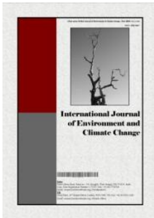

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Climate Change and Man-made Interventions, as Destabilizing Factors of the Coastal Zone: Some Examples of Coasts and Coastal Wetlands in Urban, Peri-Urban Areas and Natural Parks in Greece

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Authors' contributions

This work was carried out in collaboration between both authors. Authors Aristeidis Mertzanis and Asimina Mertzani designed the study, performed the impacts to the natural environment and the coastal zone by climate change and man-made interventions. Author Asimina Mertzani managed the analyses of the study, assisted with the "in situ" observations, revised the results and the draft manuscript. Authors Aristeidis Mertzanis and Asimina Mertzani elaborated the literature searches, the data of maps, aerial photographs, satellite images and proceeded to comparative observations on the changes has been the coastal zone in the areas under study. Both authors read and approved the final manuscript.

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ABSTRACT

The consequences of man-made interventions, Climate Change and future Sea-level rise upon some coastal plains of Greece are examined. Many urban, peri-urban areas and Natural Parks, in low elevation coastal zones in Greece are experiencing or are at risk of Sea-level rise, storm surges, water and soil pollution, saline water intrusion (salinity), coastal erosion and shoreline retreat, floods, and droughts. Sea-level rise could erode and inundate coastal ecosystems and

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disrupt wetlands, Urban and peri-Urban areas. Characteristic examples of these are the protected wetlands that exist in Greece such as those in the Delta and the river mouth areas of the Sperchios, Alfeios, Arachthos, Louros, and Inois rivers, and the small town of Tolo. Man-made interventions affect the coastal wetland ecosystems, Urban and peri-Urban areas under study. At the same time, an important factor of the destabilization of the ecological balance is the Climate Change and the expected sea-level rise. The main anthropogenic degradation and stresses on the under investigation areas, in recent decades, includes wetland draining, exsiccation of lagoons and lakes, river engineering works, dam construction, intensification and development of agriculture projects, sand mining from riverbeds and beaches, construction of motorways, construction of harbor structures, such as harbors, jetties, seawalls, groins, and breakwaters, rapid urbanization processes, holiday home building and tourist facilities, massive tourism and intense coastal development, water pollution, human-induced land subsidence (uncontrolled water abstraction from surface and underground water tables), and removal of coastal vegetation. Satellite images, maps and systematic in situ observations, integrated with the direct digitizing on the basis of different aged aerial photographs was adopted to estimate the coastal erosion and accretion rates in recent decades (1945-2019) in the areas, under study.

Keywords: Man-made interventions; environmental impact; coastline erosion; Sperchios river; Alfeios river; Arachthos river; Louros river; Inois river.

1. INTRODUCTION

The coasts of the world form a narrow interface zone between marine and terrestrial areas in which large and growing proportions of the human population and global economic activity are located. The low-elevation coastal zone (LECZ) encompassing 2% of the earth’s land area [1]. Eight of the top ten largest cities in the world and much of the world’s tourism, which are increasingly important in national economies, are situated at the coast [2]. The Coastal Zone is a highly dynamic but, at the same time, "fragile" ecosystem in which land and sea interact under the influence of the atmosphere. Natural processes occurring in the coastal zone create or destroy structures and landforms through the erosion or deposition of river and marine sediments, coastal erosion by sea action and subsidence. These processes are accelerated and strengthened or aggravated by irrational man-made interventions and Climate Change (Fig. 1a-f). Typical examples of human impact on coastal erosion, shoreline retreat and flooding can be found at the areas under investigation in the low elevation coastal zones in Greece.

Greece, is among the countries with the longest coastline, estimated at 15,147 Km [3]. According EUROSION (2004) [4], the coastline length of Greece, estimated at 13,780.4 Km and the eroding coastline, in 2001, reach 3,945 Km. A significant part of this coastline is under erosion, flooding and extensive shoreline retreat.

Settlements in coastal lowlands are especially vulnerable to risks resulting from climate change, yet these lowlands are densely settled and growing rapidly [1]. Erosion is a major threat for coasts worldwide, beaches in particular, which constitute one of the most valuable coastal landforms [5]. Beaches are by nature unstable coastal landforms as they respond to changes in sediment supply, nearshore hydrodynamics and sea level. Across Europe, coastal erosion has been a longstanding, large-scale issue [3] with more than 40% of the beaches in France, Italy and Spain being under erosion [4]. Similarly, in the USA [6] of the 33,000 km of eroding shoreline, some 4,300 km are beaches [6]. Moreover, beach erosion poses a major threat not only to interconnected ecosystems [7], but also to stakeholders, as it is related to beach property values [8] and tourism [9].

Beach evolution depends on processes such as sediment availability [10], storms causing changes that persist with time [11], complex interactions between nearshore and onshore sedimentary bodies [12], sea-level rise [13,14] and the broader coastal geological setting [15]. Factors that cause changes in the morphology of coasts are numerous and include sediment supply, variations in wave energy, tidal currents, wind action, sediment type, tidal inlet dynamics, morphological feedback, etc. Isolating the influence of sea-level rise from these other factors is perhaps the biggest challenge in discerning its impact [16]. Erosion, on the other hand, is usually the combined result of a wide range of factors, both natural (e.g. winds, storms, nearshore currents) and human-induced (e.g. coastal engineering, river basin regulation) that operate on different time and spatial scales [17].

Coastal urban and industrial sprawl has had a profound impact on peri-Urban natural resources, particularly affecting the ecological integrity of wetlands and other transitional water bodies [18]. In recent decades, peri-urban areas of Mediterranean cities have witnessed rapid land use changes, industrial development, intensive agricultural practices and poor water management practices, often causing the elimination or irreversible impacts on fragile water bodies such as coastal lagoons and small lakes [19,20]. Thus, quantification of these factors becomes more difficult due to their variability and coupling of the processes that affect coastal areas, and also to the frequency at which coastal changes occur [21].

Predictions of future sea-level rise and the resulting shoreline retreat are, however, among the most important tasks facing coastal and

Fig. 1. Man-made interventions combined with climate changes and the expected sea-level rise affect the coastal zone. Some examples of coastal erosion-shoreline retreat, along the Greek coast: Figures 1a-b: Chios island-Komi, 2017, Damages to a house in Komi beach, caused by coastal erosion, Chios island, Greece. Figures 1c-d: Patra-Rio, 2009, Damages to sea front road in Rio, caused by a storm wave event on Rio, Patra, Greece. Figures 1e-f: Amvrakikos Gulf-Preveza, 1990, Coastal erosion and shoreline retreat in the coastal zone of the Preveza city (Photos by Mertzanis A.)

global change scientists, particularly given the population concentration in coastal zones [16]. Cohen et al. [22] estimated that over 2 billion people (about 37% of the global population) live within 100 km of a coastline. Much of this concentration is in the tropics, but dramatic increases have been noted in the temperate regions of, particularly, along the Mediterranean and the USA ocean coasts. In the Mediterranean, the coastal population was estimated at 146 million in 1990 and the Urban coastal population alone is projected to rise to 176 million by 2025 with an additional 350 million tourists [23]. About 35-40% of the population of Greece lives within just 2 Km from the coastline, in peri-Urban areas, while the expanded 50 Km zone accounts for about 85% of the population, to which is added, during the summer period, a large temporary population in coastal tourist destinations or in holiday residential areas.

