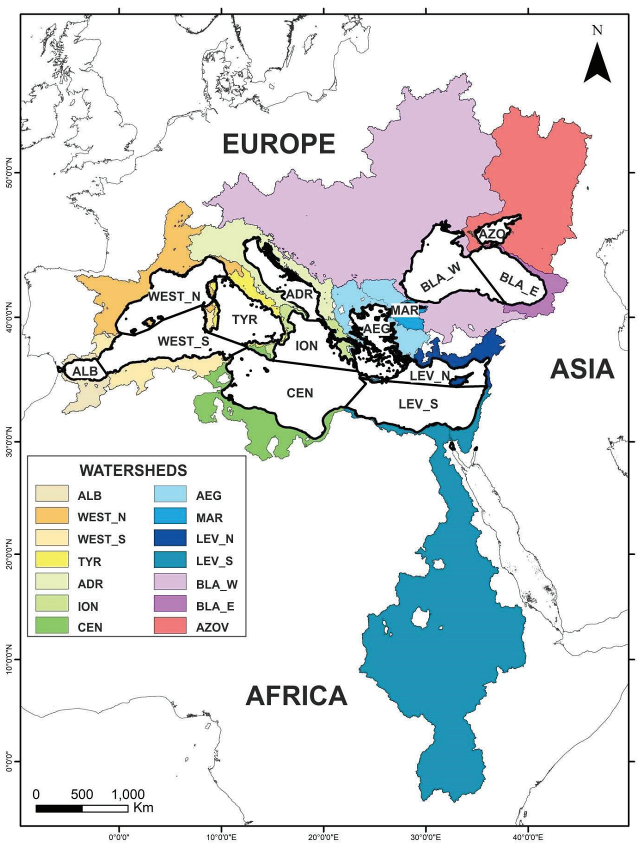

Fig. 2: The MBES marine regions and their watersheds.

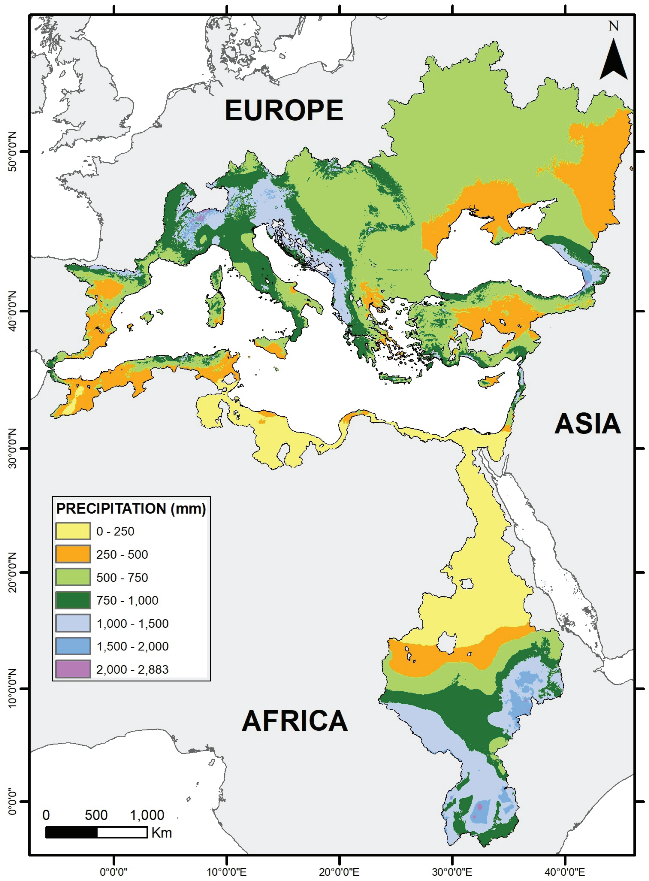

Fig. 3: The spatial distribution of precipitation within the MBES watershed (utilising the WORDCLIM2 data set).

Data collection and analysis

The rivers of the MED and BLS watersheds have not been studied to the same extend. Small Med rivers (<1000 km^2) that usually represent non-perennial rivers and streams (i.e. cease to flow for some time of the year) with remarkable hydro-geo-morphological diversity have rarely been monitored (Skoulikidis *et al.,* 2017), while long-term hydrological observations are available for the majority of rivers with watersheds >10^4 km^2. Usually, data sets refer to freshwater discharges and suspended sediment fluxes, while dissolved sediment data are rare, being usually available for large (>10^4 km^2) and, especially, very large (>10^5 km^2) river systems. Besides, bed load is the least measured hydrological element, due to the complex nature of its formation and the difficulties involved in measuring it (Jahoshvili, 2002). Overall, there is more data available for the rivers flowing to Black Sea than those debouching into the Mediterranean Sea. Furthermore, several estimates have been done regarding the suspended sediment yields for medium to small mountainous rivers utilizing sets of hydro-morphological parameters (e.g. Milliman & Syvitski, 1992; Probst & Suchet, 1992; Zarris *et al.,* 2007; Pelletier, 2012; Efthimiou *et al.,* 2017; Karalis *et al.,* 2018),

Thus, the present investigation is based on a compilation of published data (from 1974 to 2018) that refers to field measurements (prior to 2000) regarding mean annual riverine fluxes (excluding bed load) of 207 rivers with drainage basins >250 km^2, discharging along the coast of the Mediterranean (150) and Black Sea (57) (Table A in Annex I) covering >60% of the catchment area (Table 2) in most of the marine regions. Then, estimates of freshwater, suspended sediment, and dissolved sediment yields have been calculated for the measured part of the watersheds. Subsequently, these values have been used to provide a gross estimate of this part of the watershed not covered by in-situ measurements (often in the case of rivers with watersheds<1000 km^2), assuming a rather uniform spatial behaviour of the runoff and weathering processes. Thus, the total potential riverine (natural) flux for each marine region is provided by the sum of the measured and estimated fluxes. It is mentioned that in the case of the CEN, the Libyan sector has been excluded from the calculations, as it is deprived of surface water flows. Also, data availability for dissolved load fluxes is limited in the case of the Alboran, whereas for the southern sector of WEST they are absent. Thus, for these two cases, the mean value of dissolved yield from the adjacent to them WEST_N has been utilised, considering the similarities in terms of geological and climatic conditions.

The watersheds were delineated by using the Hydrosheds 15 arc-second dataset as a base (Lehner & Grill, 2013), which has a horizontal resolution of about 500 meters in the equator. Hydrosheds dataset was chosen since it has shows significantly better accuracy than other datasets (e.g. HYDRO1k, DCW etc). Flat regions without well-defined relief are the most common areas of in-

Table 2. Percentage of watershed area (A) covered by in-situ measurements along with the number of incorporated rivers (R), used in the calculations for the estimation of water (W), suspended sediment (SSL) and dissolved sediment (DL) loads.

	A_W(%)	R_W	A_{SSL}(%)	R_{SSL}	A_{DL}(%)	R_{DSL}
ALB	80.0	9	77.3	9		0
WEST_N	*84.3*	*18*	*98.0*	*15*	*70.4*	*4*
WEST_S	*62.7*	*15*	*64.7*	*15*		*0*
WEST	76.0	33	83.8	30	42.4	4
TYR	69.6	6	34.7	5	19.8	1
CEN (excl. Libya)	5.2	2	10.4	1	-	-
ION	37.0	15	26.6	10	18.3	5
ADR	81.2	37	76.2	37	13.1	2
AEG	97.5	14	91.3	11	54.2	7
MAR	67.2	3	11.2	3	56.0	1
LEV_N	*81.2*	*20*	*74.4*	*11*	*58.7*	*4*
LEV_S	*94.7*	*6*	*94.7*	*1*	*94.6*	*1*
LEV	94.2	22	85.3	11	78.8	5
MED	**87.9**	**141**	**82.0**	**117**	**66.4**	**25**
BLA_W	*96.6*	*25*	*96.6*	*20*	*89.8*	*9*
BLA_E	*79.5*	*29*	*79.5*	*29*	*25.1*	*4*
BLA	95.8	54	88.9	49	60.6	13
AZOV	85.8	3	85.8	2	75.0	1
BLS	**93.3**	**57**	**88.1**	**51**	**64.1**	**14**
MBES	**89.8**	**198**	**89.8**	**172**	**84.0**	**38**

accuracies (Lehner, Verdin & Jarvis, 2008). The vector datasets of watershed boundaries and river networks were used, and after processing these data in a GIS the combined catchment area for each of the marine regions was produced.

