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# Impact of River Damming and River Diversion Projects in a Changing Environment and in Geomorphological Evolution of the Greek Coast

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## **Authors' contributions**

*This work was carried out in collaboration between all authors. Author MA designed the study, performed the impacts to the natural environment by human activities (large dams and artificial diversion projects), the "in situ" observations for the geomorphological evolution of each area under study and managed the analyses of the study. Authors MA and MK elaborated the literature searches, the data of maps, aerial photographs, satellite images and the "in situ" observations and proceeded to comparative observations on the changes has been the natural environment and especially geomorphology in the under study areas.*

*Authors MA and MK, wrote the protocol, and wrote the first draft of the manuscript. All authors read and approved the final manuscript.*

**Research Article**

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## **ABSTRACT**

It has been observed, in many Mediterranean countries, that human activities-engineering works, such as large dams and reservoirs construction (hydroelectric power dams, irrigation dams and water supply dams), artificial river diversion projects, channelization, etc., may seriously affect the environmental balance of inland and coastal ecosystems (forests, wetlands, lagoons, Deltas, estuaries and coastal areas). Dam constructions and their operation has modified the natural evolution trends of coastal areas to a considerable extent and has arguably been the most important factor controlling the evolution of the Greek coastal zone in recent decades. While an important

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factor of the destabilization of the ecological balance is the “climate change”, the role of “climatic cycles” is not negligible. Dams and reservoirs retain vast masses of water and sediments, thus adversely affecting water resources, the seasonal hydrological and hydrogeological regimes, while this disruption of water flow and sediment transport is able to generate changes on the supply of groundwater aquifers, on the emerging coastal erosion phenomena and consequently impacts on delta evolution and coastal ecosystems. Also, the creation of artificial lakes in forest areas and deforestation, contribute to increase emissions of CO<sub>2</sub> and other greenhouse gases and climate change. The purpose of this study is to: a. describe the main man-made interferences (engineering works) which due to their nature and position, cause changes in the natural evolution of the hydro-geomorphological processes in the deltaic coastal zone of the rivers Nestos, Acheloos, Arachthos, Louros, Spercheios, Inoios and Alfeios, in Greece, b. report a synthesis of the environmental and geomorphological studies of the areas under study, c. describe the geomorphological evolution of the selected areas and d. detect and evaluate the impacts of the above mentioned anthropogenic activities and the influence of “climate change” and affect the geomorphological evolution of the Greek coast.

*Keywords: Climate change; coastal environment; dams; environmental impacts; river diversion.*

## 1. INTRODUCTION

Freshwater wetlands around the Mediterranean Sea have decreased considerably in number and quality. Greece has lost two thirds of its wetlands during the last seventy-five years; however, many wetlands with considerable conservation value remained [1,2]. Since then, extensive losses have occurred, many of the original wetlands have been drained and converted to farmland, industrial sitings and urban development. A wide range of human activities at the catchment's areas may lead to environmental deterioration of river waters or hydro-geomorphological changes and constitute the cause of environmental destabilization. Several researchers have studied the impacts of river damming, artificial river diversion projects and channelization, in the geomorphology of major river deltas around the Mediterranean and the Black Sea, including those of the Po [3,4,5], Danube [6,7,8,9], and Nile [10]. These studies concluded that man-made interventions trigger destabilization processes of the dynamic of the coastal area, coastal erosion phenomena and consequently impact on delta evolution and coastal ecosystems. In most cases, man-made interventions lead to a shrinkage of coastal wetlands and the creation of a new “fragile” ecological balance [11,12,13,14,15]. The artificial diversion of the main river channel of the Spercheios, river to the north, resulted the creation of a new Delta in the area of new mouth to the Maliakos gulf and the shrinkage of old delta [16,17,18,19].

Studies have concluded that a decrease in sediment supply, appears to be the most important factor controlling coastal retreat, while an important factor of the destabilization of the ecological balance is the climate change [20,5,9]. According Vassilopoulos et al. [21] the dam constructions have resulted in a progressive reduction of the fluvial sediments. The study of Acheloos delta evolution showed that the balance of this dynamic system changed due to dam constructions. Thus the fluvial supply has been decreased and, nowadays, marine processes predominate over the delta [21]. Poulos and Collins [22] have shown the importance of the presence of dams in reducing Mediterranean riverine sediment fluxes and the implications for the evolution of Mediterranean deltas. The same opinions prevailing in

several research who were involved for the impact of dam construction in Greece [23,24,25,26,27,28,29,30,31,32,33,34,21]. Moreover, artificial river diversion projects and channelization in the delta areas and near coastlines have caused extended shoreline displacements by altering nearshore sediment transport and/or by modifying littoral sediment budgets [8,9].

Dams are structures built in the bed of a natural stream to cut off the flow; they are used for storage, discharge for power generation (hydroelectric dams), irrigation, water supply and for flood protection. These structures caused several impacts on the natural and the built environment. Most of the impacts of river engineering are extremely difficult, and in many cases impossible, to predict with certainty. Similar impacts to the environment may be caused by other human activities such as artificial river diversion projects, channelization, sand extraction from river beds, intensification and development of agriculture projects and industrialization, infrastructure works, embankments, exsiccation, deforestation, etc. Every river is unique in terms of its flow patterns, the landscapes it flows through and the species it supports; likewise the design and operating pattern of every dam also vary, as are the effects the dam has on the river and its associated ecosystems. While the great majority of the world's large dams and all of the major dams have been completed within the last six decades, some of the environmental effects of a dam may not be identified for hundreds of years after construction [35]. A dam can thus be regarded as a huge, long-term and largely irreversible environmental experiment without a control [35]. The creation of artificial lakes in forest areas, also contributes to deforestation and consequently increases of greenhouse gas emissions (CO<sub>2</sub> equivalent) and at the changes to the climate [36]. Note that deforestation is the removal of a forest, where the land is thereafter converted to a non-forest use. Examples of deforestation include conversion of forestland to agricultural or urban land and in certain cases creating artificial lakes in forest areas, has resulted in the shrinkage of the forest.

The two main categories of environmental impacts of dams are those which are inherent to dam construction and those which are due to the specific mode of operation of each dam. The most significant consequence of this myriad of complex and interconnected environmental disruptions is that they tend to fragment the riverine ecosystem, isolating populations of species living up and downstream of the dam and cutting off migrations and other species movements [35]. Because almost all dams reduce normal flooding, they also fragment ecosystems by isolating the river from its floodplain, turning what fish biologists term a 'floodplain river' into a 'reservoir river'. The elimination of the benefits provided by natural flooding may be the single most ecologically damaging impact of a dam. This fragmentation of river ecosystems has undoubtedly resulted in a massive reduction in the number of species in the world's watersheds [35]. According Efthimiou et al. [23] the controlled water discharge in the main riverbed of r. Nestos affected the rich flora and fauna of the river ecosystems in a variety of ways through the construction of dams (in Thissavros and Platanovrisi). During the dam construction stage, the impact was felt mainly on the ecosystems around the main riverbed because the land was cleared and trees were cut down on the riverbed slopes in the area where the dams were to be built. Moreover, tunnel boring and road works of a considerable length were conducted in forest areas, while thousands of trips were performed by heavy goods vehicles transporting building materials and road work machinery [23,37,38]. Also, in all areas under study, expansion of the agricultural land and a decrease of the wet ground have been observed [23,37,38,14,15,21].

Destabilization of the balance of the coastal zones, the shoreline at the Deltas and the estuaries constitute, more so after the year 1950, a common factor in several coastal regions

of the world as in many coastal areas in Greece, such as the protected wetlands and fragile ecosystems of some river delta areas of the Greek rivers Nestos, Acheloos, Arachthos, Inois and Alfeios. This situation does not comply with the general tendency of accretion of the Mediterranean Sea coastal zone, that characterized the 19<sup>th</sup> century [39,40,41]. This situation is mainly caused by human activities and especially by the construction of all sorts of projects, big and small, (construction and operation of hydroelectric dams and reservoirs, irrigation and water supply dams, construction of anti-erosion works in mountainous catchment; small dams; drainage-anti flooding protection works, etc.), which due to their features and position, cause changes in the natural evolution of the landforms and the hydro-geomorphological processes or in most cases reduce the input of sediments in the coastal area.

