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ENVIRONMENTAL DEGRADATION OF THE COASTAL ZONE OF THE WEST PART OF NESTOS RIVER DELTA, N.GREECE

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Abstract

The coastal zone is a transitory zone between land and sea. Due to its importance to man, not only for its high food production but also for recreation, sea transportation and industrial activities, coastal zone receives high environmental pressure from him.

This paper deals with degradation phenomena of the coastal zone in the west section of the River Nestos Delta, North Aegean Sea, with special stress on the geomorphological changes in the coastline. The length of the coastline in this part of river Nestos Delta (the Kavala- Chrisoupoli part), from Nea Karvali village to the west, up to the river mouth to the east, is around 35 km long. This section constitutes the biggest and more extended sector of the Nestos Delta; it is the section where the main course and the various branches of the river were located, in the past. Along the coastal zone of this section of the delta many lagoons, sand bars, spits, barrier islands, washover fans, etc. were developed in its geologic past. Some of these geofoms still exist, but the majority of them have been destroyed by physical and/or anthropogenic interventions. Two of the last interventions are the diversion and entrenchment of the river to the east, in early 50's and the construction of two high dams in the river course inland, in 2000. These human interventions deprived this land of flooding waters and sediments resulting in: (a) drying of most of the river channels and courses crossing this area of the river's delta, (b) erosion of the coastal landforms and retreat of the shoreline in the majority of the delta coasts. There are, of course, a few places along the coastline where deposition and accretion are still taking place. In more detail, along the coastline taken into consideration in the present paper, one can meet:

- stretches with high erosion rates, like the Akroneri Cape (spit), the inner coastline of Keramoti bay (Kokala -Piges coast), the Monastiraki coastline, etc,*
- stretches with high accretion rates like the Keramoti peninsula/spit, and*
- stretches at equilibrium or low rate of change like the barrier (spit) west of Akroneri Cape up to Nea Karvali coast and a short stretch of the coastline south-east of Keramoti peninsula.*

Comparing the Delta coastline of 1945 (from available aerial photographs) and the coastline of 2002 (from high resolution satellite images), before the construction of the Thisavros and Platanovrisi high dams (period 1945-2002), it has been estimated that: 88% of the delta and the adjacent coastlines has been accreted while only 12% has been eroded. In other words, there was a surplus of accretion by 76% and the delta was procreated. Comparing the Delta coastline of 2002 (from high resolution satellite images) and the coastline of 2007 (from high resolution D-GPS field measurements), after the construction of the dams (period 2002-2007), it has been estimated that: only 39% of the delta and the adjacent coastlines has been accreted while 61% has been eroded. In other words, there was a surplus of erosion by 22% and the delta began to retreat. This was due to

the great reduction (by almost 80%) of the river's sediment load reaching to the sea. Thus, up to 2002, or so, the balance accretion – erosion in the whole delta coastline was positive, whereas after 2002 the erosion and retreat predominates in the delta's coastline.

The prevention of sediments and fresh water flooding in the delta area, has also affected the crops production in the fields in the vicinity of the delta as well as the fish output in the lakes and lagoons of the coastal zone.

Key words: Nestos Delta, coastal erosion, Aegean Sea, North Greece.

1. Introduction

The coastal zone is a transitory zone between land and sea and between fresh and salt water. It is a zone where the life is flourishing and man uses it for food production, for fishing, for recreation, for sea transportation and industrial activities. Due to these human activities, the coastal zone receives high environmental pressure from man. It should be mentioned that approximately half of the world's population are living or working in a narrow zone of a 100 km from the world coastlines. In Greece, a country with a total coastline development nearly 16000 km long and over 3000 smaller and bigger islands, about 70% of the population and more than 80% of the industrial activities in the country, are concentrated in the coastal zone. Therefore the importance of the coastal zone for the survival and the prosperity of the Greek people is vital and is subjected to high environmental pressure. The coastal zone of Nestos delta and the adjacent coastlines is an example of such a system receiving high environmental pressure by man and is discussed in detail in the following paragraphs.