For the calculation of average precipitation per year in each watershed the WORLDCLIM 2 dataset was used with a spatial resolution of 30 arc-seconds, which uses a latitude / longitude geographic coordinate system (the datum is WGS84). The dataset includes monthly average values for the years 1970-2000 with high spatial resolution (about 1 km^2). Accuracy is good with a global cross-validation correlation of 0.86 (Fick & Hijmans, 2017). The precipitation data grid was transformed to a projected coordinate system (WGS 84) that is the same as the coordinate system of the zones vector data, in order to provide uniform cell sizes for more accurate calculations. Then, the average precipitation/cell for each basin was calculated with the use of G.I.S. techniques. Total rainfall in a watershed was calculated by multiplying the average precipitation with the number of cells that are assigned to each watershed.

Finally, the slope gradient was derived from the GTOPO30 DEM in percent units (i.e., the rise divided by the run, multiplied by 100) and a new raster dataset was created in G.I.S. Subsequently, the average slope is calculated with the application of maximum downhill slope algorithm that does not overestimate slopes and have accurate results (Dunn & Hickey, 1998).

Results and Discussion

River systems

In Table 3, the watersheds for each marine region have been categorized according to their size (Poulos, 2011).

MED watershed is characterized by the presence of the extraordinary large Nile's watershed (2,880,000 km^2) and the absence of very large (10^5-10^6 km^2) river systems. The reverse situation applies to the BLS, where the very large rivers (>10^5 km^2) represent the 3/4 of its total catchment area, whilst there is no river with catchment >10^6 km^2. Very large river systems (10^5-10^6 km^2) drain >70% of

Table 3. The number of rivers and sized-categories of the watersheds of the marine regions of the Mediterranean and Black Sea Earth System.

Marine Regions	**Watershed area (km^2)**									
	Small (<10^3)		**Medium (10^3-10^4)**		**Large (10^4-10^5)**		**Very large (10^5-10^6)**		**Extra-ordinary large (>10^6)**	
	N.	km^2	N.	km^2	N.	km^2	N.	km^2	N.	km^2
ALB	>2	24.6	6	18.8	1	56.7	1			
WEST	>6	29.3	21	15.6	6	55.0	6			
WEST_N	>2	15.7	15	16.6	3	67.7	3			
WEST_S	>4	51.6	6	14.0	3	34.3	3			
TYR	>1	19.1	5	28.2	1	52.7	1			
CEN[a]	>3	88.0	3	12.0	2	(α)	2			
ION	>5	67.2	4	32.8	0		0			
ADR	>14	20.5	24	32.9	4	46.6	2			
AEG	>2	24.5	6	13.4	6	62.1	6			
MAR	>1	32.8	2	11.2	1	56.0	1			
LEV	>7	5.1	12	0.67	5	3.03	5		1	91.3
LEV_N	*>7*	*21.5*	*8*	*11.7*	*4*	*66.8*	*4*			
LEV_S	*>1*	*4.5*	*4*	*0.25*	*1*	*0.62*	*1*		*1*	*94.7*
MED	**>39**	**17.6 *(45.4)*[b]**	**83**	**5.5 *(14.3)*[b]**	**24**	**15.6 *(40.4*[b]**	**24**		**1**	**61.9**
BL	>27	6.2	17	2.0	8	19.7	2	72.2		
BL_W	*>10*	*4.4*	*10*	*1.3*	*6*	*18.6*	*2*	*75.6*		
BL_E	*17*	*44,5*	*7*	*16,1*	*2*	*42.5*	*0*			
AZOV	>1	5.5	12	7.0	2	12.5	1	75.0		
BLS	**>27**	**6.0**	**29**	**3.2**	**10**	**17.9**	**3**	**72.8**		
MBES		**13.4 (23.0)[b]**	**112**	**4.8 (8.0)[b]**	**34**	**16.4 (27.6)[b]**	**3**	**24.6 (41.4)[b]**		**40.6**

Note. (a): CEN' watershed does not include the Libyan sector; (b): Nile watershed not included in calculations.

the BLS watershed (including the AZOV). In the scale of MBES, the small (<10^3 km^2) and large (10^4-10^5 km^2) watersheds correspond to 13.4% and 16.4%, respectively, being larger than medium (10^3-10^4) watersheds (4.8%), but considerably smaller than the extraordinary large (>10^6) rivers that equals to 40.6%. If Nile's watershed is excluded from the calculations, then the very large rivers, representing the 41.4%, become the most significant followed by the large (16.4%) and the small (13.4%) rivers. For MED, the extraordinary large (>10^6) river Nile represents the 62% of its watershed, while for the BLS the very large (>10^5 km^2) rivers represent the 72% of its total watershed. In Figure 4 the watersheds of the MBES extending to >10,000 km^2 are presented.

Freshwater load

Riverine freshwater load of the MBES exceeds 1 million km^3/yr (Table 4), of which on an annual basis, 418.4 km^3 are provided by the Black Sea (including the Azov) and 590 km^3 by the Mediterranean: the latter is allocated among the catchment of MED primary marine regions as follows: WMED= 180.1 km^3; CMED= 223.3 km^3; and EMED= 186.9 km^3. Between the secondary marine regions, the largest amount is provided by the BLA (370.8 km^3) and the smallest by the MAR (8.1 km^3) and ALB (3.6 km^3) due to their small watersheds. Interestingly, LEV presents a relatively low value of 134.5 km^3 despite its huge catchment area due to Nile's drainage basin (2,880,000 km^2). This is also depicted in the water yield values, whose lowest values are given by LEV catchment (i.e. 43 m^3/km^2) when the average yield for MED is 125.7 m^3/km^2 with the highest (ADR) exceeding the 552 m^3/km^2.

BLS is characterised generally by higher water yield (174.5 m^3/km^2) compared to MED, despite the very low value of AZOV (80.7 km^3/km^2) that is associated with one of the larger catchment areas (590 10^3 km^2). This means that the rivers out-flowing into the Black Sea have freshwater yields (on an average 174.5 10^3 m^3/km^2) larger than those of the MED watershed (some 125.7 10^3 m^3/km^2).

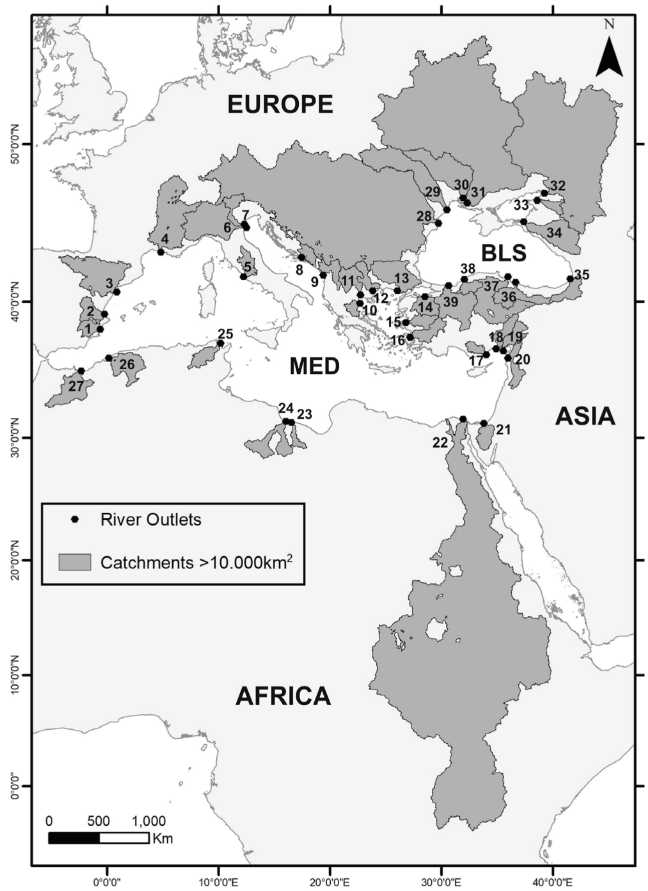

Fig. 4: MBES watersheds extending to more than 10,000 km^2 (**1:** Segura; **2**: Jucar; **3**: Ebro; **4**: Rhone; **5**: Tiber; **6**: Po; **7:** Antige; **8**: Neretva; **9**: Drin; **10**: Pinios; **11**: Axios; **12**: Strimonas; **13**: Evros; **14**: Simav; **15**: Cediz-Nehri; **16**: Büyükmenderes; **17**: Goksu; **18**: Seyhan; **19**: Ceyhan; **20**: Asi (Orontes); **21**: Wadi el Arish; **22**: Nile; **23**: Wadi Tamit; **24**: Wadi Baey al Kabir; **25**: Mejerda; **26**: Moulouya; **27**: Chelif; **28**: Danube; **29**: Dniester; **30**: Southern Bug; **31**: Dnieper; **32**: Don; **33:** Rioni; **34**: Kuban; **35**: Chorokhi (Goruh); **36**: Yesilirmak; **37**: Kizilirmak; **38**: Filyos; **39**: Sakarya).