Considerable efforts have been expended on the prediction of sea-level rise (e.g. [24–31]) although much uncertainty remains. The effort to predict shoreline behavior related to such sea level changes has, however, received less attention [16].

The main purposes of the present research are: a. to report a synthesis of the environmental and geomorphological studies on the selected coastal areas and especially of the small town of Tolo and the river mouth areas of the Sperchios, Alfeios, Louros, Arachthos and Inois rivers in Greece, b. to describe the main man-made interventions which due to their nature and position, cause changes in the natural evolution of the hydro-geomorphological processes in the coastal zone under study and c. to detect and evaluate the impacts of the above mentioned anthropogenic activities and the influence of Climate Change and the consequent sea-level rise that affect the areas under study, in such a way as to produce a manageable “tool” that will be used in order to make decisions relevant to the rational management of the coastal zone in the above mentioned areas.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

2.1.1 Geographical setting of the study areas

The Coastal zone of Greece is the most rapidly urbanizing area of the country and is attracting numerous human activities. A number of saltwater and freshwater wetlands, are locating in the coastal zone of Greece. Characteristic examples of these are the protected wetlands that are existed in the coastal zone of Greece such as those in the Delta and the river mouth areas of the Sperchios, Alfeios, Arachthos, Louros and Inois rivers. Also among the study areas is include the small town of Tolo, located in the coastal area of the Argolic Gulf. Most of these coastal regions and populations, have suffered serious alterations from the man-made interference, in the wider area or on their coastal zone and the influence of Climate Change and the consequent sea-level rise that affect these areas. A significant part of this coastline being under erosion and extensive shoreline retreat.

This paper deals with Urban and peri-Urban coastal areas and some coastal ecosystems i.e. the wetlands, deltas, estuaries, lagoons, marshes and lakes, in the Delta and the river mouth areas of the Sperchios (in Maliakos Gulf), Alfeios (in Kyparissiakos Gulf-Ionian sea), Arachthos and Louros (Amvrakikos Gulf) and Inois (Marathonas bay) rivers, and the small town of Tolo (Argolic Gulf). The natural habitats (Delta of Sperchios river, Estuaries of Alfeios river, Delta of Arachthos river, Estuaries of Louros river and Inois river) are subject to Community interest and many are designated as Special Areas of Conservation (Habitat Directive 92/43/EEC). These areas are found in Greece and more specifically these areas are [32-35] (Fig. 2):

a) Delta of Sperchios river (Central Greece/Prefecture of Phthiotis): Sperchios river drains an area of 1.907,2 Km^2 contributing significant amounts of sediments in the lower area of discharge caused by erosion flysch in its basin. These materials deposit and enrich the plane of Lamia and the Delta [35-41]. This site includes the estuaries of Sperchios river to the Maliakos gulf (NATURA 2000 SiteCode: GR2440002 http://natura2000.eea.europa.eu/#) [42] and is located east of the town of Lamia, in Fhtiotida (Code Number 1PhthiGRWetl).

b) Estuaries of Alfeios river (Western Greece/Peloponnese/Prefecture of Ilia) which is the biggest river of the Peloponnese and the ninth longest river in Greece. It drains an area of almost 2.575 Km^2 in Western Peloponnese and discharges at Kyparissiakos Gulf. Due to its extent, the Alfeios basin presents complex physiography and geomorphology [43]. It contributes significant amounts of river waters suspended material (sediments) in the lower area of discharge (around 2.500.000 m^3/year) [32-34] [44-48]. Here we are talking about the estuaries of Alfeios river (NATURA 2000 SiteCode: GR2330008 http://natura2000.eea.europa.eu/#) [42] to the Kyparissiakos Gulf (Ionian sea), south of the town of Pyrgos, as well as the desiccated lake Agoulinitsa (before the decade of 1970) to the south-east of the Alfeios estuaries in Peloponnese (Code Number 2IliaGRWetl).

c) Delta of Arachthos river (Western Greece/Epirus/Prefecture of Arta): The River Arachtos drains an area of 1.850,85 km^2. It contributes significant amounts of suspended load (around 2.900.000 m^3/year), to the low-lying area of discharge, due to the presence of erosion prone flysch in its basin [32,33,49]. These sediments are deposited and enhance the plain of the town of Arta and the Delta, which morphologically is of the type of "bird pad" [50]. 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 (NATURA 2000 SiteCode: GR2110001 http://natura2000.eea.europa.eu/#) [42]. Here we are talking about the wetlands and the estuaries of Arachthos river to the gulf of Amvrakikos, south of the town of Arta, in Ipiros area (Code Number 3aEpirusGRWetl).

d) Estuaries of Louros river (Western Greece/Epirus/ Prefecture of Preveza): Louros river drains an area of 685,50 Km^2. 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 [32,33][49]. Here we are talking about the wetlands and the estuaries of the Louros river to the gulf of Amvrakikos (NATURA 2000 SiteCode: GR2110001 http://natura2000.eea.europa.eu/#) [42], north-east of the town of Preveza, in the Ipiros area (Code Number 3bEpirusGRWetl).

e) The Inois or the Haradros rivers (Prefecture of Attica): the Inois river is one of the biggest rivers of Attica. The Inois estuary includes its mouth to the Marathon bay in the northeastern coastal area of Attica, the Marathon coastal plain, the desiccated Vrexizas fen (before the decade of 1960) to the southwest of the Inois river mouth, the Schinias marsh, as well as the pine forest (*Pinus pinea* & *Pinus halepensis*). It drains an area of almost 177.2 km^2 in northeastern Attica and discharges at Marathon gulf. The terrestrial part of the coastal zone of the Marathon gulf is of

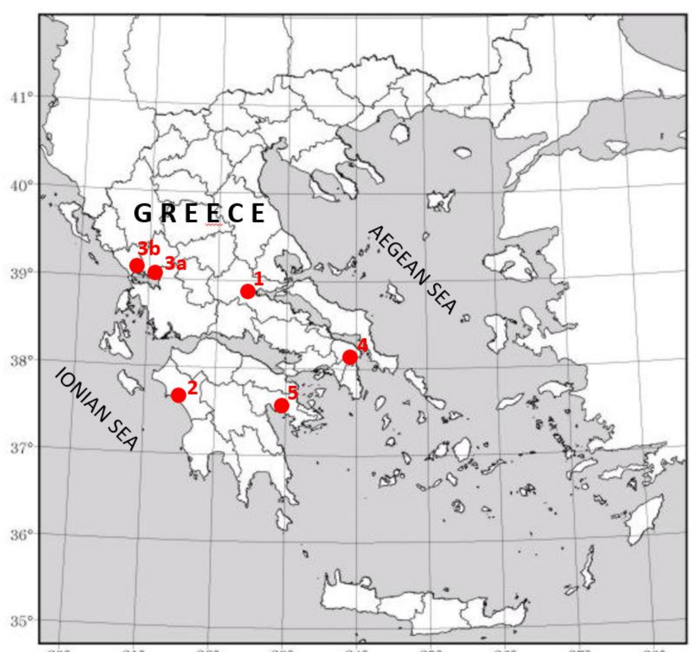


Fig. 2. Geographical location of the areas under investigation: 1. Delta of Sperchios river, 2. Estuaries of Alfeios river, 3a. Delta of Arachthos river, 3b. Estuaries of Louros river, 4. Inois river and 5. Town of Tolo