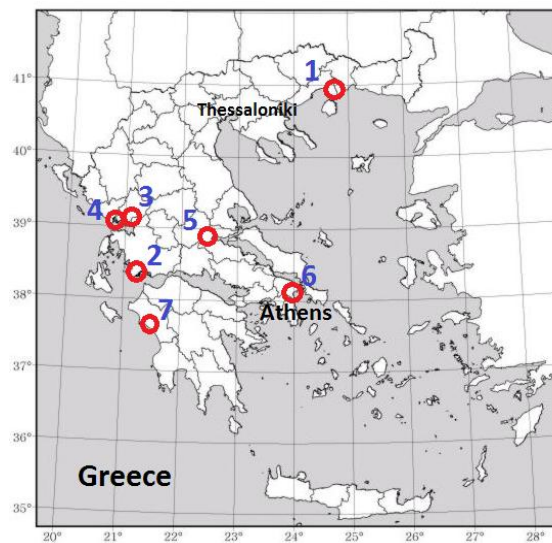
One of the consequences of the global climatic change is the loss of coastal land, coastal wetlands, deltas, lagoons and marshes (inland and coastal environments), which are important for their environmental and economic values, due to a potential sea level rise; on a global scale, the latter has been predicted to be in between 38 and 68 cm for the year 2100, according to the latest report by the IPCC [42]. This prospect has led the IPCC, in 1988, to define the term "vulnerability" as "the level in which the coastal system is influenced by the various factors that consist the climatic changes", aiming at the improvement of coastal zone management by developing strategies that will provide solutions to this problem [43,42,44,45]. Researchers have studied the influence of climatic changes on the evolution of some river deltas around the Adriatic Sea [46,20]. These sea level changes will be considerable for the coastal environment and mainly in gently sloping coastal zones of small elevations, which will face the danger to be inundated by the sea. Sigalos and Alexouli-Livaditi [17,18] attributes the future migration of the shoreline of Spercheios River Delta (Central Greece), mainly to climate change and sea level change. In the Maliakos gulf, high risk areas are estimated to be 23.9 km<sup>2</sup>, with the greater part of it placed at the lower reaches of the river Spercheios delta mouth areas and specifically in the southern and western section of the gulf. It is assessed also apart of these areas, about 13.4 km<sup>2</sup>, are likely to be flooded by the sea, until the year 2100. At the Delta of the river Spercheios, high risk areas occupy the 19.17% of the total deltaic plain, when areas with high possibility to be submerged occupy the 11.43%. As these regions have an intensive rural and economical activity, their owners and users will be intensively affected by sea level rise and will be possible forced to transfer their activities into "safer" areas. In addition, some important biotopes are likely to be vanished [17,18]. This situation it is reproduced in all the gently sloping coastal areas of small elevations in Greece and particularly in the areas under study, and it appears that these changes of shrinking of wetlands will be considerable for the coastal environment.

In this paper the counteractive dynamic river and marine environments responsible for the river mouth and delta modulations are studied, in addition to the main man-made interferences and climate change. The seven areas under study were chosen as case studies due to the recent changes taken place in their basins. The aim of this study is to analyze the present dominant environment, the impact of anthropogenic activities on this balance and the geomorphological evolution of the delta areas, combined with climate change. The study, includes an estimation of the delta forming processes, the impact of the man-made interferences on these processes, and finally, their representation. During this study was stimulated the necessity of approaching environmental problems by constructing of a database and developing a long-term monitoring mechanism for local and regional planning and the environmental protection of the coastal wetlands.

## 2. MATERIALS AND METHODS

### 2.1 Geographical Setting of the Study Areas, Geomorphology and Local Ecosystems

This study focuses in seven (7) coastal areas which have undergone alterations due to human activities in the watershed of the rivers or on their coastal zone. These areas has been included in the NATURA 2000 network "Special Protection Areas – SPA", "Sites of Community Importance-SCI" and are designated as "Special Areas of Conservation". In most cases in the central deltaic plain of the areas under study, a wide net of artificial channels (drain or irrigate channels) was constructed, while the intensification and development of agriculture-nutrients (pesticides and fertilizers) and agricultural run-off transferred by the neighbor cultivations caused impacts on the wetlands. These areas should be located in Greece and especially: 1. Nestos estuary in East Macedonia & Thrace, East Greece, 2. Acheloos estuary in Aitolioakarnania, West Greece, 3. Arachthos estuary in Epirus, West Greece, 4. Louros estuary in Epirus, West Greece, 5. Spercheios estuary in Sterea Ellada, Central Greece, 6. Inois estuary (Haradros river) in Attiki, Central Greece and 7. Alfeios estuary in Western Peloponnese, Western Greece (Fig. 1).



**Fig. 1. Geographical location of the study areas (estuaries): 1. Nestos, 2. Acheloos, 3. Arachthos, 4. Louros, 5. Spercheios, 6. Inois and 7. Alfeios**

More details regarding geomorphology and the environmental characteristics of the local ecosystems are listed below:

1. *Nestos estuary* (NATURA 2000 Code Number: GR 1150010): This site includes the lagoons of Keramoti (Agiasma, Eratino, etc.) and the estuaries of Nestos river to the Thracian Sea and is located east of the town of Kavala, in parts of Eastern Macedonia and Western Thrace. An extended bow shaped Delta of "Nile type" (615 km<sup>2</sup>) has been formed in the area of the estuary of Nestos river, which area is supplied with the sediments from its watershed and extends in an area of 5.750 km<sup>2</sup>.

This area is included in the Ramsar Treaty as an internationally important wetland complex and is one of the 11 protected Ramsar wetlands in Greece [1]. In the surface of the deltaic plain, the river Nestos, from the beginning of the Holocene and approximately up until 1945, it often overflows, the flow of water channels changes, meanders are formed and material deposits which is finally dispersed, due to the action of the waves and currents of the sea [47,32,48,49]. The deltaic plain has suffered human works all through the last half of the 20<sup>th</sup> century. Most of the natural wetland systems were drained (88.45%) and turned into irrigated fields. Only 11.55% of the total wetland areas were preserved in the deltaic plain. In the central deltaic plain a wide artificial channel was constructed (28 km<sup>2</sup> in area), to protect the fertile irrigated areas from flooding [47].

2. *Acheloos estuary* (NATURA 2000 Code Number: GR 2310001): This site includes Acheloos river mouth to the Ionian sea, the delta plain, the delta front, the prodelta and the lagoons system Mesologi – Aitoliko. Acheloos, is the biggest river of Western Central Greece, the first in water contribution and the second in length, found in Greek territory, with a total length of 220 km. It drains an area of almost 6.226 km<sup>2</sup> and contributes significant amounts of river waters and suspended material/sediments in the lower area of discharge. Due to its extent, the Acheloos catchment presents complex physiography and geomorphology (mountainous, semi mountainous regions, gorges, plains, natural and artificial lakes, delta plain, etc.). Acheloos river's action, as well as Evinos river's, resulted in the development of lagoons such as Mesolongi-Aitoliko. Its extrusions compose a unique protected ecosystem of significant ecological value. This area is included in the Ramsar Treaty as an internationally important wetland complex. Acheloos also helps to sustain multiple ecosystems, which have survived along its banks for thousands of years. Acheloos delta is a very dynamic system influenced primarily by fluvial and marine processes. Some of the delta plain features have been changed several times during the past decades [33].
3. *Arachthos estuary* (NATURA 2000 Code Number: GR 2110001): This site includes the estuaries of Arachthos river to the gulf of Amvrakikos and an extended complex of wetlands. The wetlands area, the complex of lagoons (Logarou, Tsoukalio, Rodias lagoons, etc.), the protected areas "Amvrakikos Wetlands National Park" and the estuaries of Arachthos river to the gulf of Amvrakikos, are located south of the town of Arta, in Ipiros district. River Arachthos drains an area of 1.850,85 km<sup>2</sup>. It contributes significant amounts of sediments (around 2.900.000 m<sup>3</sup>/year), to the low lying area of discharge, due to the presence of erosion prone flysch in its basin [50,28,30,31,51]. These sediments are deposited and enhance the floodplain of the town of Arta and the Delta, which morphologically is of the type of "bird pad" [52]. In the area of discharge of the estuaries of Arachthos and its neighboring Louros river, an extended complex of wetlands (lagoons and deltas), has been created. The wetlands area, the complex of lagoons (Logarou, Tsoukalio, Rodias lagoons, etc.), the protected areas "Amvrakikos Wetlands National Park" and the estuaries of Arachthos river to the gulf of Amvrakikos, are located south of the town of Arta, in Ipiros district.
4. *Louros estuary* (NATURA 2000 Code Number: GR 2110001): The complex of wetlands (Tsoukalio and Rodia lagoons) and the estuaries of Louros river to the gulf of Amvrakikos, located north-east of the town of Preveza, in Epirus. Louros river drains an area of 685,50 Km<sup>2</sup>. Due to the calcareous nature of the base of its basin,

this river does not accept significant amounts of sediments which could result in apparent differentiations of its delta shape, at least during its recent geomorphological evolution [50,53].