2. Physical Geography of the Area

2.1 Geology

The sedimentary basin of river Nestos delta constitutes part of the broader quaternary basin of Prinos that includes the Nestos delta and the sea between Thassos island and the main land around Kavala bay. The Prinos-Nestos basin is also part of the broader tectonic basin of south Rhodope Range. The bedrock of the basin consists, therefore, of Rhodope mass rocks (gneisses, schists, amphibolites, marbles, etc) (Fig. 1). Due to continuous subsidence of the basin, the thickness of its deposits ranges approximately from 2.5 to 6.0 km (Psilovikos, et al, 1988). The initial faulting and subsidence of South Rhodope is located in the Lower to Middle Miocene (Lalechos et al., 1977; Pollak, 1979; Proedrou, 1979). The deeper layers of the basin's deposits consist of conglomerates and sandstones deposited in a pre-delta environment. During the Upper Miocene, a period of intense evaporation, and the deposition of evaporates and clastic sediments, in alternative layers, followed. Later, during Pliocene and Pleistocene, sedimentation turned again to clastic materials with the deposition of sandstones, mudstones and claystones, in a marine-deltaic environment (Lalechos et al., 1977, 2000; Stournaras, 1984). The Quaternary and recent deposits of the Nestos basin delta are not more than one to two hundred meters thick and consist of gravels, sands, silts and clays in a lensial and alternating (cyclothem) pattern, deposited principally in a deltaic environment. The modern soils of the coastal zone consist of sands, silts and clays in various proportions.

The relief of the coastal zone under discussion is low to almost level. The beach consists of coarse to fine sand and its width varies from 10 m up to 50 m in some places. The beach sands are extended seawards forming a zone of 300 to 400 m of shallow waters, (less than 10 m deep), surrounding the coastline. This shallow waters zone is extended up to 900 m, in some places, e.g. at ammodis Akra (Cape Akroneri) and at the river Nestos mouth. This means that at least some of the sediments extracted from coastal erosion and/or discharged by the river Nestos waters are deposited nearshore.

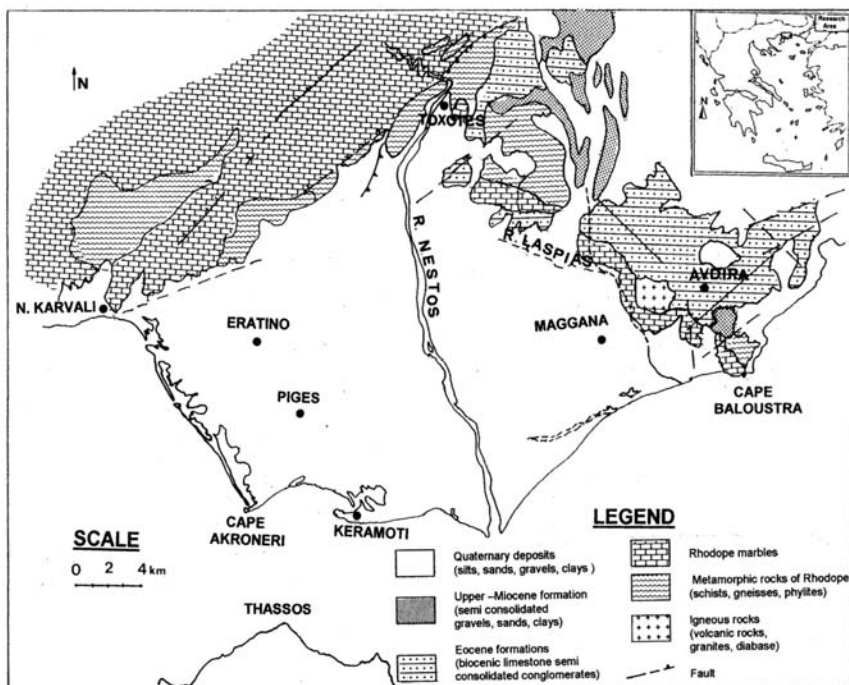


Fig. 1: Simplified geological map of the Nestos (Mesta) river modern delta.