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 mouth area, where the well-known pine-tree forest occupies the dune field [33,34,51]. The northeastern part of the area includes the Schinias-Marathon National Park, which is a protected area (NATURA 2000 SiteCode: GR3000003 http://natura2000.eea.europa.eu/#) [42]. This protected area is one of the most important ecosystems in Greece (Code Number 4AttiGRWetl).

f) Tolo (Peloponnese/Prefecture of Argolis): The small town of Tolo, is located in the eastern Peloponnese and on the eastern coast of the Argolic Gulf. The beach zone consists of mixed material, mainly sand and granules [52,53]. It is exposed to strong waves from the S and SW, even though the most frequent blowing winds are those of NW [52]. In recent decades, the coastal zone of Tolo is attracting intense touristic activities, usually including "disorderly" urbanization and development (housing, tourism infrastructure, recreation, etc.), without planning (Code Number 5ArgoGRCity).

Despite of the existing strict relevant legal system that applies to these areas and the commitments undertaken by the Greek government for the protection of these specific areas (Ramsar convention, etc.) in most cases, human activity in those areas does not take into account the necessary restrictions for the protection of the environment and this leads to unfavorable effects to the relevant wetlands which result in alterations as far as the extend and severity, depending on the type, the extend, the function and the location of the specific activity [54-56].

Note that most the names of Urban, peri-Urban areas and Natural Parks under investigation, and all the Code Numbers (e.g. 1PhthiGRWetl) have been given by the authors. These Code Numbers are combinations of letters and numbers. The number represents the serial number of the relevant category (e.g. 1). The letters represent the initials of the prefectures' name and the country (e.g. PhthiGR=Prefecture of Phthiotis, Greece). The end of the code represents the initials and the type of these areas (e.g. Wetl= Wetland, City = Urban area).

2.2 Study Methodology

The methodology followed in this investigation attempts to identify the main man-made interferences, as factors that lead to the destabilization of the coastal zone that destroys the beach biodiversity and ecological balance. It should be noted that the destabilization of the coastal zone includes inundation, due to increased sea level and coastal erosion because of the increased exposure to wave action.

This study used both secondary and primary data. Secondary data collection involved review of existing reports (unpublished, gray and published reports) from libraries and documentation centers in various institutions in Athens, Pyrgos, Arta, Preveza, Argos, Nayplion and Lamia. Some reports were also made available through internet search. Secondary information were supplemented by primary data at "wetland unit" level, whereby small meeting were made with the local commissions of Attica, Arta, Ilia, Argos and Fthiotida prefecture and the Executive Director and the Planning Officers of the "Amvrakikos Wetlands Management Body" and the "Management Body of Mt Oiti National Park, Sperchios Valley and Maliakos Gulf". The study of geomorphological and environmental changes involved a series of different stages: the study of bibliographical references, systematic in situ observations, measurements using the Global Positioning System (GPS) satellite signals, observation and direct digitizing on the basis of different aged aerial photographs, satellite images (Landsat, Google Earth) and maps. Thus the database was developed and updated with data deriving from different sources. The criteria used for the selection of the Urban, peri-Urban areas and Natural Parks under investigation (six sites) for the systematic observations are listed in Table 1.

Data collection took place involving a review of existing reports, contemporary and older topographical maps (Hellenic Army 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. To ensure that the topographic and bathymetric data correspond to the same profile, the nearshore bathymetry was derived from Hellenic Navy hydrographic charts. Also for the assessment and evaluation of the impact caused by certain man-made interventions to the natural environment and geomorphology of the coastal areas under investigation, especially to the hydro-geomorphological processes in the coastal zones, shorelines, deltas and watershed, aerial photographs 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. We also used aerial photographs of the coastal zone, taken in 2014, which were provided by the "TripInView" Geotag Aeroview S.A. [57]. These aerial photographs and satellite images combined with data from the systematic in situ observations gave the following conclusion about the evolution of the hydro-geomorphological processes (sediment deposition in the deltas, inundation, coastal erosion, 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, 2011, 2015, 2018 and July and August 2019, by means of eighteen (18) "fixed points" (three points for each area), in selected places of each site under investigation.

All primary data were imported in a suitable 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 photographs and satellite images, as well as through field work. These functions, along with the stereoscopic observation of aerial photographs were supported by photogrammetric software, enabling the user to perform on screen stereoscopic observation.

Table 1. Detailed criteria used for the selection of the Urban, peri-Urban areas and Natural Parks under investigation

S/N	Criteria	R. Sperchios	R. Alfeios	R. Arachthos	R. Louros	R. Inois	City of Tolo
1	Geographical distribution of the area under investigation in the Greek area	●	●	●	●	●	●
2	Protected area-National Park (Ramsar Convention and the "Natura 2000" European ecological network)	●	●	●	●	●	
3	Tourist destination/Holiday destination		●			●	●
4	Geological characteristics of the coastal area and the drainage basin	●	●	●	●	●	●
5	Geomorphological characteristics of the coastal area and the drainage basin	●	●	●	●	●	●
6	Hydrological-hydrogeological characteristics of the drainage basin	●	●	●	●	●	●
7	Microclimate characteristics of the drainage basin	●	●	●	●	●	●
8	Vegetation of the drainage basin and the delta area	●	●	●	●	●	
9	Oceanographical characteristics of the coastal zone	●	●	●	●	●	●
10	Location and specific features of the man-made interventions in the inland (urbanization, dams, reservoirs, artificial river diversion projects, motorways, mass touristic activities, etc.	●	●	●	●	●	
11	Location and specific features of the man-made interventions in the coastal zone (harbours, jetties, fishery shelters, etc.			●	●		●
12	Degree of deterioration of the environment	●	●	●	●	●	●
13	Coastal processes of shoreline erosion, Coastline retreat	●	●	●	●	●	●
14	Coastal processes of shoreline accretion	●					

Source: Observations of the authors, various literature sources, existing reports, aerial photographs and satellite images

3. RESULTS AND DISCUSSION

3.1 Human Interventions and Pressures on the Urban, Peri-Urban Areas and Natural Parks under Study

The world is urbanizing and the most rapid urbanization is taking place on the coast [2]. The coastal zone is the most rapidly urbanizing area on the globe and the growing urban population is severely stressing these important systems [2]. The coastal zone sustains sensitive ecosystems and areas of high ecological value (saltwater and freshwater wetlands and marshes, coastal lagoons, lakes and temporary ponds). These areas may provide critical habitat for many endangered species while in the meantime they offer highly important ecosystem services, such as coastal protection. In the coastal zone are also located the fisheries and other living resources, rich agricultural lands and areas of high aesthetic value. For all the above, the zone nearby the coast is typically held as public heritage and connects land and sea.