5. *Spercheios estuary* (NATURA 2000 Code Number: GR 2440002): This site includes the estuaries of Spercheios river to the Maliakos gulf and is located east of the town of Lamia, in Fthiotida. Spercheios river drains an area of 1.907,2 Km<sup>2</sup>. It contributes significant amounts of sediments in the lower area of discharge, due to the presence of erosion prone flysch in its basin. These sediments deposit and enrich the floodplain of Lamia and the Delta [38,16,17,54,55,56].
6. *Inois estuary (Haradros)* (NATURA 2000 Code Number: GR 3000003): This site includes the mouth of Inois river (Sechri rema and Kainourgio rema) to the Marathonas bay in the northeastern coastal area of Attica, north of the town of N. Makri and southeast of the town of Marathonas, the Marathonas coastal plain, the desiccated Vrexizas fen (before the decade of 1960) to the southwest of the Inois river mouth, the Schinias fen, as well as the pine forest (*Pinus pinea* & *Pinus halepensis*). Inois river is one of the biggest rivers of Attica. It drains an area of almost 177.2 km<sup>2</sup> in northeastern Attica and discharges at Marathonas bay (Marathonas gulf). Inois river basin presents complex physiography and geomorphology. The terrestrial part of the coastal zone of the gulf of Marathonas is of low relief, consisting of low-lying terraces, alluvial plains, valleys and eroded plain-surfaces. The subaerial part of the zone is sandy having its larger width at its northern part; some 25 m. The backshore is associated with a low-relief sand dune field which is better developed to the north Haradros (Inoi) mouth area, where the well-known pine-tree forest occupies the dune field [29].
7. *Alfeios estuary* (NATURA 2000 Code Number: GR 2330008): This site includes the estuaries of Alfeios river to the Kiparissiakos gulf (Ionian sea), south of the town of Pyrgos, as well as the desiccated lake Agoulinitza (before the decade of 1970) to the south-east of the Alfeios estuaries in Peloponnesus. Alfeios is the biggest river of the Peloponnese and the ninth longest river in Greece. It drains an area of almost 2.575 km<sup>2</sup> in Western Peloponnese and discharges at Kiparissiakos Gulf. Due to its extent, the Alfeios basin presents complex physiography and geomorphology [57]. It contributes significant amounts of river waters suspended material (sediments) in the lower area of discharge (around 2.500.000 m<sup>3</sup>/year) [58,24,59].

## 2.2 Investigation Method

The study of geomorphological and environmental changes involved a series of different stages: the study of bibliographical references, field-work, observation and direct digitizing on the basis of different aged aerial photos, satellite images and maps. Thus the database was developed and updated with data deriving from different sources. The criteria used for the selection of the rivers and deltas under study (seven sites) for the systematic observations are listed in Table 1.

**Table 1. Detailed criteria used for the selection of the rivers and deltas under study**

S/N	Criteria	r. Nestos	r. Acheloos	r. Arachthos	r. Louros	r. Spercheios	r. Inoio	r. Alfeios
1.	Geographical distribution of the area under study in the Greek area	●	●	●	●	●	●	●
2.	Geological characteristics of the drainage basin	●	●	●	●	●	●	●
3.	Geomorphological characteristics of the drainage basin	●	●	●	●	●	●	●
4.	Hydrological-hydrogeological characteristics of the drainage basin	●	●	●	●	●	●	●
5.	Microclimate characteristics of the drainage basin	●	●	●	●	●	●	●
6.	Vegetation of the drainage basin	●	●	●	●	●	●	●
7.	Vegetation of the delta area	●	●	●	●	●	●	●
8.	Oceanographical characteristics of the coastal zone	●	●	●	●	●	●	●
9.	Specific feature of the project (dam, reservoirs and artificial river diversion projects)	●	●	●	●	●	●	●
10.	Size of the project (human activity)	●	●	●	●	●	●	●
11.	Location of the project (human activity)	●	●	●	●	●	●	●
12.	Degree of deterioration of the environment	●	●	●	●	●	●	●

Data collection took place involving a review of existing reports, contemporary and older topographical maps (Hellenic Military Geographical Service, scale 1:50.000 and 1:100.000), geological (Institute of Geology and Mineral Exploration, scale: 1:50.000) and oceanographic maps and hydrological data. Also for the assessment and evaluation of the impact caused by certain human activities to the natural environment and geomorphology of the areas under study, especially to the hydro-geomorphological processes in the coastal zones, shorelines, deltas and watershed, aerial photos of various years and scale (H.A.G.S.) have been used, as well as satellite images (Google Earth). These aerial photographs were taken in the years 1945, 1960, 1963, 1970, 1972, 1984, 1985, 1986, 1995 and 2000. These aerial photos and satellite images combined with data from the systematic in situ observations (field-work) gave the following conclusion about the evolution of the hydro-geomorphological processes (sediment deposition in the deltas, erosion of the coastal area, phenomena of advance or retreat of the shoreline, vulnerability of the local coastal system, etc.). These "in situ" observations were conducted, at least, every 5 years during the months of March, July and September for the years 1985, 1990, 1995, 2000, 2005, 2010 and 2011, by means of twenty one (21) "fixed points" (three points for each area), in selected places of each delta under study.

All primary data were imported in an apposite database and were transferred in topographical map and onto satellite images (Google Earth). Data were analyzed quantitative and qualitative, while different aged thematic maps were created. The



geomorphological and man-made alterations were studied through photointerpretation of different date aerial photos and satellite images, as well as through field work. These functions, along with the stereoscopic observation of aerial photos were supported by photogrammetric software, enabling the user to perform on screen stereoscopic observation.

### 3. RESULTS AND DISCUSSION

#### 3.1 Human Activities Caused Impact on the Geomorphology and the Geomorphological Evolution of Delta Areas

Human activities, which are able to disrupt the environmental balance on the coastal zone and the fragile natural ecosystems listed in Table 2. These human activities have a significant impact on the geomorphology and the hydro-geomorphological processes of the “dynamically” developing areas (deltas, estuaries, river mouths, marshes, fen, lagoons, etc.) such as for example, those which constitute the object of this study [37,3,10,24,46,4,20,25,47,50,60,14,15,6,7,28,22,29,30,31,32,33,34,61,21,18,8,9,26,27,62]. Also, these interferences contribute to worsening the “vulnerability” of the coastal areas [43,42,14].

**Table 2. List of human activities that can have impact on environment and geomorphology in the areas under study**

S/N	Human activities	r. Nestos	r. Acheloos	r. Arachthos	r. Louros	r. Snercheios	r. Inoios	r. Alfeios
1.	Intensification and development of agriculture	●	●	●	●	●	●	●
2.	Construction of irrigation channels and drainage pits	●	●	●	●	●	●	●
3.	Deepening and creation of channels	●	●	●	●	●		●
4.	Construction of drainage - anti flooding protection works	●	●	●	●	●	●	●
5.	Construction and operation of large dams and reservoirs (hydroelectric dams, irrigation dams and water supply dams) on the main bed of the river (>15.0 m height or reservoir volume > 3.0 million m <sup>3</sup> )	●	●	●	●		●	●
6.	Construction and operation of large dams and reservoirs (hydroelectric dams, irrigation dams and water supply dams) on tributaries of major river (>15.0 m height or reservoir volume > 3.0 million m <sup>3</sup> )		●					●
7.	Anti-erosion works in mountainous catchment basins (small dams, etc.)	●	●	●		●		●
8.	Intense construction of coastal defense works (seawalls, water breakers, massive wall built out into the sea to protect a shore		●	●				

	or harbour from the force of the waves, large quarried stones, specially shaped concrete blocks)						
9.	Construction of jetties in the coastal zone	●	●	●			
10.	Motorway in operation or under construction		●	●	●		●
11.	National road work constructions or improvements on the national road network		●	●	●	●	●
12.	Opening up new agricultural and forest roads	●	●	●		●	●
13.	Railway line in operation or under construction				●		
14.	Infrastructure works	●	●	●	●	●	●
15.	Wood cutting, intense deforestation	●	●			●	
16.	Intense deforestation of riparian vegetation				●		●
17.	Industrial activities	●	●	●	●	●	
18.	Small business activities	●	●	●	●	●	●
19.	Urban and industrial development without any planning	●	●	●	●	●	●
20.	Uncontrolled deposition of urban waste, industrial effluents, solid domestic and industrial waste	●	●	●	●	●	●
21.	Excessive use of pesticides and fertilizers	●	●	●	●	●	●
22.	Contamination – pollution	●	●	●	●	●	●
23.	Alteration of the physicochemical characteristics -deterioration of the quality of water (salinity, etc.)	●	●	●	●	●	●
24.	Embankment -filling of lagoons or lakes with sediment		●			●	●
25.	Exsiccation - desiccation of lakes		●			●	●
26.	Arrangement and redirection of the main river channels/ artificial river diversion projects	●	●	●	●		
27.	Mining activities (quarries, mines)				●	●	
28.	Sand and gravel extraction from river beds	●	●	●		●	●
29.	Uncontrolled watering from surface water tables	●	●	●	●	●	●
30.	Uncontrolled pumping of underground waters	●	●	●	●	●	●
31.	Mass touristic activities, recreation	●	●	●		●	●