2.2 Evolution of Delta

At the end of Wurm glacial period, some 18.000 years ago, when the melting of ice sheets covering the earth surface started, a rise of the sea level has been initiated worldwide. It has been suggested that the total rise of the sea level since that time is around 120 to 130 m. The sea level increase was faster at the beginning (nearly 1cm/yr) and very slow the last 5000 years (about 0.2 mm/yr). The last hundred years the rate of sea level rise increased again due to rise of global temperature. During that sea level ascent most of the coastal lowlands around the world have been inundated. This rise has also happened in north Aegean coasts. The sea flooded the initial Nestos river delta (palaeodelta), which is now under the sea between Thassos island and Kavala coast, and modified greatly the flow regime of the river. The river course inclination decreased and the river started to flood the plain area adjacent to it, to bifurcate and to form new distributaries, wetlands and ultimately a new delta (Perissoratis, 1990) (Fig. 1).

It should be mentioned that the catchment area of river Nestos is around 5752 km², from which 3437 km² are inside Bulgaria and the rest 2315 km² inside Greece. The average total physical runoff from the Rila mountain up to the Nestos/Mesta estuary is 2076x10⁶ m³ and the average physical discharge is about 66.4 m³/s, based on data of the hydrological years 1965–66 to 1989–90 (Mimidis et al., 2007).

The mean annual sediment yield before the construction of the dams was 2x10⁶ tn/yr (or 1,08x10⁶ m³/yr), after the construction the dams in the river course (2002 onwards) it is 0,33x10⁶ tn/yr. *This means that after the construction of the dams the sediment load reaching at the sea was reduced by about 80%* (Hrisanthou et al., 2002; Beamed-e final report, Sub-program 3.3 «GESA», 2008). The River's modern delta area is almost 440 km² and the delta shoreline is 51 km long. The river course was diverted and confined by artificial levees during fifties due to flooding control operations. This de-



Fig. 2: Sites of coastline changes (erosion-accretion) along the west section of the Nestos' River Delta.

prived the wetlands in the delta area of flooding waters, sediments and nutrients. The modern (diverted) river course axis has an almost N-S direction and is almost in the middle of its delta, dividing it into two nearly equivalent parts, the east part and the west part. Due to the river levees (embankments) the area outside the levees is poorly drained and thus many small and big swamps and marches are formed during the rainy season, especially near the shore. Most of them usually dry up during summer. There are also many dunes in the coastal zone, behind the shoreline. Unfortunately many of the earth features are nowadays destroyed either by sea erosion and retreat of the shoreline inland or by human activities like agriculture, construction of settlements, etc. The Nestos river delta is classified as an *arcuate delta* according to Shepard's (1963) classification (Stournaras, 1984; Psilavikos, 1988).

Figure 2, illustrates the coastline change trends (erosion-accretion) along the west section of the Nestos' river delta that resulted from macroscopic observations and traditional field measurements, conducted by Democritus University of Thrace, in the last decade.

2.3 Climate.

The climate of the broader area is of Mediterranean type: marine, humid with warm summer and rainy winters. It is classified as Cfa or Cfb in the Koppen classification and as Csa along the coastal zone or C₂S₂b'2a' in the Thornthwaite one (Flokas, 1997). The colder month of the year in the area is January with a mean temperature 4.8 °C and the warmest is July with a mean temperature 23.6 °C. The mean annual rainfall in the plain area is 546.5 mm (data from Chrysoupolis meteorological station). In the North Aegean sea, north winds are prevailing but in Autumn and Spring, south winds are more frequent than the north ones. In winter, the north winds are alternated to south and vice versa. In general, the north winds in the area are of NE direction and the south winds are of SW di-

rection. In summer time, Trade winds, characteristic of the North Aegean region, called *Etesians* locally, are blown. They are north to north-east winds, quite strong (5-8 Beauforts), blown from May up to October and are strongest during July-August. They usually cease in middle September each year (Greek Waters Pilot, 1991).