Man-made interventions and pressures in the Urban, peri-Urban areas and Natural Parks under investigation, was of different aims in each location, but it all resulted in the disruption of the natural environment and alteration of the dynamic evolution of the hydro-geomorphological processes which has led to the creation of an “artificial” environment, controlled to a great extent by human power and which in turn, in the long term re-strengthens and re-enforces the possibility of environmental destabilization [35,58-64].

The main anthropogenic degradation and stresses at the low elevation coastal zones in Greece, include wetland draining, exsiccation of lagoons and lakes, river engineering works, dam construction, intensification and development of agriculture projects, sand mining from riverbeds and beaches, construction of motorways. In parallel, the construction of harbor structures (such as harbors, jetties, seawalls, groins, and breakwaters), the rapid urbanization processes and the construction of holiday home buildings and tourist facilities are affecting tremendously these areas, while the massive tourism and the intense coastal development are maximizing this effect to the environment. Moreover, under the umbrella of the anthropogenic stresses we have to add increasing water pollution and human-induced land subsidence which are additional reasons of disturbances. Pollutants such as sediment, nutrients, pesticides, and heavy metals degrade wetlands and water quality. Diverse land use changes concerning the coastal and inland plains, lakes, deltas and coastal wetlands are also detected [32-35]. At the same time, an important factor of the destabilization of the ecological balance of the coastal zone is the Climate Change.

Coastal regions and populations are exposed to pressures and hazards from both land and sea making the coastal zone “Arguably the most transformed and imperilled social-ecological system on earth, [which] are characterized by pervasive unsustainable practices” [65]. Coastal Zone is attracting numerous human activities that usually include "disorderly" urbanization and development. Some of these activities are the following:

1. Housing
2. Tourism infrastructure
3. Recreation (improperly sited coastal buildings, unplanned and sporadic tourist facilities)
4. Harbor structures (improperly sited harbors, revetments, jetties, seawalls, groins and breakwaters)
5. Industry
6. Agricultural production
7. Food and raw materials production
8. Livestock farming
9. Transport
10. River sand mining
11. Beach sand mining
12. Uncontrolled water abstraction from surface and underground water tables
13. Removal of coastal vegetation (in most cases, without central or environmental planning).

The results of the above are causing of irreversible damage to the environment such as:

- Overexploitation and depletion of natural resources
- Rapid degradation or drainage/desiccation of coastal wetlands (lagoons, lakes, marshes and ponds)
- Salinization of groundwater in shallow aquifers up to 10 Km inland
- Coastal erosion
- Shoreline retreat
- Human-induced land subsidence

The areas that we investigate in this study (such as lowland areas, areas covered by perennial and intermittent marshes and swamps, coastal lagoons, coastal lakes and temporary ponds, formed behind barrier beaches) are important for their environmental and economic values.

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 (Figs. 3&4). While an important factor of the destabilization of the ecological balance of the coastal zone 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 the coastal ecosystems and especially in the evolution of deltaic coasts. Also, the construction of upstream dams and artificial lakes in the river basins in forest areas and deforestation, contribute to increase emissions of CO_2 and other greenhouse gases and climate change [33]. The creation of artificial lakes in forest areas, deforestation and air pollution, at the global scale, lead to global warming, which in turn causes large-scale ice melt, thereby contributing to eustatic sea level rise.

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 [66,67]. Since then, extensive losses have occurred, many of the original wetlands have been drained and converted to farmland, industrial sittings 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 [68-70], Danube [71-74], and Nile [75]. 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 [32,59,60,63,76]. 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 [33,40,41,77,78].

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 [70,74,79]. According Vassilopoulos et al. [80] the dam constructions have resulted in a progressive reduction of the fluvial sediments. The study of the 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 [80]. Poulos and Collins (2002) [81] have shown the importance of the presence of dams in reducing Mediterranean riverine sediment fluxes and the implications for the evolution of the Mediterranean deltas. The same opinions prevailing in several research who were involved for the impact of dam construction in Greece [45,51,80-91]. 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 [33,73,74].

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 [92]. A dam can thus be regarded as a huge, long-term and largely irreversible environmental experiment without a control [92]. The creation of artificial lakes in forest areas, also contributes to deforestation and consequently increases of greenhouse gas emissions (CO_2 equivalent) and at the changes to the climate [93]. Note that deforestation is the removal of a forest, where the land is thereafter converted to a nonforest 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 [33].

Fig. 3. Deltaic coastline retreat on the River Alfeios mouth area due to dam construction. Coastal erosion in the Spiatza beach (in the north-west of the estuaries of Alfeios river), results in damage or loss of houses and other coastal structures (Kyparissiakos Gulf-Greece). The area most affected by coastal erosion is the deltaic coast of the Alfeios river, and especially its mouth area, in which has been caused a retreat of the shoreline, of approximately 450 m during recent decades. Coastal erosion and shoreline retreat is expected to increase due to Climate Change and the potential future Sea-level rise (Photos by Mertzanis A.-August 2019)

Fig. 4. Coastal erosion along the Spiatza beach results in damage or loss of houses and undermines roads (Kyparissiakos Gulf-Greece). Coastal erosion and shoreline retreat is expected to increase due to Climate Change and the potential future Sea-level rise (Photos by Mertzanis A.-August 2019)

Destabilization of the ecological 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 19th century [94-96]. 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 [33] (Fig. 5).

The intensification of multiple anthropogenic pressures and interventions in recent decades in the river mouths, deltas and lagoons and in the drainage basin of its rivers has affected the natural ecosystems, especially degrading sensitive wetland habitats [32,35, 59,61,64,97,98].

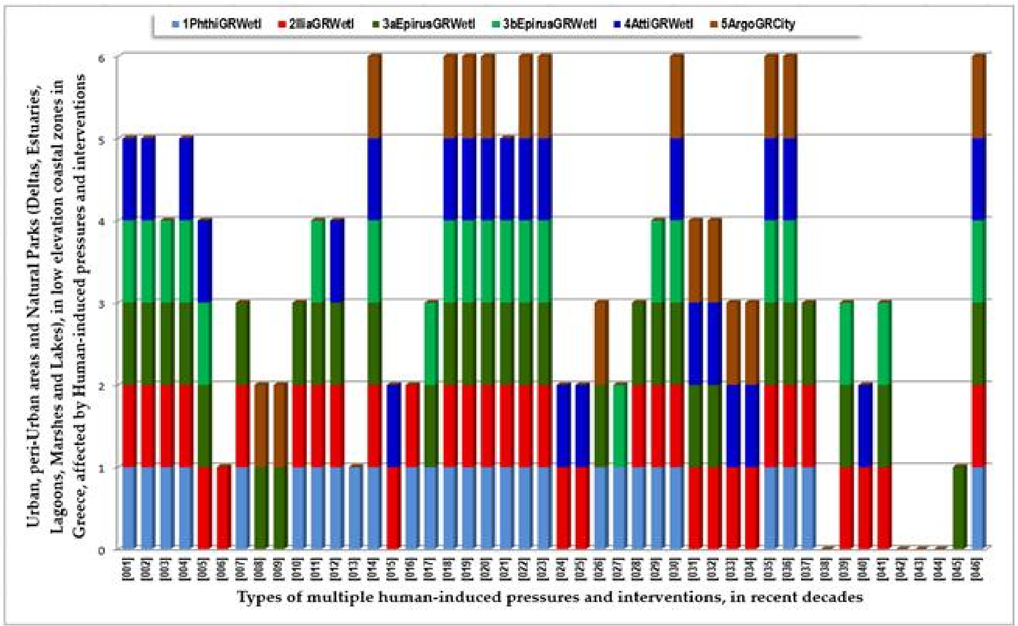
Climate change has a very important impact on the marine environment of Greece [99]. According Travers et al. (2010) [99] the temperature increases during summer can lead to the gradual decrease of summer tourism in the Mediterranean, but in increase during spring and autumn.