Source: Observations of the study group and various literature sources and existing reports

### 3.2 Impact to the Environment Caused by Dam Construction

Woods, forests and the coastal and riparian vegetation, can provide a wide range of environmental, climatic and other benefits. The environmental destabilization of the forest environment in the mountainous regions, such as the areas under study, as far as the geomorphological processes are concerned is mainly due to certain anthropogenic interventions (large dams and reservoirs construction, etc.) which alter “critical” parameters of the environment (artificial creation of lakes, deforestation, changes on the seasonal hydrological and hydrogeological regimes, disruption of water flow and sediment transport, etc.). The exact effects of dams and reservoirs construction are quite specific to the site. It

nearly always involves some habitat destruction and changes at erosion phenomena of the river basins. Moreover the deposition of sediments into the artificial lakes of large dams and reservoirs can be appeared, as well as erosion phenomena of the coastline. These effects can be reasonably short term, and followed by regrowth, or severe and permanent. It is noted that those interventions that result in the alteration of the natural evolution of the geomorphological processes, usually lead to the creation of an “anthropogenic” environment which to a great extend is man controlled, and which in turn in the long run resupplies and reinforces the environmental threats in the area [14,15,62].

The impact to the environment is reinforced when the forest environment in the mountainous regions and the coastal environment in the delta area, are burdened by human activities with the emission of pollutants or other substances, radiation or noise. This is also the case when in the area there are works or constructions of different type and size with no prior consideration of the possibility of the destabilization of the environmental equilibrium and in general of the protection of the natural environment, the wild life and the fowl fauna of the specific area [62]. The most important of these human activities in the under study areas are large dams and reservoirs construction (hydroelectric power dams, irrigation dams and water supply dams) and artificial river diversion projects, as well as other human interventions and activities (deforestation, grazing in the forest, forest fires, opening up new dense road network constructed in order to get access to the artificial lakes, channelization, sand extraction from river beds, intensification and development of agriculture projects and industrialization, infrastructure works, embankments, exsiccation, deforestation, etc. [14,15,62]. The features of dams in the rivers/basins under study listed in Table 3.

In order to assess and evaluate the impacts to the environment that result from the dams and reservoirs construction, it is necessary to take into account the fact that all human activity as well as the natural phenomena, cause alterations to the environment that are in a position to cause disturbances. The term “disturbance” defines every action or row of actions that cause and affect the structure and the operations of the environment. Whether the alteration becomes disturbance, depends on the type of natural, chemical, biological or other parameters, which are altered and on the magnitude of their alteration which in turn brings on the events which affect the structure and the operations of the environment. The transformation of “disturbances” into “impacts”, depends on the ability of the environment which is subjected to the disturbances, to restore them. It is underlined that human activities (Hydroelectric power plant to produce energy and other infrastructure areas, transportation of energy, opening up new dense road network constructed in order to get access to the dam and the artificial lake, etc.) can cause environmental impacts not only as a result of the emission of pollutants (dust during the construction phase of the project, etc.), but just as a result of their presence [63,64,62].

The large dams and reservoirs construction in the areas under study, in conjunction with the forest fires, the illegal woodcutting, deforestation and the grazing constitute the main burden to the natural ecosystems in the mountain drainage basins, while the artificial river diversion projects, channelization, sand extraction from river beds, intensification and development of agriculture projects and industrialization, infrastructure works, embankments, exsiccation, deforestation, etc. constitute the main burden to the natural ecosystems and the wetlands in the coastal areas and the deltas. These interferences led to the creation of a peculiar environmental entity and an human-made “artificial” environment which to a great extend is man controlled. The human-made characteristics of this environmental entity are aggravated by the extensive road works in the forests and in the wetlands [14,15]. Also climate change is likely to affect coastal ecosystems through of mean sea level [43].

Following that, we refer to the most important impacts/changes, that are noted to the areas under investigation, which are [65,63,64,62]: 1. Changes to the flora and fauna and the natural ecosystems, deforestation, habitat destruction, 2. Changes to the landscape, 3. Land use changes, 4. Changes to the quality of the air and of the soil (during construction of the project), 5. Climate Change, 6. Changes to the surface and underground waters, 7. Changes in the geomorphology and the hydro-geomorphological processes. More specifically, the main impacts to the natural environment (reversible or not) caused by large dams construction and especially caused by the creation of artificial lakes in forest areas, depend on the location and size of interruption of the natural continuity of the land relief, the deforestation as well as on the changes of the seasonal hydrological and hydrogeological regimes of the rivers and the natural hydro-geomorphological processes in the area. These hydro-geomorphological processes, are disruption of water flow and sediment transport, deposition of sediments into artificial lakes, absence of the naturally expected "ecological" sediment supply downstream of dams. In most cases there is also an extensive flooding of large part of forests and forest areas, that existed in the region, before the construction of the dam. Shrinkage of the forest is part of the land use change and deforestation which contribute to increase emissions of CO<sub>2</sub> and other greenhouse gases [36] (Figs. 2a & 2b).

Table 3. The features of dams and reservoirs in the rivers/basins under study

River / Basin	Name of dam	Nearest city	Type of dam	Height (m)	Volume of Dam ( $10^6 \text{ m}^3$ )	Storage capacity/ Reservoir ( $10^6 \text{ m}^3$ )	Year of Completion
<b>Nestos</b>	<b>Thissavros</b>	Paranesti / Drama	Rock-fill dam with central clay core	172	12,0	705	1996
<b>Nestos</b>	<b>Platanovrissi</b>	Paranesti / Drama	Gravity dam/ Roller Compacted Concrete dam (RCC)	95	0,45	57	1998
<b>Acheloos</b>	<b>Kremasta</b>	Karpenisi	Earthfill/ Rock-fill riprap dam (sand and gravel with central clay core)	165	8,1	3.828	1965
<b>Acheloos</b>	<b>Kastraki</b>	Agrinio	Earthfill dam with central clay core	96	5,2	--	1969
<b>Acheloos</b>	<b>Stratos I</b>	Agrinio	Earthfill dam with central clay core	26	2,8	14,9	1988
<b>Acheloos</b>	<b>Sykia</b>	Arta	Earthfill dam with central clay core	170	12,4	600	Under Construction
<b>Acheloos</b>	<b>Mesochora</b>	Mesochora / Trikala	Rock-fill dam (Concrete Faced Rockfill Dam)	150	5,5	358	Under Construction
<b>Acheloos (Tavropos)</b>	<b>Tavropos (Plastiras Lake)</b>	Karditsa	Arch-gravity dam	83	0,10	400	1959
<b>Arachthos</b>	<b>Pournari I</b>	Arta	Earthfill dam with central clay core	87	9,0	730	1981
<b>Arachthos</b>	<b>Pournari II</b>	Arta	Earthfill dam with central clay core	15	0,70	4,5	1998
<b>Louros</b>	<b>Louros</b>	Filippiada / Arta	Arch-gravity dam	22	0,01	1,0	1954
<b>Spercheios</b>	--	--	--	--	--	--	--
<b>Inois (Haradros)</b>	<b>Marathonas</b>	Marathonas / Athens	Concrete gravity dam	54	0,18	41	1929
<b>Alfeios</b>	<b>Flokas</b>	Ancient Olympia / Pyrgos	Gravity dam	10	--	--	1968
<b>Alfeios (Ladonas)</b>	<b>Ladonas</b>	Tropea / Pyrgos	Gravity dam	56	0,03	46	1955