2.4 Sea climate

The surface sea currents in N. Aegean are affected by the Elispontos straits current (Canakkale bogazi) which fans out in N. Aegean and meets the northwards sea current flowing along the Asia Minor coasts. They both turn to the west side of N. Aegean reaching south of Thasos island, where they turn to SW and S at Athos peninsula. They are affected much by the local winds. Thus, the main alongshore current in North Aegean coasts is from the east to the west. This current changes direction and speed locally, near the coast, responding to the direction of the coastline, the geomorphology of sea bottom near the coast, the direction of the blowing wind, etc. For example, in the straits between Thasos island and the mainland (Cape Akroneri and Nestos mouth), when strong S and SE winds are blown, sea water moves to NW along the east coasts of Athos peninsula to Strymonikos bay and it turns to east at Kavala bay, passing from Thasos Straits as an eastwards current. In contrary, with N and NE winds the alongshore current is westwards. Sometimes two simultaneous and opposite sea currents are observed along Thasos straits; one to the westwards nearshore and another to the eastwards offshore, or vice versa, depending upon the direction and the speed of the winds. The speed (the celerity) of these currents reach sometimes up to 1,5 knot = 0,772 m/s=2,78 km/h. (Greek Pilot 1991)

The waves height, with strong south winds, can reach up to 2-3 m, and the tide (high water level near the coast) up to 0,40 m, u.m.s.l.; whereas with north winds the waves nearshore are lower and the sea level up to 0,50 m lower than the mean sea level (m.s.l.).

3. Wetlands of the Nestos River Delta

In the coastal area of the Nestos river delta there are some very important wetlands (small lakes, lagoons, marches, bogs, etc). The whole Nestos delta is under the Ramsar convention and is a highly protected area, for its ecological interest (see Natura 2000). Most of the wetlands of the coastal zone are of lagoon type, connected directly to the sea. Around the lagoons there are many marshes, bogs, swamps, etc. They extend during the rainy season landwards and shrink or dry up during the dry season (summer).

The ten major wetlands have a very rich biodiversity and are of high ecological and scientific interest. 570 species and subspecies of plants, 25 species of mammals, 43 species of fishes, 12 species of amphibians, 30 species of reptiles and 277 species of birds have been registered, so far, as living or nesting in the Nestos delta area (Panagiotopoulou, 2000).

The deforestation of much of the delta area and the extension of agricultural fields up to the river external levees, together with the intensive use of fertilizers and pesticides for crops, contribute greatly to deterioration of the soils and the waters in area.

The building of big dams on the Nestos river course and its tributaries; the confinement of many water courses (creeks, torrents, etc) on the plain area of delta, for avoiding flooding; the construction of a net of drainage canals; the over-pumping of the groundwater aquifers, etc., deprive sediments, nutrients and fresh water of delta plain, helping the reduction of soil productivity, the intrusion of sea water inland and the salinization of the groundwater aquifers and soils in the coastal

zone. For example, the salinization of the groundwater on the coastal zone due to sea water intrusion has been extended up to 5 km inland nowadays. All these human and natural interventions on the delta area affect directly all the organisms living in the area. In addition they influence the crop production in the fields and the fish output in the lakes and the lagoons of the area. Due to over-pumping of the groundwater aquifers, and lowering the groundwater table, the rate of intrusion of seawater inland, has been increased lately and the ground water in many places of the coastal zone, turned to brackish. Pumping and irrigating with brackish water leads to *salinization* of the soils and to a serious brought down of the crops output. (Diamantis, 1994, 1999; Delimani, 2000; Delimani et al., 2002, Xeidakis and Delimani, 2003).