Man-made interventions combined with Climate Change and the expected sea-level rise affect the coastal wetland ecosystems, Urban and peri-Urban areas. Also affect various sectors of the economy, including infrastructure and land-use planning, agricultural production, sufficiency of goods and services, quality of life and public health and well-being of urban and rural communities.

Fig. 5. In the Delta of the Arachthos river, since the construction of upstream dams in the Arachthos river basin, the deltaic shoreline, sandy coasts and the sand barrier which connects Koronisia with Fidokastro, are subject to erosion processes. The thin sand barrier between the Tsoukalio lagoon-Amvrakikos Gulf (Fotos 5a-b) as well Logarou lagoon -and Amvrakikos Gulf (Fotos 5c-d), being under erosion by wave action, but are supported by coastal protection works along the shoreline (rock armour, riprap, etc.)(Photos by Mertzani As.-August 2019)

As a specific and non-neutral space, a peri-Urban area refers to a transition or interaction zone, where urban and rural activities are juxtaposed, and landscape features are subject to rapid modifications, including by human activities [100]. Peri-Urban areas, include valuable protected areas, forested hills, preserved woodlands, prime agricultural lands and important wetlands. McGranahan et al. (2004) [101] observed that peri-urban zones are often far more environmentally unstable than either urban or rural settings. From ecosystem's point of view, physical, chemical and biological factors generally interact among themselves, and are interrelated with socioeconomic forces. These factors have their own functions, which can be enhanced or reduced depending on the conditions of other factors in the same system [102]. A peri-Urban area is not only a zone of direct impact experiencing the immediate impacts of land demands from urban growth and pollution, but is also a wider market-related zone of influence that is recognizable in terms of the handling of agricultural and natural resource products [103].

Below there are presented the cumulative chart of the anthropogenic pressures and interventions that stress the Urban, peri-Urban areas and Natural Parks, under investigation, in Greece (salt and freshwater wetlands such us deltas, estuaries, lakes, ponds, lagoons and marshes, and the small town of Tolo) (Fig. 6).



Legend: (**001**). Intensification and development of agriculture, (**002**). Construction of irrigation channels and drainage pits, (**003**). Deepening and creation of channels, (004). Construction of drainage - anti flooding protection works, (**005**). Construction and function of large dams and reservoirs (hydroelectric power 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^3), (**006**). Construction and function of large dams and reservoirs (hydroelectric power dams, irrigation dams and water supply dams) on tributaries of major river (>15.0 m height or reservoir volume > 3.0 million m^3), (**007**). Intense construction of anti-erosion works in mountainous catchment basins (small dams, etc.), (**008**). Intense construction of coastal defence management schemes (seawalls, breakwaters, groins, revetments, rock armour, gabions, beach replenishment, sand dune stabilization, etc.), (**009**). Construction of ports, jetties and fishery shelters in the coastal zone, (**010**). Motorway in operation or under construction, (**011**). National or provincial roads in operation or under construction, (**012**). Opening up new agricultural and forest roads, (**013**). Railway line in operation or under construction, (**014**). Infrastructure works, (**015**). Wood cutting, intense deforestation/Forest fires, (**016**). Intense deforestation of riparian vegetation, (**017**). Industrial activities upstream, (**018**). Small business activities upstream, (**019**). Urban and industrial development without any planning, (**020**). Uncontrolled deposition of urban waste, industrial effluents, solid domestic and industrial waste, (**021**). Excessive use of pesticides and fertilizers, (**022**). Contamination-pollution (water & soil pollution, etc.), (**023**). Alteration of the physicochemical characteristics - deterioration of the quality of water (salinity, etc.), (**024**). Embankment-filling of lagoons or lakes with sediment, (**025**). Drain of marshes, lakes lagoons/Exsiccation-desiccation of marshes and lakes, (**026**). Canal shifting and entrenchment of the main river channels/river diversion projects, (**027**). Intense mining activities (quarries, mines)/in upstream, (**028**). Sand and gravel extraction from river beds (in upstream), (**029**). Uncontrolled watering from surface water tables, (**030**). Uncontrolled pumping of underground waters, (**031**). Mass touristic activities, recreation, (**032**). Domestic use, (**033**). Intense urbanization of large coastal zones with impacts on the natural environment and the local natural ecosystems, (**034**). Holiday home building, (**035**). Sources of water pollution/in upstream, (**036**). Solid wastes/Rubbish water pollution, (**037**). Grazing in the forest, (**038**). Overgrazing, (**039**). Hunting-poaching, (**040**). Various off-road 4x4 and motocross races, (**041**). Use of lagoons or lakes for fishery, water cultivations, (**042**). Coastal farming - Fish farming in coastal waters <500 m from shore and <10 m water depth, (**043**). Coastal farming - Fish farming in coastal waters <500 m from shore and >10 m water depth, (**044**). Off-coast farming - Fish farming in coastal waters 500 m to 3 Km from shore and 10 to 50 m water depth, (**045**). Use of lagoons for salt production, (**046**). Climate Change.

Fig. 6. Cumulative chart of the human-induced pressures and interventions, in recent decades, that stress many urban, peri-urban areas and Natural Parks, under investigation, in low elevation coastal zones in Greece

Note: It should be noted that in this cumulative chart, each one of the anthropogenic pressures and interventions that stress the Urban, peri-Urban areas and Natural Parks, under investigation, in Greece, receive one point (1 point)

This Cumulative chart serves as a "tool" to identify the anthropogenic pressures and for the reduction of man-made eco-environmental impact on the Urban, peri-Urban areas and Natural Parks, under investigation, in Greece. Also serves as a "tool" for the rational environmental management of these areas, offering an overall visualization of the pressures/impact, in order to protect the function and value of the coastal ecosystems [104,105].