Source: Various literature sources and existing reports



**Figs. 2a & 2b. Shrinkage of the natural riparian vegetation and of the forest, caused by the creation of the dams & artificial lakes – Landscape and Land use changes. View of the artificial lake of Tavropos (Plastiras Lake), in Acheloos drainage basin (Fig. 2a). View of the artificial lake of Kremasta dam, on the Acheloos river (Fig. 2b). (Photos by Mertzanis, 2010)**

### **3.3 Established Changes to the Natural Environment and on the Hydro - Geomorphological Processes of the Greek Coastal Zone due to Large Dams and River Diversion Projects**

The intensification of human activities and especially the large dams and reservoirs construction, in the mountain drainage basin of the Greek rivers Nestos, Acheloos, Arachthos, Louros, Inoios and Alfeios, that took place since the '50s, have affected the natural ecosystems, wetlands and “dynamically” developing areas, one way or another and to a different extend, depending on the type, the size and the operation and location of the intervention. “Dynamically” developing areas of this type are the areas of the estuaries and river deltas, coastal valleys, lakes, lagoons and fens which are subjected to intense variations as far as the “positive” or “negative” shift of the shoreline. This process is defined as “advance” or “retreat” depending on the capability of the rivers (material transported by the rivers to the sea, etc.), to supply the coastal area with sediments or on the inhibition of the supply of the coastal area with sediments, respectively.

Also, among the human-made changes on the natural environment, on the geomorphology and the hydro-geomorphological processes which appear in most of the study areas, including the following: a. Changes at erosion phenomena of the river basins and at the movement-deposition of suspended load, b. Deposition of the suspended load into the artificial lakes of large dams and reservoirs, c. Absence of the naturally expected “ecological” sediment supply downstream of the large dams and reservoirs, d. Filling of lakes or lagoons with sediment, e. Land sinking, land subsidence, f. Elevation of the riverbed, g. Creation of new Delta- advance of the coastline, etc. Noted that deltas and lagoons under study constitute dynamic geomorphological systems where the hydro-geomorphological processes evolve at a relatively high speed. More specifically, the most common human-made changes/impacts on the natural environment of the delta areas and especially on the geomorphology and the hydro-geomorphological processes, due to the large dams and reservoirs construction which appear in the mentioned areas, listed in Table 4.

**Table 4. Dam construction impact on geomorphology and the hydro geomorphological processes of the seven areas under study**

S/N	Established changes/impacts caused by large dams and reservoirs construction	r. Nestos	r. Achelooos	r. Arachthos	r. Louros	r. Spercheios	r. Inoio	r. Alfeios
1.	Changes at erosion phenomena of the river basins and at the transportation-deposition of suspended particulate matter and sediments	●	●	●	●	●	●	●
2.	Disruption of the face, morphology of the river basins (river network shape, valley floor morphology and Delta)	●	●	●	●		●	●
3.	Deposition of the suspended particulate matter and sediments into the artificial lakes of large dams and reservoirs	●	●	●	●		●	●
4.	Absence of the naturally expected "ecological" sediment supply downstream of the large dams and reservoirs	●	●	●	●		●	●
5.	Disruption of the face, morphology of the Deltas/estuaries and lakes/lagoons	●	●	●		●	●	●
6.	Significant banking up - clogging of artificial lakes with sediment (shrinkage of artificial lakes)				●			●
7.	Decrease of the rate of the filling of lagoons in the delta area with sediment	●	●	●			●	
8.	Shrinkage of lakes or lagoons - total or partial exsiccation (dried up of the lakes, decrease of the wet ground)		●				●	●
9.	Creation of destabilization processes of the dynamic of the coastal area	●	●	●		●	●	●
10.	Decrease of the rate of the advance of the shoreline in the greater part of the coastal front of the Deltas/estuaries and at the coastal zone	●	●	●	●		●	●
11.	Local phenomena decrease the rate of advance of the shoreline in front of the Deltas/estuaries and at the coastal zone	●	●	●	●	●	●	●
12.	Local phenomena increase the rate of advance of the shoreline in front of the Deltas/estuaries and at the coastal zone	●	●	●		●		
13.	Local phenomena of retreat of the shoreline in front of the Deltas/estuaries and at the coastal zone	●	●	●		●	●	●
14.	Creation of new Delta - advance of the coastline					●		

Source: Observations of the study group and various literature sources and existing reports

The phenomena of advance or retreat of the shoreline can be attributed to human intervention or natural processes. These phenomena mainly depend on the potential of each area, to the deposition of sediments or their withdrawal from it, depending on the geomorphological and oceanographic characteristics of the river catchment terrestrial, coastal and marine area. Especially for the delta-lagoon-marine ecosystems, an important element is the rate of supply with water and sediments in the area but also important element is the qualitative data of the above mentioned characteristics. It is noted that those interventions that result in the alteration of this dynamic evolution of the geomorphological processes, usually lead to the creation of an "artificial" environment which to a great extent is man controlled, and which in turn in the long run resupplies and reinforces the environmental threats in the region [11,14,15,62].

### **3.4 Geomorphological Evolution and Changes of the Hydro-Geomorphological Processes**

The geomorphological evolution of the areas under study and changes of the hydro-geomorphological processes are listed below and constitute the basis for the investigation and assessment of impact-changes in the natural and anthropogenic environments and landforms, caused by human activities. All study areas represent dynamic geomorphological systems which develop with relatively great speed. More detailed data concerning the geomorphological characteristics of each area is given below:

#### **3.4.1 Nestos estuary – site 1 (GR 1150010) (East Macedonia & Thrace, East Greece)**

The period from the year 1945 onwards, is a period in time where appear the early human interferences in the Nestos delta; drainage and irrigation canals. In 1983, started the engineering works for the construction of the hydroelectric dams "Thissavros" and "Platanovrissi" on the main river channel of Nestos. The construction of "Thissavros" dam was completed in 1996, while the "Platanovrissi" dam in 1998. As a result, the Nestos river network shape, the valley floor morphology and the Delta has presented significant changes due to hydroelectric dams, irrigation and water supply dams; Thissavros and Platanovrissi [23,50,60,32]. In the mountainous area, has presented alterations to the flora and especially decrease of the natural riparian vegetation and of the forest, caused by the creation of the mentioned artificial lakes (Thissavros and Platanovrissi) and from the construction works of the project (Figs. 3a & 3b). This deforestation contribute to increase emissions of CO<sub>2</sub> and other greenhouse gases and at the climate change [36]. Also have appeared retreat tendency of the shoreline at some positions on the coastal zone. Specifically the following changes have occurred: Disruption of the transport-deposition of sediments from Nestos watershed, towards the downstream from the hydroelectric dams, in the delta, the estuary and the coastal zone. The sediments are deposited into the artificial lakes of Thissavros and Platanovrissi and so, the deltaic plain and the coastal zone, are deprived of a significant amount of sediments. It is noted that the Deltas of the rivers owe their existence to the deposition of the particulate matter/sediments that are transferred from the upstream watershed, while they constitute dynamic systems which develop with great speed [23,50,60]. In this site, from the year 1945 onwards, a period in time where we see the early human interferences in the area (drainage & irrigation canals), and up until 1983, the geomorphological conditions in the watershed and the Nestos Delta are altered. The artificial diversion to the east by 4 km of Nestos river channel and the realignment of the lowest course of the river, resulted in erosion phenomena in a part of Nestos river in the west



(Akroneri), and these sediments are moved west-northwest along with the waves and the coastal currents [32].



**Figs. 3a & 3b. Thissavros earth dam with central clay core, in Nestos river (Fig. 3a). Changes in landscape, landforms, geology and vegetation in the area downstream of the Thissavros dam, caused by the dam construction works (Fig. 3b) (Photos by Mertzanis A. 2010)**

After the completion of the hydroelectric works (Thissavros & Platanovrissi dams) along the main river course, the sediments are deposited in the reservoirs of the dams. It is estimated that the estuary are deprived of about 2.600.000 m<sup>3</sup> per year of sediments and this has as a result the appearance of local phenomena of erosion and retreat of the coast line in certain areas of the coastal zone (Fig. 5a) [47,49]. This situation is expected to worsen in the near future, if the necessary measures to avert the phenomena of “erosion” and “desertification” of the coastal zones are not taken.