Sediment Loads

The MBES coastal waters could potentially receive some 894$10^6$t on an annual basis (Table 4), prior to river damming, most of which is provided by MED (708 10^6 t). Between the primary marine regions, CMED provides the highest amount (287 10^6 t) with the lowest amounts provided by BLS (185 10^6 t) and EMED (182$10^6$ t). Between the secondary marine regions, the smallest amount is associated with MAR (2.1 10^6 t) and the largest amount with ADR (196 10^6 t). In terms of annual values of suspended sediment yields, the primary marine regions EMED and BLS are associated with low values of 53 t/km^2 and 77.3 t/km^2, respectively, when WMED and CMED (exluding Libya) present substantially higher values of 367t/km^{2}and 507t/km^2, respectively. Among the secondary marine regions, we can distinguish those having SS yields <100 10^6 t (BLA, AZOV, LEV, MAR) those of 100-350 10^6 t (AEG, CEN, ALB, WEST) and those having yields >800 10^6 t (ION, ADR, TYR).

The contribution of dissolved load (DL) is less than half (376 10^6 t km^2) compared to SSL (894 10^6 t km^2) of MBES (Table 4), of which 215 10^6 t (approximately 60% of the MBES) is provided by the MED's watershed and the 161 10^6 t by the BLS. Between the primary marine regions, BLS presents the highest value (161 10^6 t), while EMED has the smallest amount of only 36.6 10^6 t; the latter is due to the exceptionally low DL yield of the Nile's watershed (i.e., 2 10^6 t /km^2) that consists the 97% of the SLEV catchment. DL yields of the secondary marine regions could also be grouped into those with values <100 10^6 t/km^2 (LEV, BLA, AZOV, AEG), of 120-135 10^6 t/km^2 (ALB, WEST, CEN) and to those of 200-350 10^6 t /km^2 (ADR, ION, TYR).

The relationship between SSL and DL could be further investigated through the ratio SSL:DL (Table 4). The pri-

Table 4. Catchment area (CA in km^2) and annual estimates of water load (WL in km^3) / water yield (WY in $10^3 m^3/km^2$), suspended sediment load (SSL in 10^6 tones)/yield (SSY in t/km^2), dissolved sediment load (DL in km3) and dissolve sediment yield(DLY in t/km^2), the ratio between DLY and SSY, the mean precipitation (P in mm) and mean (average) hypsometric slope gradient (SL in %) for the marine regions (M.R.) of the Mediterranean and Black Seas Earth System.

M. R.	CA	WL	WY	SSL	SSY	DL	DLY	SSL/ DL	P	SL
ALB	90,000	3.6	40.0	21.1	234.4	11.7	130.0	1.8	393.2	5.6
WEST_N	303,000	145.4	479.9	85.7	282.8	37.6	124.1	2.3	785.7	7.8
WEST_S	185,000	13.9	75.1	64.4	348.1	24.1	130.3	2.7	524.7	5.1
WEST	488,000	159.3	326.4	155.4	318.4	61.7	126.4	2.5	692.5	6.8
TYR	74,000	17.2	232.4	62.5	844.6	25.7	347.3	2.4	750.9	8.7
WMED	652,000	180.1	276.2	239	366.6	99.1	152.0	2.4	660.4	6.8
CEN(-Lib.)*	45,700	3.3	72.2	10.6	231.9	6.1	133.5	1.7	144.8	1.2
ION	70,400	51.1	725.9	80.6	1144.9	21.4	304.0	3.8	791.7	9.5
ADR	229,000	154.5	674.8	196.0	855.9	52.09	227.5	2.0	979.9	11.0
CMED	605,400	208.9	345.1	287.2	474.4	79.59	131.5	2.2	563.2	5.8
AEG	240,000	44.3	184.6	28.6	119.2	19.3	80.4	1.5	632.9	7.4
MAR	40,000	8.1	202.5	2.1	52.5	2.1	52.5	1.0	718.7	6.4
LEV_N	114,600	39.9	348.2	25.9	226.0	8.8	76.8	2.9	674.1	9.6
LEV_S	3,045,000	94.6	31.1	125.7	41.3	6.38	2.1	19.7	639.3	1.8
LEV	3,159,000	134.5	42.6	151.6	48.0	15.18	4.8	10.0	640.9	2.1
EMED	3,439,600	186.9	54.3	182.3	53.0	36.58	10.6	5.0	641.3	2.5
MED	**4,697,000**	**575.9**	122.6	**708.5**	150.8	**215.27**	45.8	2.7	633.1	3.5
BL_W	1,724,385	304.6	176.6	138.2	80.1	129	74.8	1.1	650.7	3.7
BL_E	83,615	66.2	791.7	28.4	339.7	15.6	186.6	1.8	924.6	15.4
BLA	1,808,000	370.8	205.1	166.6	92.1	144.6	80.0	1.2	662.0	4.2
AZOV	590,000	47.6	80.7	18.8	31.9	16	27.1	1.2	523.7	1.6
BLS	**2,398,000**	**418.4**	174.5	**185.4**	77.3	**160.6**	67.0	1.2	627.1	3.6
MBES	**7,095,000**	**994.3**	140.1	**893.9**	126.0	**375.87**	53.0	2.1	630.7	3.5

*CEN (total)= 306,000 km^2

mary marine regions WMED and CMED present ratios >2, the BLS 1.2:1 and EMED the highest (5:1). Most of the secondary marine regions have ratios between 1 and 3, with LEV presenting the highest ratio (10:1) and MAR the lowest (1:1). The differences between the SS:DL ratios within the MBES are related to different hydromorphological conditions, induced by climate variability, and various geological (e.g. lithology) and morphological aspects.

Table 5 demonstrates the relative contribution of the large river systems in the accumulation of the total amount of freshwater, suspended sediment and dissolved sediment load in each catchment area of the primary (WMED, CMED, EMED, and BLS) and secondary marine regions. MED large rivers provide the 59.5% of its total water load, although their catchment area corresponds to 77.2% of the total MED catchment area. This is due to the fact that CEN and ION do not have any large rivers with surface flows, while the rivers of the other secondary marine regions contribute smaller percentages of freshwater despite to their much larger watersheds. Therefore, the medium and small river systems (<10^4 km^2) have also an important role in developing the total water load for the MED. In contrast, the BLS and its secondary marine regions receive >85% of freshwater load from large river systems. For the suspended and dissolved sediment loads, the MBES large river systems, corresponding to 82% of its total watershed, provide 57% of SSL and 43% of DL, respectively.

Statistical relationships of fluvial fluxes and watershed variables

The outcome of the investigation concerning the relationships between some key-parameters of marine region's watershed (i.e. area, mean slope, mean precipitation) and fluvial variables (water load, suspended sediment load, dissolved load) is presented in Table 6. Best statistical correlations have been given either with the use of linear or expo-

Table 5. Number (N) of large rivers (>10,000 km^2), catchment area (CA), suspended sediment load (SSL) and dissolved sediment load (DL) together with their corresponding percentages with respect to their total (T) values, for the primary and secondary marine regions of the MBES.