4. Erosion / Accretion Phenomena in the west part of Nestos River Delta

4.1 General

The length of the coastline of the west part of river Nestos Delta (the Kavala- Chrisoupoli part) from Nea Karvali village, to the west, up to the river mouth to the east, is around 35 km long. This part constitutes the biggest and more extended part of the Nestos delta where the main channel of the river and its tributaries were developed. Along the coastal zone of this part of the delta many lagoons, sand bars, spits, barrier islands, washover fans, etc. were developed. Some of these ge-forms still exist.

After the diversion and entrenchment of the river Nestos course to the east, in its modern site, in late '50s, most the river channels and courses crossing the west part of delta were dried up and deprived this part of the river's delta of water and sediments. As a result, erosion of the coastal landforms started with varied intensity in places.

Along the coastline, under discussion, one can meet:

- stretches with high erosion rates, like at the Acroneri Cape/spit, the inner coastline of Keramoti bay (Kokala -Piges coast), the Monastiraki coastline, etc,
- stretches with high accretion rates like at Keramoti peninsula/spit, and
- stretches at equilibrium or low rate of change like at the barrier/spit west of Akroneri Cape and a short stretch of the coastline southeast of Keramoti peninsula.

4.2 Shoreline Evolution Monitoring

In order to quantify the shoreline evolution in the wider region of Nestos river delta, archive Quick-Bird (2002) high resolution, satellite images as well as available aerial photographs (year 1945), were geo-referenced from which the instantaneous shorelines were extracted. Moreover high resolution D-GPS measurements were conducted (2006, 2007) in order to extract a coastline which approximates the high water line (HWL) the day of measurements ("wet sand"). In addition, ground control points were installed in selected locations, to facilitate frequent field measurements for shoreline seasonal variability determination. The accuracy of the instantaneous shorelines, extracted automatically using ARC GIS from the satellite images, is checked on sections where the change from land to water is sharp (shore protection structures, ports, etc). It is estimated that the accuracy of determining the instantaneous shoreline is of the order of 2 to 3 pixels or else 1.2 to 1.8 m for the extracted shoreline from pan-sharpened Quick Bird Satellite Images (Pixel Dimension 0.6 m in each band, R-G-B-IR) (Beacmed-e final report, Sub-program 2.1 «OPTIMAL», 2008). The main "hot spots" regarding large values of erosion or accretion in the neighbour of river Nestos delta are illustrated in Figure 3.

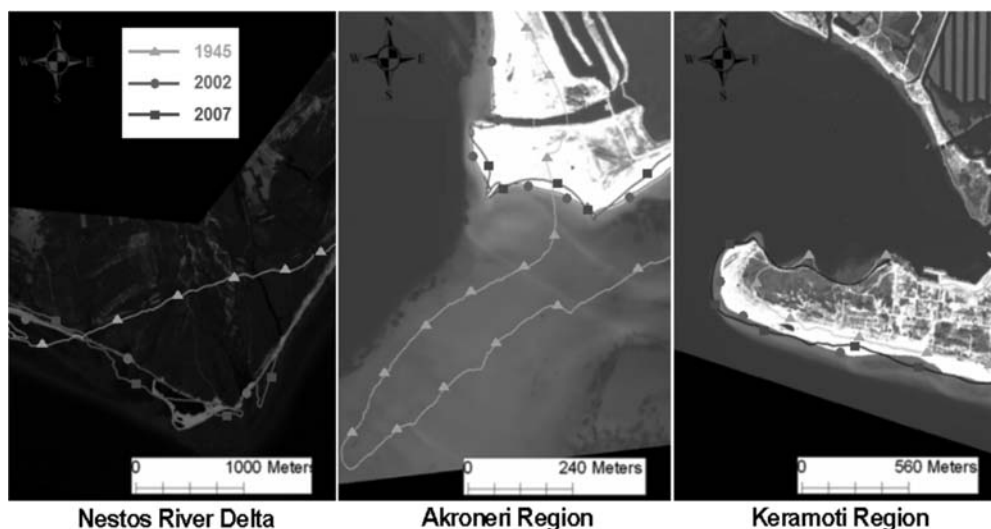


Fig. 3: Shoreline Evolution Monitoring results in Hot Spots of Erosion & Accretion in the Pilot Study Areas.