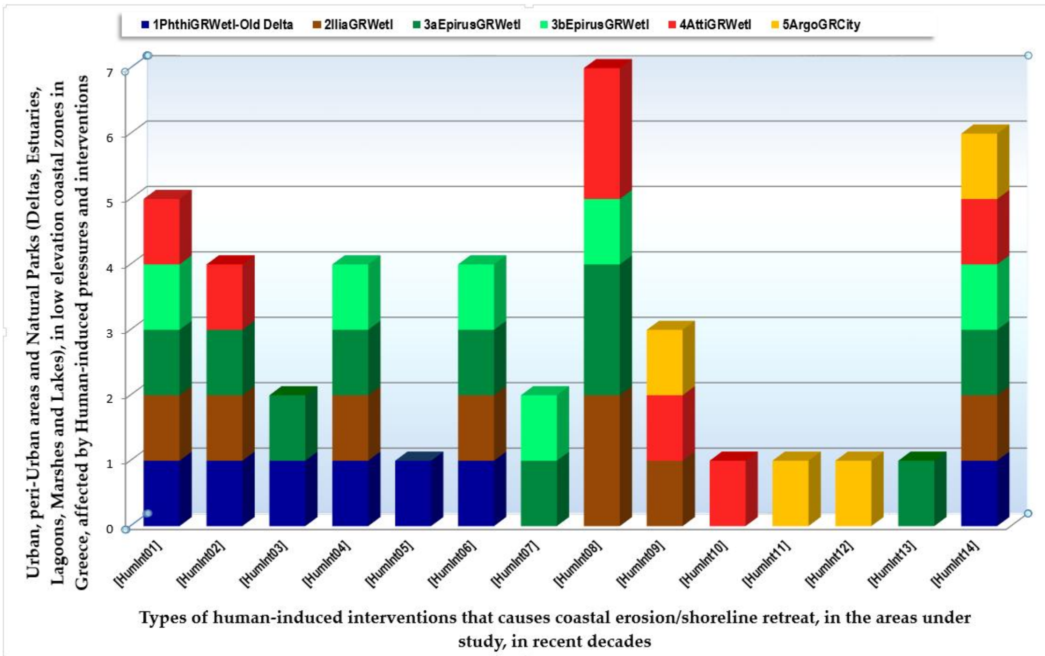
As shown in Fig. 6, there are several established anthropogenic pressures and interventions that stress the Greek Urban, peri-Urban areas and Natural Parks that we investigate. The most important are the following, mentioned in decreasing order:

1. “Infrastructure works-Code 14”
2. “Small business activities upstream-Code 18”
3. “Urban and industrial development without any planning -Code 19”
4. “Uncontrolled deposition of urban waste, industrial effluents, solid domestic and industrial waste-Code 20”
5. “Uncontrolled pumping of underground waters-Code 30”
6. “Sources of water pollution/in upstream-Code 35”
7. “Solid wastes/Rubbish water pollution-Code 36”
8. “Climate Change-Code 46”.

3.2 Human Activities Caused Coastal Erosion and Accretion-Climate Change and Future Sea-Level Rise

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 reports by the IPCC [24-31]. 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 [24-31,106,107]. Researchers have studied the influence of climatic changes on the evolution of some river deltas around the Adriatic Sea [79,108]. The coastal climate change impacts, in Greece, include accelerated erosion of susceptible areas of coast and inundation of low lying areas due to sea-level rise and flooding. The current rate of coastal erosion is estimated at 1.2 mm *per annum* [99]. 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.

Below there are presented the cumulative chart of the human-induced pressures and interventions, in recent decades, caused coastal erosion in the areas, under investigation (salt and freshwater wetlands such us deltas, estuaries, lakes, ponds, lagoons and marshes, and the small town of Tolo), in low elevation coastal zones in Greece (Fig. 7). This Cumulative chart serves as a "tool" to identify the main anthropogenic interventions which, cause coastal erosion/shoreline retreat on the Urban, peri-Urban areas and Natural Parks, under investigation, in Greece and for the reduction of man-made impact in a shrinkage of the coastline.



Legend: -**Delta of Sperchios River:** (HumInt**01**Sperchios). Construction of irrigation channels and drainage pits/Construction of The Lamia Trench (also known as the German Trench)(built in 1944), (HumInt**02**Sperchios). Sand and gravel extraction from the lower course of the riverbed in Lamia plain, (HumInt**03**Sperchios). Motorway in operation (P.A.TH.E. Motorway), (HumInt**04**Sperchios). National or provincial roads in operation (Old National Road Athens to Lamia), (HumInt**05**Sperchios). Railway line in operation or under construction in Lamia plain, (HumInt**06**Sperchios). Canal shifting and entrenchment of the main river channels/river diversion projects/Construction of an overflow channel (new river bed) at the north to the present Riverbed of Sperchios river (built in 1957), (HumInt**14**Sperchios). Climate Change and sea-level rise. **-Estuaries of Alfios River:** (HumInt**01**Alfios). Construction of irrigation channels and drainage pits in Pyrgos plain (built in 1960), (HumInt**02**Alfios). Sand and gravel extraction from the lower course of the Alfios riverbed (1967-2000), (HumInt**04**Alfios). National or provincial roads in operation (Old National Road Patras to Kyparissia), (HumInt**06**Alfios). Canal shifting and entrenchment of the main river channel of Alfios river (built in 1960), (HumInt**08**Alfios). Construction and operation of Ladonas hydroelectric power dam and reservoir in Ladonas River (Alfios tributary) (built in 1951), (HumInt**08**Alfios). Construction and operation of Flokas irrigation dam in Alfios River (built in 1967), (HumInt**09**Alfios). Intense urbanization of the coastal zone (Katakolon, Kavouri, Kiani Akti, Letrina, Spiatza, Paralia Epitalion), (HumInt**14**Alfios). Climate Change and sea-level rise. **-Delta of Arachthos River:** (HumInt**01**Arachthos). Construction of irrigation channels and drainage pits in Arta plain (built in 1945-1960), (HumInt**02**Arachthos). Sand and gravel extraction from the lower course of the riverbed near Arta, (HumInt**03**Arachthos). Motorway in operation (Ionia Motorway), (HumInt**04**Arachthos). National or provincial roads in operation (Old National Road Athens to