		N.	*CA* (*km^2*)	CA/total (%)	*WL* (*km^3*)	WL/T_{WL} (%)	*SSL* (*10^6 t*)	SSL/T_{SSL} (%)	*DL* (*10^6 t*)	DL/T_{DL} (%)
ALB		1	51000	56.7	1.60	43.84	**12.00**	57.48	0.00	0.00
	WEST_N	3	205084	67.7	108.50	75.40	77.80	90.82	27.00	71.88
	WEST_S	3	85525	46.2	5.34	39.01	**14.50**	22.91	0.00	0.00
WEST		6	290609	59.6	113.84	72.23	92.30	61.96	27.00	44.12
TYR		1	17000	23.0	7.40	44.11	**7.50**	12.33	5.90	23.59
WMED		**8**	**358609**	55.0	**122.84**	**69.00**	**111.80**	**48.47**	**32.90**	**33.66**
CMED (ADR)*		**4**	**123582**	53.4	86.74	48.23	51.20	25.07	6.85	6.36
AEG		7	139267	60.8	29.28	59.16	**22.43**	69.39	5.31	28.74
MAR		1	22400	56.0	4.40	57.62	0.00	0.00	1.20	59.60
	LEV_N	4	76561	66.8	21.60	54.78	**15.10**	59.10	4.30	49.17
	LEV_S	2	2899000	95.2	90.00	95.34	120.00	95.59	6.10	95.56
LEV		6	2975561	94.2	111.60	83.39	135.10	89.42	10.40	68.75
EMED		**14**	**3137228**	91.5	**145.28**	**76.08**	**157.53**	**84.96**	**16.91**	**47.48**
MED		**26**	**3656419**	77.2	**347.56**	**59.50**	**318.93**	**45.19**	**55.06**	**21.15**
	BLA_W	10	1624563	94.2	285.10	94.07	130.10	94.64	110.50	86.25
	BLA_E	2	35500	42.4	18.33	28.14	11.83	42.27	2.80	18.18
BLA		12	1660063	92.3	303.43	82.40	141.93	85.78	113.30	78.95
AZOV		3	516300	87.5	40.80	84.89	**16.15**	84.33	12.00	73.76
BLS		**15**	**2176363**	**90.8**	**344.23**	**82.69**	**188.08**	**85.63**	**125.30**	**78.42**
MBES		**41**	**5832782**	**81.8**	**691.79**	**72.40**	**507.01**	**56.95**	**180.36**	**42.93**

(*) ION does not include any large river, while the two large rivers of CEN do not have surface flow.

nential fitting equations. More specifically, the relationship between watershed area and water and sediment loads are best described by the exponential equations (Table 6) with the variables of water load, suspended sediment and dissolved load presenting good correlations ($0.4<r^2<0.7$) with the catchment area. Interestingly, the correlations between water and/or sediment yields are described better by linear equations (Table 6), with r^2 ranging from 0.45 to 0.87. Exponential equations with relatively good correlations ($0.40<r^2<0.71$) express the relationship between water and sediment loads with mean precipitation load. On the other hand, very poor correlation ($r^2<0.15$) is presented by catchment's mean (hypsometric) slope with all fluvial loads (i.e. WL, SSL, DL).

Concluding comments

The overall freshwater potential inputs of the MBES watershed reach 1000 km^3/year, of which the 590 km^3 are attributed to MED and 418 km^3 to BLS. The large rivers (>10,000 km^2) in the case of MED provide about 60% of its freshwater loads although they represent the 79% of the total catchment area, while in the case of BLS, the large river systems provide about 83%, corresponding to the 91% of BLS's catchment area. The smaller freshwater potential of the MED (126 m^3/km^2) (compared to 174 m^3/km^2 of the BLS), is explained by the fact that the African part of MED's watershed (Libya and Egypt) is deprived form surface flows due to very low precipitation levels (<100 mm; Jahosvili, 2002). Despite its huge size the Nile Rive used to provide about 80 km^3 that corresponds to a water yield of only 27.8 m^3/km^2. The large freshwater influx in the case of the Black Sea basin has many environmental implications, among which the most important could be considered the strong stratification of its water column with brackish waters (salinities<25 psu) at the upper layer and the anoxic conditions developed in its lower water mass (Konovalov, Murray & Luther III, 2005). Moreover, anthropogenic interventions (i.e. dam construction, freshwater utilisation etc) have altered the natural flows, causing an overall reduction, which in the case of BLS accounts for about 10% of its water discharge (Jahosvili, 2002). An analogous and even higher reduction is expected also for the MED's watershed as 40% of its waterflows area is trapped, although temporarily, in reservoirs, and subsequently utilized for irrigation and watering purposes. In the future, a further reduction is expected due to climate change, which is associated with a reducing trend of precipitation levels (Giorgi &

Table 6. Statistical relationships between the watershed variables (catchment area (CA), mean slope (SL), mean precipitation volume (PR), suspended sediment load (SSL), dissolved sediment load (DLS), water yield (WY), suspended sediment yield (SSY), dissolved sediment yield (DLY) of the MBES' marine regions (ALB, WEST, TYR, WMED, CEN, ION, ADR, CMED, LEV, AEG, MAR, EMED, BLA, AZO, BLS).

	Linear		Exponential	
	Equation	**r^2**	**Equation**	**r^2**
f (CA, WL)	y = 7E-05 x + 71.725	0.37	$y = 0.0011\ x^{0.8556}$	0.68
f (CA, SSL)	y = 3E-05 x + 86.994	0.20	$y = 0.0198\ x^{0.6343}$	0.48
f (CA, DSL)	y = 2E-05 x + 35.953	0.13	$y = 0.0441\ x^{0.5066}$	0.43
f (WY, SSY)	y = 1.3977 x - 11.458	0.71	$y = 2.2685\ x^{0.8559}$	0.46
f (WY, DSY)	y = 0.3196 x + 46.967	0.45	$y = 0.8606\ x^{0.8821}$	0.46
f (SSY, DSY)	y = 0.2664 x + 36.563	0.87	$y = 0.9113\ x^{0.8569}$	0.72
f (WL, PR)	y = 0.1006 x + 76.321	0.34	$y = 0.6347\ x^{0.8539}$	0.71
f (SSL, PR)	y = 0.0484 x + 93.805	0.14	$y = 2.4955\ x^{0.6144}$	0.46
f (DL, PR)	y = 3.4177 x + 386.75	0.06	$y = 20.817\ x^{0.7008}$	0.41
f (WL, SL)	y = -16.341 x + 235.37	0.14	$y = 280.62\ x^{-0.9}$	0.11
f (SSL, SL)	y = -4.0483 x + 146.79	0.02	$y = 104.79\ x^{-0.263}$	0.01
f (DL, SL)	y = -1.6068 x + 67.823	0.01	$y = 34.806\ x^{-0.058}$	0.001

note: (1) values refer to european sector, due to the lack of any surface flow at the african sector;

Lionello, 2008), which is going to be more pronounced at the southern MED (Xoplaki *et al.,* 2006; Rouholahnejad-Freund *et al.,* 2017). In addition, the variability of the freshwater discharge has significant impact on the habitats of the receiving waters, as they have to adjust their lives in different eutrophic status and sedimentological changes (e.g. channel abandonment, new depositional lobes) associated with morphological changes as discussed below.

The total amount of the sediment transferred in suspension by the MBES rivers exceeds the 900 10^6 of which about the 80% is provided by the MED watershed and the remaining 20% by the BLS watershed. High MED sediment fluxes are associated with steep relief, erodible catchment lithology and heavy storm events (Thornes, Lopez-Bermudez & Woodward, 2009). On the other hand, the lower BLS suspended sediment yields are related to increased amounts of sediment transferred in solution (i.e., SSL:DL= 1.2:1), when in the case of MED is 2.7:1; this increased dissolved loads may be explained by BLS much larger river watersheds associated with lower slopes and the prevailing weathering and erosional processes due to prevailing climatic conditions (i.e. tundra type). Moreover, in the case of MED the medium and small in size catchments have an almost equal contribution compared to the large (>10^4 km^2) and very large (>10^5 km^2) watersheds for both water and sediment fluxes, when in the case of BLS the large river systems provide more than 3/4 of those fluxes.