#### **3.4.2 Acheloos estuary – site 2 (GR 2310001) (Aitolokarnania, West Greece)**

On the main river channel of Acheloos has built and operates many hydroelectric dams of Public Enterprise of Electricity (Kremasta, Kastraki, Stratos I & Stratos II). The “Kremasta” dam built at 3 Km south-western of the junction of the rivers Tavropos, Agrafiotis and Acheloos. The construction of this dam was completed in 1966 and it is the first dam developed in Acheloos watershed and one of the highest earthfill dams in Europe. The surface of the artificial lake is about 81,0 km<sup>2</sup> at full supply level. The “Kastraki” dam is the second dam developed in Acheloos watershed and was completed in 1969. “Stratos I” & “Stratos II” dams was completed in 1989 and are situated 8 Km southern of Kastraki dam and 62 Km of Acheloos mouth. Also, at the final stage of construction the dams “Sykia” and “Mesochora”, which form part of the overall project of “diverting the Acheloos”. “Tavropos” dam (Plastiras Lake) built on the river Tavropos, in 1959. The surface of the artificial lake is about 24,0 km<sup>2</sup> at full supply level. As a result, the Acheloos river network shape, the valley floor morphology and the Delta has presented significant changes caused by the dams and reservoirs (Kremasta, Kastraki, Stratos I & Stratos II, Sykia & Mesochora). Also, has presented alterations to the flora and especially decrease of the natural riparian vegetation and of the forest, caused by the creation of the mentioned artificial lakes (Figs. 4a, 4b, 4c & 4d).

Other anthropogenic interventions have changed the river network shape, the valley floor morphology and the Delta of the river Acheloos, such as the intensification and development of agriculture, construction of irrigation channels and drainage pits, uncontrolled watering from surface water tables, uncontrolled pumping of underground waters, urbanization of large coastal zones without regarding the natural environment, etc. [14,15,62].



**Figs. 4a, 4b, 4c & 4d. The arch-gravity dam of Tavropos (Plastiras Lake), in Tavropos river (Acheloos drainage basin) (Fig. 4a). Shrinkage of the natural riparian vegetation and of the forest, caused by the creation of the Kremasta dams in Acheloos river (Fig. 4b) (Photos by Mertzanis A. 2010). Decrease of the natural riparian vegetation and of the forest, by flooding caused by the operation of the Plastiras artificial Lake (Fig. 4c & 4d) (Photos by Mertzanis A. 2004)**

Comparing the aerial photos, dated in 1960, and the satellite images of 2000, many changes of the coastline, the river mouth and the land use have been observed. Prominent changes concerning the fluvial environment, such as abandonment of the old drainage system (ox-bow lakes, old delta mouth) have been mapped. Also an expansion of the agriculture land and a decrease of the wet ground are observed [21]. The shape of the deposition tongue in Acheloos river mouth at the west part of the area has been eroded; consequently it appears to be more elongated nowadays (Fig. 5b). Moreover, the shape of the coastline has been altered during those years due to wave and the current action. The delta front has also been extensively modified in the past decades [21]. According to Vassilopoulos et al. [21] the human interventions have modified the physical environment to a great extend. The dams construction has resulted in a progressive reduction of the fluvial sediments. Diverse

geomorphologic and land use changes concerning the coastal plains and the coastal area are also detected. The degradation of this coastal area is accelerated by the salt water's intrusion, the over-exploitation of the groundwater and the expansion of the touristic structures.



**Figs. 5a & 5b. Satellite images of Nestos (Fig. 5a) and Acheloos deltas (Fig. 5b) (Source: Google Earth 2012 modified, by authors). The dotted lines (red) represent the medium-high vulnerability coastal zones to a potential rise of sea level. The yellow line indicates shoreline accretion trend**

### **3.4.3 Arachthos estuary – site 3 (GR 2110001) (Epirus, West Greece)**

After studying the temporal evolution of the coastal area and of the Delta of the river Arachthos, one can see the overall tendency of the sand barriers to shrink, and a tendency of retreat of the coast line to the west part of its estuaries until Koronisia, with the exception of the occurrence of some local phenomena of advance at the mouth of the river. This general tendency of retreat follows the deprivation of some volume of sediment from the area us mentioned around 2.900.000 m<sup>3</sup>/year, caused by the Pournari I dam construction and operation, but it is also due to the natural movement of the Delta towards the east [66]. This tendency, for at least as far as the part of the sand barrier which connects Koronisia with Fidokastro is concerned, has been set back in the last 20 years when its largest part was converted to a road with the known necessary procedures, such as supportive-anti erosion works (water breakers, large limestone concrete rocks, rockfill dams, etc.).

More specifically, ever since the decade of 1960, when we had the construction of the first levees for the protection from floods, the irrigation channels and the drainage pits, in the area of the Delta of Arachthos, we have started to experience the disturbance of the balance of the coastal area [50,53]. This particular destabilization of the balance of the coastal area was worsened by the construction of the hydroelectric power dam "Pournari I", during the period 1973-80, in the main bed of the Arachthos river, which is used for coverage of irrigation and potable water supply and flood protection in the region. The dam "Pournari I", built at 4,5 Km north-eastern of the town of Arta, and came into operation in the year 1981. The surface of the artificial lake is about 20,6 km<sup>2</sup> at full supply level and length 17 km. The operation of the dam "Pournari I", combined with the small dam "Pournari II" newly constructed downstream of the above and operated since 2000. The dam "Pournari II" regulates the flow of river water Arachthos, ensuring a minimum continuous flow irrigation) (Figs. 6a & 6b).



**Figs. 6a & 6b. Pournari I earth dam with central clay core, in Arachthos river (Fig. 6a).  
The small dam Pournari II, regulates the flow of river water Arachthos (Fig. 6b)  
(Photos by Mertzanis A. 2010)**

The placement of the dam “Pournari I”, in the main riverbed of Arachthos, in a short distance from the area of the estuaries of Arachthos river to the gulf of Amvrakikos, were the cause of interruption the transportation and deposition of some volume of sediments from the drainage basin to the downstream of the dams “Pournari I & II and in the Delta. Around 2.900.000 m<sup>3</sup>/year, sediment deposited in the reservoir “Pournari I” and thus low alluvial plain of Arta, the Delta and the Amvrakikos gulf devoid of significant amounts of sediments and limited to 700.000 m<sup>3</sup>/year, resulting in reducing of the rate of advance of the coastline at the Delta and at the coastal zone and in locations show retreat tendency [67] (Fig. 8b).

Local phenomena of sediment deposition, along the shoreline and of advance of the coastline are observed in the area near at the outlet mouth of Arachthos river to the gulf of Amvrakikos. This advance was mainly due to the supply of the coastal zone with suspended load derived from erosion of the riverbed and the banks of Arachthos river, downstream of the hydroelectric power dams and irrigation dams “Pournari I & II”, during the operation of the dams and of the power plants. The suspended load despite the small quantity, shipped directly to the mouth of Arachthos river, without "losses" because of embankment built on the banks of that river.

#### **3.4.4 Louros estuary – site 4 (GR 2110001) (Epirus, West Greece)**

On the main river channel of Louros has built and operates the hydroelectric dam “Louros”, during the period 1954-63. The “Louros” dam, built at 20 Km north-west of the town of Arta (Figs. 7a & 7b). As a result, the Louros river network shape and the valley floor morphology has presented significant changes due to hydroelectric dam; Louros; [50,61,28,30,31].



**Figs. 7a & 7b. Louros arch-gravity dam, in Louros river (Fig. 7a). Partial filling of the Louros artificial lake with sediments (Fig. 7b) (Photos by Mertzanis A. 2008)**

Also have appeared alterations in geomorphological processes (disruption of the morphology of Louros river watershed, etc.), which are caused by Louros hydroelectric dam which result to changes at erosion phenomena of the river basin and at the transport-deposition of sediments. Changes in the delta and the coastline are negligible because of the limestone composition of geological substrate in the Louros watershed and low particulate matter/sediments production. Despite the construction of the Louros dam; in 1954; in the Louros river; up-dam area: 43%; the sediment load of the river has not changed significantly, due to its initially low sediment load [30,31] (Fig. 8a).