The shoreline evolution for a short term period (year 2002 to 2007 that corresponds to the period after the construction of dams) and a long term period (year 1945 to 2002, that corresponds to the period before the construction of dams) were determined, from the analysis of the overall extracted shorelines. It is found that the maximum transverse variation (accretion) of the shoreline position between the year 1945 and the year 2002 (before the construction of dams) at the mouth of Nestos river was about 1100 m or about 18 m per year. The maximum transverse erosion of the shoreline position between the year 1945 and the year 2002 (before the construction of dams) at Akroneri, was about 780 m or about 12.5 m per year. An interesting result regarding the evolution of the beaches at the east and west of Nestos river delta (coastal length about 25 km), for the two time periods mention previously is shown in Table 1 and some examples of intense erosion and accretion phenomena from the overall study area are depicted in Figure 4.

Table 1. Comparison of sediment balance in the beaches close to river Nestos mouth (from Akroneri to Dasoxori, about 25 km) before and after the construction of dams.

Area of sediment change	2002-2007 (after dams)	1945-2002 (before dams)
Total evolution area (m ²)	665531	2608678
Accretion (m ²)	261873	2304096
Erosion (m ²)	403658	304582
Accretion (%)	39	88
Erosion (%)	61	12
Erosion area / Accretion area	1.54	0.13