During the past decades, the construction of river dams for irrigation and watering purposes have had a great impact, especially in suspended sediment fluxes, as most of them are trapped in reservoirs. In the case of MED, more than 40% of its watershed (excluding the Nile) is dammed; this becomes 80% when the Nile's watershed is included in the analysis (Poulos & Collins, 2002). Similarly, based on measured flows, an equal reduction has been reported for the BLS watershed by Jahosvili (2002). Moreover, Vörösmarty (1997) have foreseen that within the next few decades, more than 50% of the total global river flow would be dammed, globally, having a series of environmental implications, such as the export of carbon to the atmosphere and ocean by fluvial systems and continental shelves receiving fewer nutrients that leads to reduced fish production. Meanwhile, most of the world river deltas have undergone severe erosion following dam construction (e.g. Poulos & Collins, 2002; Syvitski & Saito, 2007; Syvitski *et al.,* 2009; Vörösmarty *et al.,* 2009). Retreating rates for some of the largest MBES deltas are: 10-60 m/year for the Ebro delta between 1957 and 1973 [Jimenez, Sanchez-Arcilla, & Maldolado (1997)];about 25 m/year for the Rhone delta during the period 1954-1971 (Bird, 1988); 120-240 m/year for the Nile between the years 1965 and 1991, soon after the Aswan Dam construction (Simeoni & Bondesan, 1997); and up to 20 m/year for the Danube for the period 1900-1988 (Mc Manus, 2002).

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References

Algan, O., 2006. Riverine fluxes into the Black and Marmara Seas. In Fluxes of Small and Medium-size Mediterranean Rivers: *Impact on Coastal Areas. CIESM Workshop Monographs*, 30, 47-53.

Amery, H.A., 1993. The Litani River of Lebanon. *Geographical Review*, 83 (3), 229-237.

Bianchi, T.S., Allison, M.A., 2009. Large-river delta-front estuaries as natural "recorders" of global environmental change. *Proceedings of the National Academy of Sciences*, 106 (20), 8085-8092.

Bird, E.C., 1988. Coastline Changes: A Global Review. John Wiley & Sons, Chichester, 220 p.

Carter, G.T., Flanagan, J.P., Jones, C.R., Marchant, F.L., Murhinson, R.R. *et al.,* 1972. A new bathymetric chart and physiography of the Mediterranean Sea, p. 1-23, In: *The Mediterranean Sea: a Natural Sedimentation Laboratory*. Stanley, D.J. Stroudsburg, Pennsylvania: Dowden, Hutchinson & Ross.

Cidu, R., Biddau, R., Manca, F., Piras, M., 2007. Hydrogeochemical features of the Sardinian rivers. *Periodico Mineral*, 76, 41-57.

CIESM, 2006. Fluxes of small and medium-size Mediterranean rivers: impact on coastal areas, CIESM Workshop Monograph n° 30, CIESM Publisher, Monaco, 119p.

Cruzado, A., 1985. Chemistry of Mediterranean Waters. Editor: Pergamon Press.

Dunn, M., Hickey, R., 1998. The Effect of Slope Algorithms on Slope Estimates within a GIS. *Cartography*, 27, 9-15.

Efthimiou, N., Lykoudi, E., Karavitis, C., 2017. Comparative analysis of sediment yield estimations using different empirical soil erosion models. *Hydrological Sciences Journal*, 62 (16), 2674-2694.

Estrela, T., Quintas, L., Alvarez, J., 1997. Derivation of flow discharges from runoff maps and digital terrain models in Spain, *IAHS Publication*, 246, 39-48.

EUROSION, 2004. Living with coastal erosion in Europe; sediment and space for sustainability. Part II: Maps and Statistics, DG Environment EC.

Fick, S.E., Hijmans R.J., 2017. Worldclim 2: New 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, 37 (12), 4302-4315.

Furlani, S., Pappalardo, M., Gómez-Pujol, L., Chelli, A., 2014. The rock coast of the Mediterranean and Black seas: *Geological Society, London, Memoirs*, 40 (1), 89-123.

Geiger, R., 1961. Überarbeitete Neuausgabe von Geiger, R.: *Köppen-Geiger/Klima der Erde. (Wandkarte 1:16 Mill.) KlettPerthes, Gotha, KlettPerthes, Gotha.*

Giorgi, F., Bi, X., Pal, J., 2004. Mean interannual variability and trends in a regional climate change experiment over Europe. II: Climate change scenarios (2071–2100). Climate Dynamics, 23 (7-8), 839-858.

Giorgi, F., Lionello, P., 2008. Climate change projections for the Mediterranean region. *Global and planetary change*, 63 (2-3), 90-104.

Hill, P.S., Fox, J. M., Crockett, J. S., Curran, K. J., Friedrichs, C. *et al.*, 2007. Sediment delivery to the seabed on continental margins, Continental Margin Sedimentation: From Sediment Transport to Sequence Stratigraphy, p. 49-99, In: Continental Margin Sedimentation: Transport to Sequence, Nittrouer C.A. *et al.,* (Eds), IAS Special Publication 37, Blackwell Publishing Ltd, Oxford.

Jimenez, J.A., Sanchez-Arcilla, A., Maldolado, A., 1997. Long to short term coastal changes and sediment transport in the Ebro delta; a multi-scale approach, p. 169-185, In: Transformations and Evolution of the Mediterranean coastline, Briand, F., Maldolado, A., (Eds), *Bulletin de l' Institut Oceanographique*, no special 18, CIESM Science Series no 3.

Jaoshvili, Sh., 2002. "The rivers of the Black Sea", European Environmental Agency, Technical report no. 71 (http:// reports.eea.eu.int/technical_report_2002_71/).

Karalis, S., Karymbalis, E., Mamasis, N., 2018. Models for sediment yield in Mountainous Greek catchments. *Geomorphology*, 322, 76-88.

Karditsa, A., Poulos, S.E., 2013. Sedimentological investigations in a river-influenced tideless coastal embayment: The case of inner continental shelf of the NE Aegean Sea. *Continental Shelf Research*, 55, 86-96.

Kamizoulis, G., 1997. Water quality of Turkey and Israel rivers. (pers. comm.). OMS, Bureau regional de l'Europe, Vas Konstantinos 48, P.O. Box 18019, 11610 Athens, Greece. www.unepmap.org.

Konovalov, S.K., Murray, J.W., Luther III, G.W., 2005. Black Sea Biogeochemistry. *Oceanography*, 18 (2), 24-35.

Korzoun, V.I., Sokolov, A.A., Budyko, M.I., Voskresensky, G.P., Kalinin, A.A. *et al.,* 1977. Atlas of World, Water Balance. UNESCO Press, Paris, 36 p.

Lehner, B., Verdin, K., Jarvis, A., 2008. Hydrosheds Technical documentation V.1.1. (available from: www.hydrosheds.org)

Lehner, B., Grill G., 2013. Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. *Hydrological Processes*, 27 (15), 2171–2186.

Ludwig, W., Bouwman, A.F., Dumont, E., Lespinas, F., 2010. Water and nutrient fluxes from major Mediterranean and Black Sea rivers: Past and future trends and their implications for the basin-scale budgets: *Global biogeochemical cycles*, 24 (4).

Ludwig, W., Dumont, E., Meybeck, M., Heussner, S., 2009. River discharges of water and nutrients to the Mediterranean and Black Sea: Major drivers for ecosystem changes during past and future decades? *Progress in Oceanography*, 80, 199-217.

Ludwig, W., Meybeck, M., Abousamra, F., 2003. Riverine transport of water, sediments, and pollutants to the Mediterranean Sea. UNEP MAP Technical report Series 141, UNEP/MAP Athens, 111 p. (available from: http://www.unepmap.org/)

Ludwig, W., Probst, J.-L., 1998. River sediment discharge to the oceans: Present-day controls and global budgets. *American Journal of Science*, 298, 265-295.

Margat, J., Treyer, S., 2004. L'eau des Mediterranens: situation et perspectives. MAP Technical Report Series No. 158, 366 p. (available from: http://www.unepmap.org/).