Ioannina), (HumInt**06**Arachthos). Canal shifting and entrenchment of the main river channel of Arachthos river (built in 1945-1960), (HumInt**07**Arachthos). Construction of drainage - anti flooding protection works on the banks of Arachthos river (built in 1945-1960), (HumInt**08**Arachthos). Construction and operation of Pournari I hydroelectric power dam and reservoir (irrigation dam and flood control dam) in Arachthos River (built in 1981), (HumInt**08**Arachthos). Construction and operation of Pournari II hydroelectric power dam and reservoir (irrigation dam) in Arachthos River (built in 1999), (HumInt**13**Arachthos). Uncontrolled pumping of underground waters in Arta plain, (HumInt**14**Arachthos). Climate Change and sea-level rise. **-Estuaries of Louros River:** (HumInt**01**Louros). Construction of irrigation channels and drainage pits in Arta-Louros plain (built in 1945-1960), (HumInt**04**Louros). National or provincial roads in operation, (HumInt**06**Louros). Canal shifting and entrenchment of the main river channel of Louros river (built in 1945-1960), (HumInt**07**Louros). Construction of drainage - anti flooding protection works on the banks of Louros River, (HumInt**08**Louros). Construction and operation of Louros hydroelectric power dam and reservoir in Louros River (built in 1954), (HumInt**14**Louros). Climate Change and sea-level rise. **-Inois River:** (HumInt**01**Inois). Construction of irrigation channels and drainage pits in Marathon plain, (HumInt**02**Inois). Sand extraction from the lower course of the Marathon riverbed, (HumInt**08**Inois). Construction and operation of the Marathon water supply dam and reservoir in Inois River (or R. Haradros) (built in 1929), (HumInt**08**Inois). Construction and operation of Rapentosa flood control dam, in Rapentosa River (Inois tributary) (built in 2004), (HumInt**09**Inois). Intense urbanization of large coastal zones (Nea Makri, Agios Panteleimonas, Paralia Marathonas), (HumInt**10**Inois). Coastal development plans, including the constructions for the Olympic Games of 2004 (Schinias Olympic Rowing and Canoeing Center), in Marathon marsh (Schinias-Marathon National Park). (HumInt**14**Inois). Climate Change and sea-level rise. **-Town of Tolo:** (HumInt**09**Tolo). Intense urbanization of large coastal zones of Tolo, (HumInt**11**Tolo). Construction of port (fishery shelter) and jetties in the coastal zone of Tolo, (HumInt**12**Tolo). Arbitrary installment of small groins in the coastal zone of Tolo, (HumInt**14**Tolo). Climate Change and sea-level rise.

Fig. 7. Cumulative chart of the human-induced pressures and interventions in recent decades caused coastal erosion in the areas under investigation along the low elevation coastal zones of Greece

Note: It should be noted that in this cumulative chart, each one of the anthropogenic pressures and interventions caused coastal erosion in the areas, under investigation, in Greece, receive one point (1 point)

Human interventions, such as construction of irrigation channels and drainage pits, construction of anti-flooding protection works on the banks of the rivers, river diversion projects, construction of upstream dams in the river basins, sand mining from riverbeds and beaches, construction of motorways, improperly sited harbours, revetments, jetties, seawalls, groins and breakwaters, intense urbanization processes of the coastal zone and human-induced land subsidence, are the main causes of coastal erosion, in the areas under study in Greece (Fig. 7). At the same time, destabilization of the ecological balance of the coastal zone and coastal erosion, inundation and shoreline retreat constitute main reasons of the Climate Change and future Sea-level rise upon the coastal plains under study.

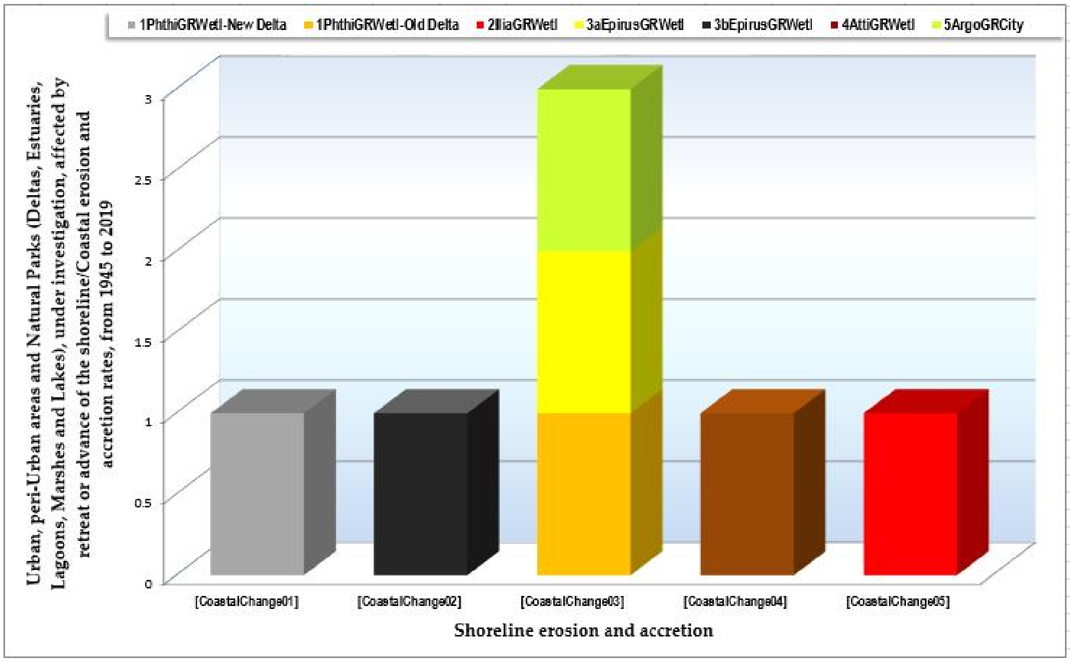
Coastal erosion, inundation and shoreline retreat, continues to be a major issue in coastal zone management of the areas under investigation in the low elevation coastal zones in Greece. Coastal erosion has been accelerated in many segments of the shoreline in Greece, due to man-made interventions, both within and at the inland of the coastal zone. Coastal erosion, inundation and shoreline retreat, are serious problems in some coastal zones in Greece, that results to a degradation and shrinkage of coastal wetlands and in damage to or loss of houses, coastal buildings, hotels, tourist facilities and other coastal structures (Fig. 8).

For the six areas that we investigate, the results have shown that the rate of changes in the coastline (from 1945 to 2019), is significantly different among them. Sperchios River Delta has both advanced and retreated shorelines, however in the northern estuarine shoreline (new delta) the accretion is dominant. Considering the old Delta, the retreat is dominant but the most affected area by coastal erosion is the deltaic coast of Alfeios river. Especially its mouth area the retreat of the shoreline was approximately 450 m (from 1945). Coastal erosion, inundation and shoreline retreat, result in a shrinkage of the coastal wetlands (lagoons, lakes, marshes and ponds), and destroy houses, coastal buildings, hotels, tourist facilities. The estimated value of this factor is estimated on average at between 0.1 and 8 m/year, in the last six decades. These changes are described below (Fig. 9).

In the event of a sea-level rise, significant parts of many Urban, peri-Urban areas and Natural Parks, in low elevation coastal zones in Greece, will be inundated and shoreline will retreat. Maroukian (1989) [109] has studied the consequences of sea-level rise along the Greek coast. In addition, Gaki-Papanastasiou et al. (1997) [110] have found that, in the case of four Greek river deltas, some 12% of their coastal area will be submerged if sea-level rises by 0.5m. Further, Poulos et al. [111,112] has studied the consequences of a future eustatic sea-level rise on the deltaic coasts of Inner Thermaikos Gulf (Aegean Sea) and Kyparissiakos Gulf (Ionian Sea) in Greece, have found that, coastline retreat in the case of Alfeios is related primarily to the process of shore zone erosion; in the case of the Axios and Aliakmon, it is related to the process of inundation. According Ghionis [113,114], since the construction of dams (1954 and 1988), the deltaic shoreline of Alfeios has retreated at an average rate of 8 m/year, which has produced a maximum shoreline recession of 340 m at the river mouth. 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 Marathon dam, in 1929; and 2. The sand extraction from the lower course of the riverbed [91]. In the Delta of Arachthos river, since the construction of upstream dams in the Arachthos river basin (dam Pournari I-operation in the year 1980, and dam Pournari II-operation in the year 2000), the deltaic shoreline of Arachthos, sandy coasts and the sand barrier which connects Koronisia with Fidokastro, are subject to erosion processes.