**Figs. 8a & 8b. Satellite images of Louros (Fig. 8a) and Arachthos estuaries (Fig. 8b) (Source: Google Earth 2012 modified, by authors). The dotted lines (red) represent the medium-high vulnerability coastal zones to a potential rise of sea level. The yellow line indicates shoreline accretion trend. Are distinguished the complex of lagoons (Logarou, Tsoukalio, Rodia) and the thin sand barriers**

#### **3.4.5 Spercheios estuary – site 5 (GR 2440002) (Sterea Ellada, Central Greece)**

It should be noted that a significant element as far as the changes in geomorphological evolution and the hydro-geomorphological processes of the delta area is concerned, is the partial diversion to the north of the main bed of the Spercheios river. The construction of the

artificial partial diversion to the north, of the Spercheios river channel was completed in 1958 (Figs. 9a & 9b). This artificial channel is approximately 9.0 km long, 20 m wide and protected by two parallel embankments spaced 60 meters. In 2007, started the engineering works to improve Spercheios diverted river channel for the stream discharge of peak flow (flood events), in Maliakos Gulf. Constructed a special construction (distributor) for the diversion of the stream discharge, while the channel was dredged. The continuous flow of drainage in the Spercheios old riverbed (Alamana) guaranteed by the southern embankment culvert upstream of the distributor with the bottom level below the crest overflow.



**Figs. 9a & 9b. A special construction (distributor) for the artificial diversion of the Spercheios stream discharge of peak flow (flood events), in Maliakos Gulf (photos by Mertzanis A. 2011)**

The aforementioned human activities have led to the following changes to the natural environment and geomorphological evolution of the Spercheios river delta:

- Destabilization processes in the coastal zone that are caused by the diversion to the north of the main river channel of the Spercheios river (Figs. 10a & 10b). The result of this diversion is the creation of a new Delta in the area of the new site of the estuaries to the Maliakos gulf, while there were created new destabilization processes of the dynamic of the coastal area and a set back of the rate of advance of the coast line towards the sea, in the old position of estuary (old Delta) or even the creation of retreat conditions of the coast line in this site [16,68,17,18,19].

Often Spercheios river overflows at the Delta and in this way the main flow of its river channel is changed, even though it remains in the southern part of the valley of the river. In 1889 as a result of the disruption of the natural bund, we had the last diversion of flow of the Spercheios river. Also, after 1957 begun the illuviation of a large area of the shallow part north to the present river channel due to the construction of an overflow channel. Already ever since the ancient times (480 b.C) the shift of the coastline and the Delta to the east comes to 8-10 km, while the well known historical site of the “narrow passage of Thermopylae” where according to references the sea line was up to the present monument of Leonidas in the old national road Athens - Lamia [69,70,68,54,19,55,56]. Kotoulas [71] studied the evolution of the river delta during 1943-1971 and came to the conclusion that the overall size of the delta has increased in these 28 years by 6,62 Km<sup>2</sup>, which corresponds to 0,236 Km<sup>2</sup>/year. More specifically, in the diverted river bed where, the Delta has increased by 4,0 Km<sup>2</sup>, which correspond to 0,33 Km<sup>2</sup>/year. The above demonstrates explicitly the great

transfer of sediments by the Spercheios river and their deposition into the Delta and coastal areas.



**Figs. 10a & 10b. The old and new delta of Spercheios river in Maliakos Gulf (Fig. 10a) (Photo by Mertzanis A. 2009). Satellite image of Spercheios estuary (Fig. 10b) (Source: Google Earth 2012 modified, by authors). The dotted lines (red) represent the medium-high vulnerability coastal zones to a potential rise of sea level. The yellow line indicates shoreline accretion trend**

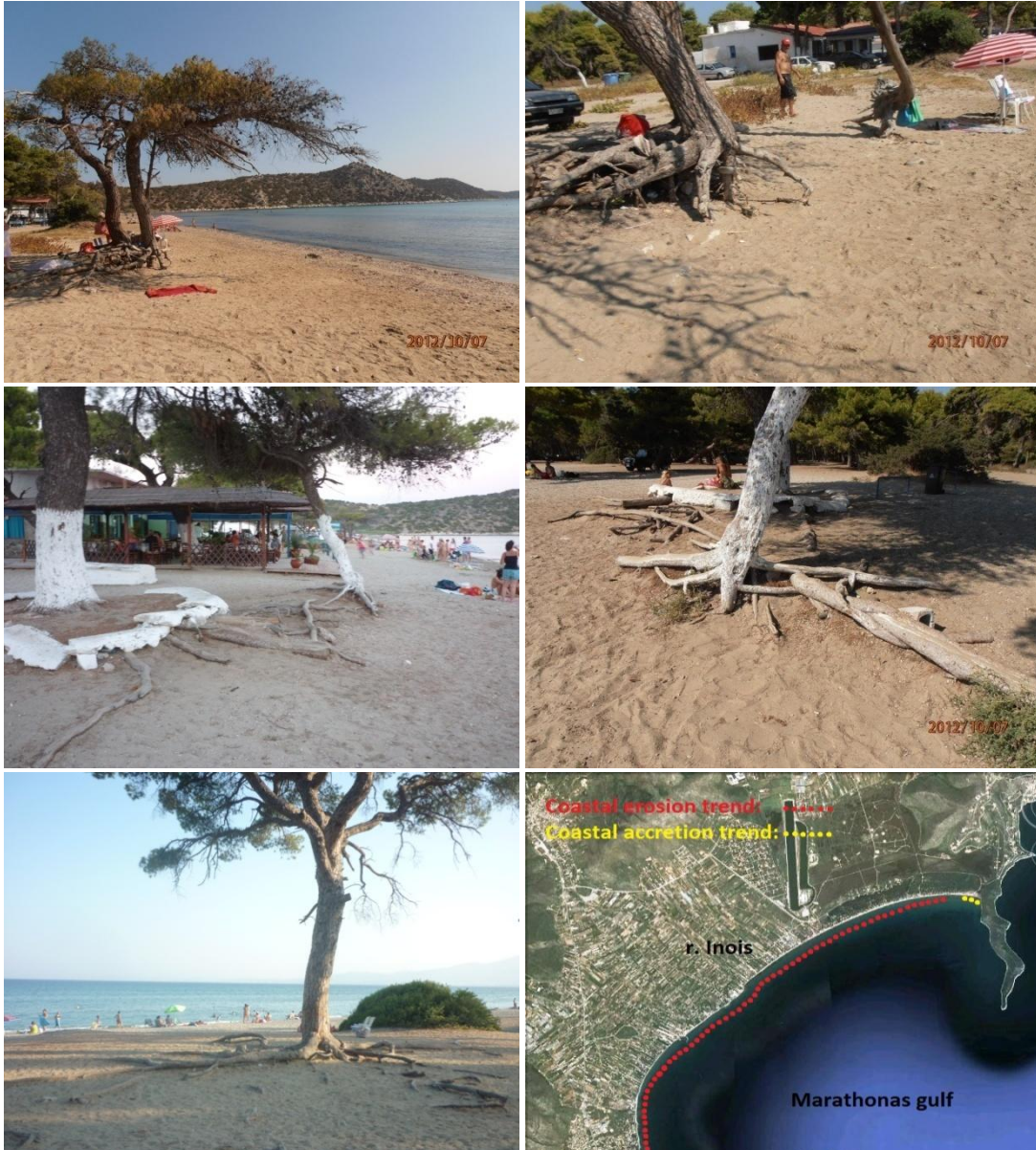
Also, indicative of the transferring activity of the Spercheios river is the fact that during 1958-1970, that is, a duration of 12 years, in the main river channel alone there were deposited 310.000 m<sup>3</sup> of sediments. Over the same period, the river delta in the area of the diverted river channel moved towards the sea 2 Km, that is by 160 m/year while the bottom of the sea at a distance of 1.020 m from the Delta was limited to only 0,80 m [71].

### **3.4.6 Inois estuary (Haradros river) – site 6 (GR 3000003) (Attiki, Central Greece)**

Until the beginning of the 20<sup>th</sup> century, natural processes control the evolution of the Marathonas plain, whilst afterwards, they are of less importance due to increasing human activities. During the last decades, a rapid expansion of constructing activities; buildings, roads, bridges, irrigation network, etc; reduces the wetlands and not-cultivated areas; pin-tree forest of Schinias, Drakonera lake, Marathonas swamp [34]. Dune field in places has been abused by human activities; mainly due to building development. The marine part of the shore zone as the rest of the Marathonas gulf floor used to receive the water/sediment influx of the Inois river (Haradros river) that drains an area of 177.2 km<sup>2</sup> before the construction of the Marathonas dam. The wave energy is dissipated due to shallow bathymetry creating weak longshore currents that usually are not capable to initiate sediment transport [29]. On the main river channel of Inois has built and operates the water supply dam “Marathonas”.