McCarney-Castle, K., Voulgaris, G., Kettner, A.J., 2010. Analysis of Fluvial Suspended Sediment Load Contribution through Anthropocene History to the South Atlantic Bight, Coastal Zone, USA. *The Journal of Geology*, 118 (4), 399-416.

Mc Manus J., 2002. Deltaic response to changes in river regimes. *Marine Chemistry*, 79, 155-170

MedHycos, 2001. The Mediterranean hydrological cycle observing system. Medhycos phase ii, period 2002-2005 (available from http://medhycos.mpl.ird.fr)

Mikhailov, V.N., Mikhailova, M.V., 2008. River inputs. The Black Sea Environment. Springer, pp. 91-134.

Milliman, J.D., Farnsworth, K.L., 2013. River discharge to the coastal ocean: a global synthesis. Cambridge University Press.

Milliman, J.D., Syvitski, J.P., 1992. Geomorphic/tectonic control of sediment discharge to the ocean: the importance of small mountainous rivers. *The Journal of Geology*, 100 (5), 525-544.

Okay, N., Ergün, B., 2005. Source of the basinal sediments in the Marmara Sea investigated using heavy minerals in the modern beach sands. *Marine Geology*, 216 (1-2), 1-15.

Panin, N., 2007. The Black Sea Coastal Zone: Present-day state and threats arising from global change and from regional variability. *Rapport Communicacion international Mer Méditerranee*, Instabul 2007, 38, 21-22.

Pelletier, J.D., 2012. A spatially distributed model for the long-term suspended sediment discharge and delivery ratio of drainage basins. *Journal of Geophysical Research, Earth Surface*, *117* (F2).

Poulos, S.E., Collins, M.B., 2002. Fluviatile sediment fluxes to the Mediterranean Sea: a quantitative approach and the influence of dams: *Geological Society, London, Special Publications*, 191 (1), 227-245.

Poulos, S.E., 2011. An insight to the fluvial characteristics of the Mediterranean and Black sea watersheds, p.191-198, In: *Advances in the Research of Aquatic Environment*, N. Lambrakis, K. Katsanou (Eds.) Springer Berlin Heidelberg,

Prat, F.N., Rieradevall, S.M., 2006. 25-years of biomonitoring in two Mediterranean streams (Llobregat and Besos basins, NE Spain). *Limnetica*, 25 (1-2), 541-550.

Probst, J.L., Amiotte-Suchet, P., 1992. Fluvial suspended sediment transport and mechanical erosion in the Maghreb (North Africa), *Hydrological Sciences Journal*, 37 (6), 621-637.

Rouholahnejad-Freund, E., Abbaspour, K.C., Lehmann, A., 2017. Water Resources of the Black Sea Catchment under Future Climate and Landuse Change Projections. *Water*, 9 (8), 598.

Reshetnikov, Y. S., 1992. An overview of research on Coregonids in the USSR. *Polskie Archiwum Hydrobiologii*, 39 (3-4).

Sabater, F., Guasch, H., Martí, E., Armengol, J., Sabater, S., 1995. *The Ter: A Mediterranean river case-study in Spain*, p. 419-438. In: River and stream ecosystems, Cushing, C.E., Cummins K.W., Minshall G.W. (Eds.), Elsevier.

Selenica, A., 2001. Water resources of Albania (2001/2), p. 1-9, In: MED- Online International Interdisciplinary Research Journal, HYCOS MED-HYCOS (Mediterranean Hydrological Cycle Observing System) joint meeting in Montpellier, June 2001, MED-HYCOS Phase 2, period 2002-2005. Project Proposal Montpellier, June 1, 2001, Report n° 17.

Simeoni, U., Bondesan, M., 1997. The role and responsibility of man in the evolution of the italian Adriatic coast, p. 75-96, In: Transformations and Evolution of the Mediterranean coastline, Briand F. and Maldolado A. (Eds). *Bulletin de l' Institut Oceanographique*, no special 18, CIESM Science Series no 3.

Simonov, A.I., Altman, E.N., 1991. Hydrometeorology and Hydrochemistry of the USSR seas. Vol. IV. The Black Sea.

Skoulikidis, N.T., 2018. The State and Origin of River Water Composition in Greece, p. 97-128, In: *The Rivers of Greece*, Skoulikidis, N., Dimitriou, E., Karaouzas, I., (Eds.), Springer.

Skoulikidis, N.T., Kondylakis, J.C., 1997. Seasonal variations of biogeochemical processes affecting Greek rivers composition. *Geochemical Journal*, 31(6), 357-371.

Skoulikidis, N.T., Sabater, S., Datry, T., Morais, M.M., Buffagni, A. *et al.,* 2017. Non-perennial Mediterranean rivers in Europe: status, pressures, and challenges for research and management. *Science of the Total Environment*, 577, 1-18.

Syvitski, J.P., Peckham, S.D., Hilberman, R., Mulder, T., 2003. Predicting the terrestrial flux of sediment to the global ocean: a planetary perspective. *Sedimentary Geology*, 162 (1-2), 5-24.

Syvitski, J.P.M., Vörösmarty, C.J., Kettner, A., Green, P., 2005. Impact of humans on the flux of terrestrial sediment to the global coastal ocean. *Science*, 308, 376-80.

Syvitski, J.P., Saito, Y., 2007. Morphodynamics of deltas under the influence of humans. *Global and Planetary Change*, 57 (3-4), 261-282.

Syvitski, J.P., Kettner, A.J., Overeem, I., Hutton, E.W., Hannon, M.T. *et al.,* 2009. Sinking deltas due to human activities. *Nature Geoscience*, 2 (10), 681.

Therianos, A.D., 1974. The geographical distribution of the river water supply in Greece. *Bulletin Geological Society of Greece*, 11, 28-58 (in Greek).

Thornes, J.B., Lopez-Bermudez, F., Woodward, J.C., 2009. Hydrology, river regimes, and sediment yield. *The Physical Geography of the Mediterranean. Oxford University Press, Oxford,* 229-253.

Vörösmarty, C.J., 1997. The storage and aging of continental runoff in large reservoir systems of the world. *Ambio*, 26, 210-219.

Vörösmarty, C.J., Wasson, R., Richey, J., 1997. *Modelling the transport and transformation of terrestrial materials to freshwater and coastal ecosystems workshop report* (No. F/304.2 I5/39). International Geosphere Biosphere Programme (Stockholm).

Vörösmarty, C.J., Fekete, B.M., Tucker, B.A., 1998. Global river discharge, 1807-1991, version 1.1 (RivDIS). *Data set. Available on-line [http://www. daac. ornl. gov] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, USA.*

Vörösmarty, C.J., Fekete, B.M., Meybeck, M., Lammers, R.B., 2000. Global system of rivers: Its role in organizing continental land mass and defining land-to-ocean linkages. *Global Biogeochemical Cycles*, 14 (2), 599-621.

Vörösmarty, C.J., Syvitski, J., Day, J., De Sherbinin, A., Giosan, L. *et al.,* 2009. Battling to save the world's river deltas. Bulletin of the Atomic Scientists, 65 (2), 31-43.

Vörösmarty, C.J., Mc Intyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A. *et al.,* 2010. Global threats to human water security and river biodiversity. *Nature*, 467 (7315), 555.

UNEP, 1978. Provisional inventory data on surface water in the Mediterranean. Meeting of experts on fresh water resources management in the Mediterranean region, Cannes, 25-29.