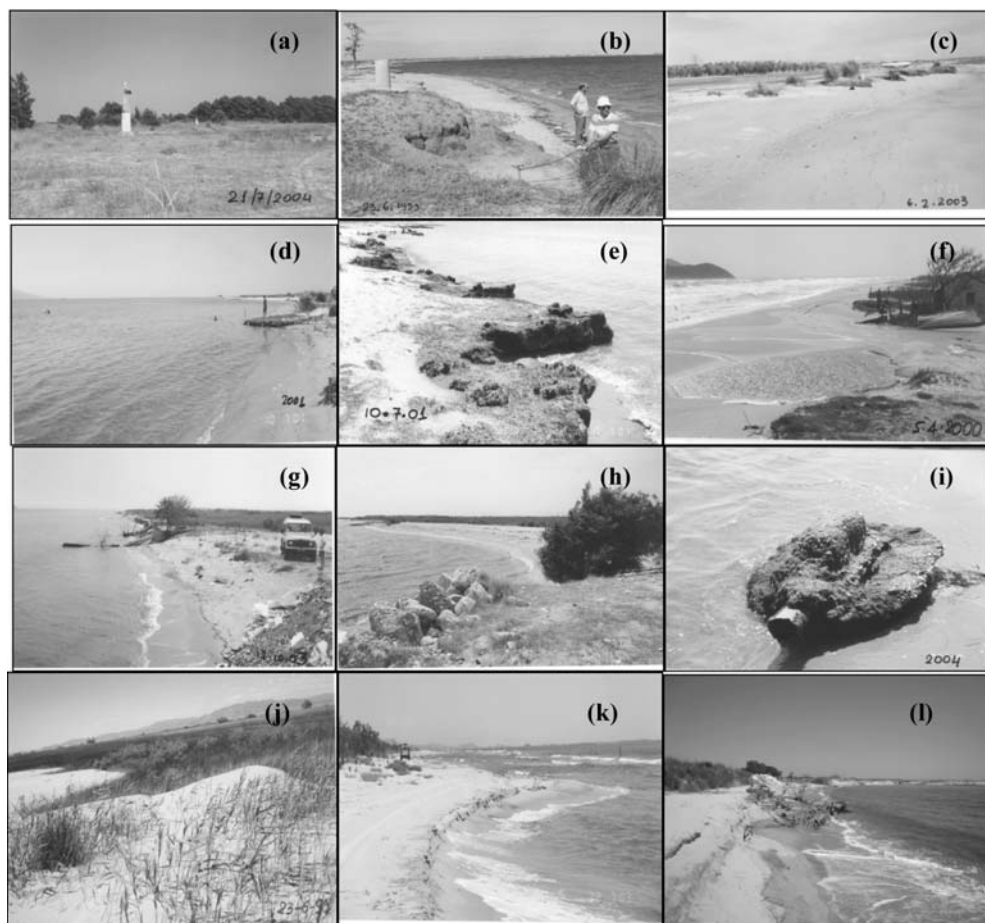


Fig. 4: (a) Lighthouse at Cape of Keramoti (in 1950 was 48m from the west coast) moved to the west (near the coast) in 1981 by 70 m. Today it is some 150m away from the west coast. Coastline under accretion. (b) Agiasma Coast (Kokkala). Topographic post in 1999. Coastline under intense erosion. (c) Agiasma Coast (Kokkala). Topographic post in 2003. It has been completely eroded transferred into the sea. Coastline under intense erosion. (d) Agiasma Coast (Kokkala). The modern position of two boreholes for irrigation. They both were situated inland some 100 m. (e) Agiasma Coast (Kokkala). Intense retreat of the coast and uncover of the bog surface under the beach sand. (f) Monastiraki Beach. House near the beach. In 1998 it was inhabited and has a small garden in the front. Between 1998 and 1999 it was destroyed completely. (g) Monastiraki Beach. The same house in 2003. Coastline under erosion. (h) Monastiraki Beach. The place of the house in April 2006. (i) Agiasma beach. Borehole in the sea due to retreat of the coastline by erosion. (j) Monastiraki coast. Sanding of the bog. (k) Dasoxori coast borehole about 40 m offshore. (l) East Monastiraki coast. Intense coastal erosion and destruction of fish pond outlet.

The overall balance of the area of sediment accretion or erosion from the year 1945 up to the year 2002, indicates that accretion is the dominant mechanism, with a total area of accretion about 8 times larger than the erosion area. The large accretion was due to the river Nestos sediment yield. However, this situation has dramatically changed, due to the construction of the big dams along the Nestos river. Therefore for the same beaches and for the short term balance 2002-2007 (after the construction of the dams) it is found that the area of erosion is 1.5 larger in comparison with the area of

accretion. This shows that after the construction of dams there is a net deficit in the sediment balance which confirms the initial assumption that the construction of dams upstream of River Nestos Delta and the consequent trapping of the sediments has altered the dynamic sediment balance (Beacmed-e final report, Sub-program 2.1 «OPTIMAL», 2008).

5. Conclusions-Recommendations

The reduction of sediment yield of river Nestos/Mesta because of the two big dams' construction in Greece (Thissavros and Platanovrisi) and one big dam in Bulgaria (Dospat) implies a dramatic decrease (about 80%) of the sediments supplied directly to the river mouth and indirectly to the neighbored coast. This fact has as consequence the alteration of the sediment balance in the delta area, with a dramatic impact on the washout of the river Nestos mouth and erosion of the adjacent coastline.

Although there are many regulations regarding the water management and the obligation of the dam owner to ensure a minimum water discharge to the river for ecological purposes, unfortunately, there is not similar regulation regarding minimum sediment discharge from the artificial reservoirs. Hence, we recommend the necessity of establishing an “ecological minimum sediment discharge downstream of the dam” in the design process of future dams. The advances of modern engineering practice makes possible the achievement of this, environmentally plausible, task.

6. Acknowledgements

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