The construction of this dam was completed in 1929. The surface of the artificial lake is about 2.45 km<sup>2</sup> at full supply level. As a result, the Inois riverbed has presented significant changes to its network shape. In addition, a significant retreat of the shoreline (~100 m) near the Inois (Haradros) river mouth during the last 120 years, may be caused mainly by: 1. the drastic reduction of riverine sediment supply due to the construction of the Marathonas dam, in 1929; and 2. The sand extraction from the lower course of the riverbed [34]. Erosion in this coastal zone is still active, and in spite of the presence of some protection measures (i.e.

sea walls, artificial nourishment), the erosion rate is likely to increase because of the prospective rise of the sea level [25,26,27,34] (Figs. 11a,11b,11c,11d,11e & 11f).



**Figs. 11a, 11b, 11c, 11d, 11e & 11f. Erosional phenomena of Schinias beach and dune-field. The retreat of the coast line is documented by the form and shape of the coast and also by the presence of residues of tree roots (Fig. 11a, 11b, 11c, 11d&11e) (Photos by Mertzanis A. April 2012). Satellite image of Inois estuary and Marathonas plain (Fig. 11f) (Source: Google Earth 2012 modified, by authors). The dotted lines (red) represent the medium-high vulnerability coastal zones to a potential rise of sea level. The yellow line indicates shoreline accretion trend.**



Currently, erosional phenomena have been observed to the south of the mouth of river Inois, whilst to its northern part not significant changes have been recognized so far [29]. According to Poulos et al. [29] the human interference is related to: a. the construction of the Marathonas dam that basically inhibits fluvial sediment to reach the coast, b. coastal development plans, including the constructions for the Olympic Games of 2004 and c. several constructions related to the shore zone and the associated dune-field.

#### **3.4.7 Alfeios estuary – site 7 (GR 2330008) (Western Peloponnese, Western Greece)**

On the main river channel of Alfeios has built and operates the irrigation dam “Flokas”. The construction of this dam was completed in 1968. The “Flokas” dam, built at 13 Km south-east of the town of Pyrgos. Since June 2010 the irrigation dam “Flokas”, also serves as a hydroelectric power dam. Also, on the river channel of Ladonas, a tributary of Alfeios river, has built and operates the hydroelectric power dam “Ladonas”, during the period 1950-55. The “Ladonas” dam, built at 47 Km north-east of the town of Pyrgos. As a result, the Alfeios riverbed has presented very rapid vertical and horizontal (lateral) erosion and significant changes to its network shape. The drainage network follows a straighter course, the number of meanders has been reduced and the seventh order branch is deeply incised [72,57]. Also have appeared retreat tendency of the coastline (shoreline) at the estuaries and at some positions on the coastal zone [14,15]. This general tendency of retreat follows the deprivation of some volume of sediment from the area, around 2.500.000 m<sup>3</sup>/year, due to the Ladonas and Flokas hydroelectric power dams, but it is also due to the action of the waves and currents of the sea. The waves on the coast, often reaching the height of over 3.00 m with a maximum height of 6.00 meters [24,57]. In the case of Alfeios river, after the operation of the Ladonas dam (in 1955), were blocked of the 25% of its total catchment area, and after the operation of the Flokas dam (in 1968), located only 12 km from the river mouth, which blocked of the 97%, revealed a significant reduction in the mean annual water discharge [24]. That geomorphological processes and especially advance or retreat of the coastline in the delta area, due to human activities, are evidence in the aerial photographs of the years 1945 (before the construction of the dams), and 1960, 1963, 1972 and 1984 (after the construction of the dams) [24].

Already in 1960 after the operation of Ladonas dam, there is considerable retreat of the coastline in relation to the position it had in 1945. The construction and operation of the Flokas dam strongly reinforces the erosion phenomena of the coastal zone and regression of the coastline, due the greater retention of sediments in the artificial lakes of the Ladonas and Flokas dams. In the Alfeios river mouth and at the coastal zone at the north-west (Spiantza) and south-east (Paralia Epitalion), the retreat phenomena of the coast line has reached about 25 m, for the period from 1960 to 1984, with severe damage to houses and buildings in most coastal areas (Spiantza, Paralia Epitalion, etc). The speed of the coastline retreat is estimated about 1 m/year, and in most places at the north-west coast, exceeds 2-3 m/year. The year 2010, the regression of the shoreline in some places has reached about 150-200 m [24] (Figs. 12a,12b,12c,12d,12e & 12f).



**Figs. 12a, 12b, 12c, 12d, 12e & 12f. Certain damages caused by coastline erosion in Epitalion and Spiantza, near at the mouth of Alfeios river (Pyrgos) (Fig. 12a, 12b, 12c & 12d) (Photos by Mertzanis A. 2010 & 2011). Satellite image of Alfeios estuary and Spiantza coastal area (Fig. 12d & 12f) (Source: Google Earth 2012 modified, by authors). The dotted lines (red) represent the medium-high vulnerability coastal zones to a potential rise of sea level. The yellow line indicates shoreline accretion trend (Fig. 12e). Into the circle the destroyed houses by coastline erosion in Spiantza (Fig. 12f)**

Besides the morphological impacts to the river network shape there are also serious economic damages caused by human activity. During the winter of 1999, the Flokas dam bridge was closed for a long period due to damages at its foundation caused by the heavy

rain and illegal gravel extraction. Transportation between the villages in the area became extremely difficult and time consuming and the cost of the repairs was estimated at 500.000 euros [57].

#### **4. CONCLUSION**

A significant segment of the Greek marine littoral zone is in a fragile equilibrium, mainly because of the anthropogenic interventions that were carried out without preliminary studies regarding the long-term consequences of these activities. The intensification of human activities, such as river damming and river diversion projects and the climate change, influence the local environment and geomorphological evolution processes, constitute the main causes this problem. Diverse geomorphologic and land use changes concerning the coastal plains, deltas and coastal wetlands are also detected.

- It should be mentioned that the decrease in the sediment quantity is the main cause of the problem, in the rivers in which dams are in operation. The dam constructions have resulted in a progressive reduction of the fluvial sediments. Dams and the presence of artificial lakes has modified the morphology (river network shape, valley floor morphology and Delta) of the river system and the natural evolution trends of coastal areas to a considerable extent and has arguably been the most important factor controlling the evolution of the Greek coastal zone in recent decades. In most cases, these activities, lead to the appearance of erosion phenomena on the coastal zone. The significant retreat of the shoreline which sometimes exceeds 100 m in the study areas, during the last 70 years, is attributed to mainly by the drastic reduction of riverine sediment supply due to the construction of the dams (hydroelectric dams, irrigation dams and water supply dams). In the river deltas of Nestos, Acheloos, Arachthos, Inoio and Alfeios, the coastal erosion and retreat phenomena are the results of the construction of large dams and reservoirs at the main river channel, that cause the reduction of the natural input of sediments in the Delta area and the coastal zone.
- The artificial river diversion to the north of the Spercheios main river channel has led to the creation of a new Delta in the area of the new site of the estuaries to the Maliakos gulf, while new destabilization processes were created because of retreat conditions, in the old position of estuary (old Delta).
- In the Louros estuary, despite the construction of the Louros dam (in 1954) in the main river channel of Louros river, the sediment load and the shape of delta of the river has not changed significantly, due to the calcareous geological substratum of the drainage basin and its initially low sediment load
- The creation of artificial lakes in forest areas, contribute to shrinkage of the forest and consequently at the increase of greenhouse gas emissions and to the climate change.
- The environmental impact depends on the type, the size, the features and the location of the anthropogenic intervention. The impact on the local environment and on the wetlands is intensified when these human activities are located at positions which can possibly affect directly or indirectly these fragile ecosystems and dynamically evolving areas, such as those that exist in the areas under investigation. Human activities in the study areas, had different aims in each location, but all of them resulted in the disruption of the natural environment and the change of the geomorphological evolution which has led to the creation of an environment, controlled by human power.

The proper evaluation of the environmental impacts caused by human activities, constitute a useful “tool” to the protection of the natural environment and ecosystems. The impact on the environment is intensified when these activities are: a. located at “dynamically” developing areas, such as the estuaries, Deltas or coastal areas, which are in threshold environmental equilibrium and b. located at positions that can possibly affect directly or indirectly wetlands such as those that exist in the areas under study. The prompt and precise evaluation of the magnitude and duration of these impacts, as well as the capability of reversing them during the stage of planning, constitute and the conditions for the containment of the disturbance to the environment. Another condition to contain of the environmental impact caused by the implementation of the “development projects” is to take suitable measures and to implement specialized works for the restoration of the environment which will suit the special conditions of these particular environments.

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## **COMPETING INTERESTS**

Authors have declared that no competing interests exist.

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