04. 1978. UNEP/WG. 16/INF.6.
UNEP/MAP/MED_POL, 2003. Riverine Transport of Water, Sediments and Pollutants to the Mediterranean Sea, in MAP Technical Reports Series No 141, UNEP/MAP, Athens, 111 p.
UNEP/MAP/MED POL, 2005, Transboundary Diagnostic Analysis (TDA) for the Mediterranean Sea. UNEP/MAP, Athens, 228 p.
UNEP-MAP RAC/SPA, 2010. The Mediterranean Sea Biodiversity: state of the ecosystems, pressures, impacts and future priorities. In: Bazairi, H., Ben Haj, S., Boero, F., Cebrian, D., De Juan, S.et al. (editors), RAC/SPA, Tunis, 100 p.
UNEP/MAP, 2012. State of the Mediterranean Marine and Coastal Environment, UNEP/MAP – Barcelona Convention, Athens, 2012, 92 p.
UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE, 1999. Committee on Environmental Policy, ECE, Economic and Social Council (1999). Environmental Performance Reviews Series No. 7, UNITED NATIONS, New York and Geneva.
Walling, D.E., Webb, B.W., 1983. Patterns of sediment load, pp. 69-100, In: *Background to Palaeohydrology*, Gregory K.J., (Ed), Wiley, Chichester, UK.
Woodward, J.C., 1995. Patterns of erosion and suspended sediment yield in Mediterranean river basins. In: Foster, I.D.L., Gurnell, A.M. and Webb, B.W, (Eds). *Sediment and Water Quality in River Catchments*. John Wiley; 1995. p. 365-389.
Xoplaki, E., Gonzalez-Rouco, J.F., Luterbacher, J.U., Wanner, H., 2004. Wet season Mediterranean precipitation variability: Influence of large-scale dynamics and trends: *Climate dynamics*, 23 (1), 63-78.
Zarris D., Lykoudi E., Panagoulia, D., 2007. Sediment yield estimates in north-western Greece and analyses with hydrologic and Geomorphologic factors. *Bulletin of the Geological Society of Greece*, 40 (2), 629-640.

ANNEX I

Table A. Mean annual values of water discharge (Q in km^3), suspended sediment load (SSL, in 10^6 tones) and dissolved load (DL, in 10^6 tones) for rivers with catchment areas (CA) >250 km^2 for the watersheds of the MBES marine regions.

ALB

River (country)	A	Q	SSL	DL	Ref.
Guadiaro (ES)	1500	0.3	0.04		1
Guadalhorce (ES)	3200	0.2	0.09		1, 7
Guadalfeo (ES)	1300	0.02	0.08		1
Adra Adria (ES)	750	0.03	0.15		1
Andarax (ES)	2200	0.01	0.18		1, 7
Tafna (DZ)	8800	0.28	1.0		1
Moulouya (MA)	51000	1.6	12		2, 1, 7
Kerte (MA)	3100	0.25	0.40		2
Nekor (MA)	790	0.9	2.8		1, 2

WEST_N

River (country)	A	Q	SSL	DL	Ref.
Jucar (Xïquer) (ES)	22084	4.5	0.8	1.0	18, 1, 7
Turia (ES)	6400	0.46			4, 7
Mijares (ES)	4028	0.2			4, 7
Ebro (ES)	85835	50.0	18.0	9.0	1, 2, 7
Llobregat (ES)	5200	0.69	0.07		5, 7
Besos (ES)	1000	0.13	0.015		5, 7
Ter (ES)	3000	0.84	0.045		6, 7
Fluvia (ES)	1124	0.31	0.02		2, 7
Tet (FR)	1600	0.3	0.5		1
Orb (FR)	1800	1.3	0.05		2, 1, 7
Aude (FR)	5900	1.31	0.07		1, 7
Herault (FR)	2900	1.5	0.09		1, 7
Rhone (FR)	96000	54.0	59.0	17.0	2, 1, 7
Argens (FR)	2600	0.6	0.03		1, 7
Var (FR)	2800	1.3	10.0		1, 7
Coghinas (IT, Sar)	2551	0.6			1, 2
Magra (IT)	1200	1.3	0.5		1, 2
Arno (IT)	8183	3.2	2.2	1.4	1, 2, 7

WEST_S

River (country)	A	Q	SSL	DL	Ref.
Segura (ES)	19525	3.1	1.1		1, 7
Tirso (IT-Sar)	3375	0.14	0.51		1
Miliane (TN)	2000	0.02	0.9		1,2
Medherda (TN)	22000	0.94	9.4		1, 2, 7
B. Namoussa (DZ)	570	0.15	0.18		2, 1
Seybousse (DZ)	5500	0.43	1.2		1, 7
Kebir O. (DZ)	1100	0.23	0.22		1, 7
Saf-Saf (DZ)	300	0.07	0.37		2
Agriun (DZ)	660	0.17	4.8		1
Soummam (DZ)	8500	0.79	4.1		1, 7
Sebau (DZ)	2500	0.51	1.2		1
Isser (DZ)	4200	0.36	8.3		1, 7
El Harrach (DZ)	390	0.13	0.63		1
Mazafran (DZ)	1900	0.44	3.0		1, 2
Cheliff (DZ)	44000	1.3	4.0		1, 2, 7

continued

Table A continued

TYR

River (country)	A	Q	SSL	DL	Ref.
Ombrone (IT)	3200	0.79	10.0		2, 7
Tevere (Tiber) (IT)	17000	7.4	7.5	5.9	2, 1, 7
Liri (Gorigliano) (IT)	5000	3.15	3.25		1
Volturno (IT)	5500	3.1	4.2		2, 1, 7
Sele (IT)	3400	2.84	2.38		1
Flumendosa (IT)	1775	0.69	1.15		25
Cixerri (IT)	500	0.63			25

CEN

Gela (IT, Sic)	569	0.02	0.13		1
PlatanI (IT, Sic)	1785	0.24			25

ION

Alcantara (IT, Sic)	573	0.08			2
Simeto (IT, Sic)	4186	0.8	3.5		1, 7
Agri (IT)	278	0.25	0.07		2, 1
Basento (IT)	1400	0.11	0.35		2
Bradano (IT)	2743	0.2	2.8		2, 7
Thiamis (Kalamas) (GR)	1899	1.22	2.37	0.68	2, 22
Louros (GR)	931	0.38	0.8	0.17	1, 22
Arachthos (Arakhthos) (GR)	2443	2.25/1.22	7.47	0.76	2, 22
Acheloos (Akheloos) (GR)	5688	7.78/5.67	3.29	1.5	2, 1, 22
Evinos (GR)	1070	1.47	0.37	0.14	2, 3
Mornos (GR)	1010	1.13	0.35		2 ,3
Selinountas (GR)	245	0.01			21, 22
Pinios Pel. (GR)	913	0.51			2
Alfios (Alpheios) (GR)	3501	1.71/1.21	3		2, 1, 22
Evrotas (GR)	1738	0.76			19, 20, 22

ADR

Ofanto (IT)	2716	0.37	0.9		2, 1, 7
Fortore (IT)	1126	0.42	1.5		2, 7
Biferno (IT)	1290	0.66	2.2		2, 7
Trigno (IT)	1200	0.1	0.42		1
Sangro (IT)	1900	1.42	0.52		1
Pescara (IT)	3300	1.7	1.9		2, 1, 7
Tavo (IT)	250	0.06	0.04		2, 1
Tronto (IT)	1200	0.5	1.1		2, 1
Tenna (IT)	490		0.45		2
Aso (IT)	280		0.18		2
Tena (IT)	490		0.45		2
Chienti (IT)	1300	0.3	0.85		2
Potenza (IT)	770	0.2	0.56		1
Misa (IT)	380	0.2	0.47		2
Esino (IT)	1200	0.35	0.27		2
Musona (IT)	1200	0.35	0.27		2
Metauro (IT)	1045	0.43	2.02		2, 7

continued

Table A continued

River (country)	A	Q	SSL	DL	Ref.
Foglia (IT)	700	0.25	1.4		2
Marrechia (IT)	357	0.31	1.6		2
Savio (IT)	597	0.33	1.35		2
Lamone (IT)	710	0.28	1.3		2
Reno (IT)	3410	0.9	2.7		2, 7
Po (IT)	54290	46.0	15.0		1, 7
Adige (IT)	17000	7.3	1.6	1.6	1, 7
Brenta (IT)	1563	2.3	0.19		2, 1, 7
Piave (IT)	4100	3.2	1.23		1
Tagliamento (IT)	3600	2.7	1.08		1
Mirna (HR)	500	0.3			1, 7
Zrmanja (HR)	900	1.39			8
Krka (HR)	2200	2.01			7, 8
Cetina (HR)	1500	1.31			7, 8
Neretva (HR)	13000	12	13.6	5.25	2, 7
Buna (AL)	5200	10.1	2.5		2, 7
Drin (AL)	19582	21.44	21		2, 1, 7
Mati (AL)	2300	3.4	2.6		1, 7
Ishem (AL)	670	0.66	2.0		2, 7
Erzen (AL)	760	0.57	3.2		2, 7
Shkumbin (AL)	2444	1.94	7.2		1, 2, 7
Semani (AL)	5649	3.02	24		2, 7
Osum (AL)	2000		5.6		1
Vijose (Aoos)(AL)	6800	5.5	29		2, 7
AEG					
Asopos (GR)	1100	0.7			21
Sperchios (GR)	1662	1.14/0.4			2, 3, 22
Pinios Th (GR)	10850	3.8/2.4			2, 3, 22
Aliakmon (GR)	9455	3.6/2.3	4.35	1.21	2,3, 1,22
Axios (Vardar) (GR)	24398	5.3/7.7	11.0	1.7	2, 1, 10, 22
Gallikos (GR)	930	0.79	0.004		3, 2, 1
Strymon (GR)	16816	5.2/2.8	4.0	1,5	3, 2, 1,22
Nestos (Mesta) (GR)	6213	3.5	0.99	0.78	3, 2, 1
Evros (Meric) (GR-TR)	53025	8.12	8.5	2.6	11, 1, 22,23
Karamenderes (TR)	1569.4	0.42	0.08		1, 7
Bakir / Bakircay TR)	3400	0.56	0.17		1, 7
Cediz-Nehri (TR)	18000	2.3	1.30	3.7	1, 7
Kujuk Menderes (TR)	6900	1.00	0.60		1,2, 7
Buyukmenderes (TR)	25000	4.7	0.78	3.4	1, 2, 7
MAR					
Gonen (TR)	1451	0.46	0.15		16, 17
Biga (TR)	2096	0.6	0.09		16, 17
Simav (TR)	23765	4.55	0.88	1.2	16, 17

continued

Table A continued

LEV_N

River (country)	A	Q	SSL	DL	Ref.
Dalaman (TR)	4481	1.52	0.75		2
Eşen (TR)	2458	1.32	2.26		2
Aksu (TR)	1579	0.96	0.23		2
Kopru (Köprücay)(TR)	1974	2.67	0.47		2
Manavgat (TR)	1300	4.1	0.28	0.9	1, 2, 7
Goksu (TR)	10561	3.9	2.50		2, 1, 7
Lamas (TR)	2200	0.154	0.22		18, 7
Tarsus (TR)	1400	0.1	0.13		1, 2
Seyhan (TR)	22000	8.0	5.20	1.3	1, 7
Efrenk (Muftu) (TR)	480	0.16			19
Ceyhan(TR)	21000	7.0	5.50	2.0	1, 7
Asi (Orontes)(TR)	23000	2.7	19.0	1.0	1
Serrachis (CY)	735	0.04			12, 1
Pediaios (CY)	870	0.024			12
Gialias (CY)	600	0.018			12
Kouris (CY)	340	0.02			12
Diarizos (CY)	280	0.016			12
Xeros (CY)	255	0.014			12
Ezousas (CY)	250	0.013			12
Litani (LB)	2500	0.125			13

LEV_S

Qishon (IL)	1100	0.06			7, 14
Yarcon (IL)	1800	0.2			1
Lachish (IL)	1000	0.013			14, 1
Qama (IL)	800	0.04			1
Besor (IL)	3700	0.01			1
Nile (EG)	2880000	90.0	120	6.1	1

BLA_W

Rezovska (BG)	183.4	0.025			15
Veleka (BG)	995	0.296	0.078		15
Ropotamo (BG)	248.7	0.037	0.024		15
Khadjiska (BG)	355.8	1.53	0.046	0.048	15
Dvoinitsa (BG)	478.8	0.065	0.045		15
Kamchea (BG)	5358	0.61	1.12	0.87	15
Batova (BG)	338.8	0.023	0.048	0.023	15
Danube (RO)	817000	200.0	87.8	80.0	15
Dniester (UA)	72100	10.2	2.5	6.1	15
South Bug (UA)	63700	2.2	0.2		15
Ingul (UA)	9700	0.6	0.126		15
Dnieper (UA)	516300	53.0	2.1	15.0	15
Alma (UA)	633	0.044	0.04		15
Salhir (RU/UA)	3750	0.063			15
Kokozka (RU/UA)	840	0.037	0.026		15
Belbek (RU/UA)	270	0.068	0.032		15
Bolamani (TR)	1063	0.57	0.77		15
Yeshil Irmak (TR)	36100	5.3	12.5	1.0	15
Kizil Irmak (TR)	78600	5.9	16.7	5.5	15

continued

Table A continued

River (country)	A	Q	SSL	DL	Ref.
Kure (Inebolu) (TR)	425	0.13			15
Kojachai (Devrekani) (TR)	2254	0.22			15
Filios (TR)	13100	2.9	3.7		15
Melen cayi (TR)	2174	1.51			15
Sakaria (TR)	56500	5.6	4.6	2.9	15
Sarisu deresi (TR)	2000	0.4	0.12		15
AZOV					
Don (RU)	442500	28.0	7.75	12.0	15
Kuban (RU)	63500	12.8	8.4		15
Salhir (RU)	3750	0.63			24
BLA_E					
Pshada (RU)	360	0.31	0.057		15
Vulan (RU)	280	0.2	0.059		15
Shapsukho (RU)	300	0.222	0.113		15
Tuapse (RU)	350	0.404	0.111		15
Ashe (RU)	280	0.39	0.057		15
Psesuapse (RU)	290	0.486	0.091		15
Shakhe (RU)	550	1.161	0.211		15
Sochi (RU)	300	0.508	0.101		15
Mzymta (GE)	885	1.562	0.258		15
Psou (GE)	420	0.606	0.158		15
Bzyb (GE)	1510	3.79	0.767	0.23	15
Aapsta (GE)	250	0.341	0.038		15
Gumista (GE)	580	1.051	0.264		15
Kodori (GE)	2030	4.17	1.295	0.39	15
Mokva (GE)	336	0.571	0.047		15
Galidzga (GE)	483	0.928	0.095		15
Okumi (GE)	265	0.458	0.034		15
Inguri (GE)	4060	5.207	2.7	0.51	15
Khobi (GE)	1340	1.895	0.221		15
Rioni (GE)	13400	9.62	3.39	2.8	15
Supsa (GE)	1130	1.581	0.246		15
Natanebi (GE)	657	0.773	0.156		15
Kintrishi (GE)	291	0.527	0.022		15
Chorokhi (Goruh) (GE)	22100	8.71	8.44		15
Firtina (TR)	1149	0.9	0.075		15
Iyidere (TR)	1047	0.895	0.125		15
Deghir menderes (TR)	730	0.377	0.132		15
Kharshit (TR)	3500	1.1	0.51		15
Melet cayi (TR)	1024.4	0.34	0.190		15

References. 1: Milliman & Farnsworth (2013) and references herein; 2: Poulos & Collins (2002) and references herein; 3: Poulos *et al.* (1996) and references herein; 4: Estrela, Quintas & Alvarez (1997); 5: Prat & Rieradevall (2006); 6: Sabater *et al*. (1995); 7: UNEP/MAP/MED_POL (2003); 8: United Nations Economic Commission for Europe (1999); 9: Selenica (2001); 10: Medhycos (2001); 11: Skoulikidis & Kondylakis (1997); 12: Ministry of Agriculture, Natural Resources and Environment (MoA) (2005); 13: Amery (1993); 14: Kamizoulis (1997); Jaoshvili (2002) and references here in; Algan (2006); Okay & Ergün (2005); 18: Eurosion (2004); 19: https://en.wikipedia.org/wiki /Efrenk_River#cite_note-1; 20: Skoulikidis (2009); 21: Therianos (1974); 22: Skoulikidis, (2018); 23: Karditsa & Poulos (2013); 24: Wikipedia; Cidu *et al*. (2007); 25: https://it.wikipedia.org/wiki/Platani].

Country's abbreviation: Albania (AL), Algeria (DZ), Bulgaria (BG), Croatia/Hrvatska (HR), Cyprus (CY), Egypt (EG), France (FR), Georgia (GE), Greece (GR), Israel (IL), Italy (IT), Lebanon (LB), Morocco (MA), Romania (RO), Russian Federation (RU), Spain (ES), Tunisia (TN), Turkey (TR), Ukraine (UA), Israel (IL).