Fig. 8. Difference between the year 2010-11 and 2019 of the Deltaic coastline retreat in the River Alfeios mouth area due to dam construction. Coastal erosion in Paralia Epitalion (Epitalion beach in the south-east of the estuaries of Alfeios river), results in damage or loss of houses and other coastal structures (Kyparissiakos Gulf-Greece). The coastal area of Paralia Epitalion during 2010 (December 2010) and 2011 (March 2011), is shown in the figures 8a and 8b. The same location during 2019 (August 2019), is shown in the figures 8c and 8d. (Photos by Mertzanis A.)

At the beach zone of the small town of Tolo (Argolic Gulf), according Giannouli et al. (2010) [52], human intervention is very important. In the figure below (Fig. 10), we can observe the construction of a fishery shelter, the creation of a road parallel to the shoreline in a small distance from it, the regulation of torrent's channels and the arbitrary installment of small groins. All the mentioned interventions seem to have either initiate and/or enhanced erosion, which locally accounts several meters, despite the non-intense nearshore hydrodynamic conditions.



Legend: [CoastalChange0**1**] Shoreline accretion > 100 m (in total), [CoastalChange0**2**] Coast in equilibrium/Stable, [CoastalChange0**3**] Shoreline retreat < 20 m (in total), [CoastalChange0**4**] Shoreline retreat > 20 m and < 100 m (in total), [CoastalChange0**5**] Shoreline retreat > 100 m (in total).

Notes*: 1* Sperchios River Delta (New Delta): Shoreline accretion > 100 m (in total). Sperchios River Delta has both advanced and retreated shorelines, however in the northern estuarine shoreline (new Delta), the accretion is dominant. After 1957 begun the illuviation of a large area of the shallow part north to the present river bed due to the construction of an overflow channel (Shoreline accretion about 2.500 m from 1945 to 2019). According Kotoulas (1988), during 1958-1970, the delta of the river in the area of the diverted river bed 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. **2* Estuaries of Louros river:** Coast in equilibrium/Stable. 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 (Poulos et al. 2005, Poulos et al. 2008). **3* Sperchios River Delta (Old Delta):** Shoreline retreat < 20 m (in total). In the southern estuarine shoreline of Sperchios River Delta (old delta), the retreat is dominant. **4* Delta of Arachthos river:** Shoreline retreat < 20 m (in total). The operation of the dam "Pournari I", combined with the small dam Pournari II" constructed downstream of the above and operated since 2000. Since the construction of dams (1980 and 2000), the deltaic shoreline of Arachthos, sandy coasts and the sand barrier which connects Koronisia with Fidokastro, are subject to erosion processes and the retreat is dominant. The thin sand barrier between Logarou-Tsoukalio Lagoons and Amvrakikos Gulf, being under erosion by wave action, but are supported by coastal protection works along the shoreline (rock armour, riprap, etc.). **5* Town of Tolo:** Shoreline retreat < 20 m (in total). Along the coastal zone, of Iria (eastern coast of the Argolic Gulf), shoreline erosion processes has occurred. The beach zone of the town of Tolo being under erosion by wave action. According

Giannouli et al., (2010) the beach zone consists of mixed material, mainly sand and granules (Seni et al. 2007). It is exposed to strong waves from the S and SW, even though the most frequent blowing winds are those of NW; the later is related to small height waves due to limited fetch distances. Human intervention is very important and includes the construction of a fishery shelter, a road parallel to the shoreline and in a small distance from it, regulation torrent's channels and the arbitrary installment of small groins. All the aforementioned interventions seem to have either iniatiate and/or enhanced erosion, which locally accounts several metres, despite the non-intense nearshore hydrodynamic conditions. **6* Inois river:** Shoreline retreat > 20 m and < 100 m (in total). On the main river channel of Inois has built and operates the Marathon water supply dam. The construction of this dam was completed in 1929. 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 Marathon dam, in 1929; and 2. The sand extraction from the lower course of the riverbed (Seni et al. 2004). **7* Estuaries of Alfeios river:** Shoreline retreat > 100 m (in total). According Ghionis et al. (2013), the deltaic coast of the Alfeios river, and especially its mouth area, is undergoing intense erosion over the last decades. This erosion has been caused primarily by the dramatic reduction of the fluvial sediment fluxes, following the construction of two dams (in 1954 and 1967), with the second dam being located at a distance of only 6 km from the river mouth. A further decrease in sediments reaching the sea is induced by the extended (even not continuous) abstraction of sand and gravel from the river's lower route. The resulting sediment deprivation in association with the highly energetic nearshore hydrodynamic regime has caused a retreat of approximately 450 m (from 1945 to 2003) of the mouth area of the R. Alfeios. The northern part of the mouth has been affected more heavily by the erosional processes (shoreline retreat between 200 and 445 m) than the southern part (100-240 m retreat), the sediment losses of which are partially replenished by the northward longshore sediment transport of Kyparissiakos Gulf. According Poulos et al. (2009), coastline retreat in the case of Alfios delta is due mostly to erosion accompanying and/or following sea-level rise and, secondarily, to the process of inundation; this is due to its coastal morphology, which is characterised by the presence of sand dunes and relatively high slopes of the backshore zone, attributed to its exposure to intensive wave activity.

Fig. 9. Coastal erosion and accretion rates in recent decades (1945-2019) in the areas, under investigation along the low elevation coastal zones of Greece. Noted that in this cumulative chart each one of the changes (Shoreline erosion or accretion) receive one point

Sigalos and Alexouli-Livaditi [40,41], attributes the future migration of the shoreline of Sperchios 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^2, with the greater part of it placed at the lower reaches of the river Sperchios 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^2, are likely to be flooded by the sea, until the year 2100. At the Delta of the river Sperchios, high risk areas occupy the 19.17% of the total deltaic plain, when areas with high possibility to be submerged occupy the 11.43% [40,41]. 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 [33]. 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 [33,40,41,77,78] (Fig. 11).

Both identification and characterization of the critical parameters that control shoreline behavior is difficult. While the prospect of future shoreline erosion related to sea-level rise is of global concern [115], it is increasingly apparent that the patterns of shoreline change during transgression are non-uniform and highly site-specific [116]. Thus, it might be expected that predictions of future shoreline erosion rates for given sea-level rise must be based, in significant part, on local geomorphological and sedimentological characteristics including the geological framework, sediment supply and dispersal rates, sediment type, existing geomorphology, vegetation, lithification rates, abrasion, contemporary dynamics, human influences, etc. [16].

Fig. 10. Along the coastal zone, of Iria (eastern coast of the Argolic Gulf) and the small town of Tolo, shoreline erosion processes have occurred. Human intervention is very important and includes the construction of a fishery shelter, a road parallel to the shoreline and in a small distance from it, regulation torrent's channels and the arbitrary installment of small groins. All the aforementioned interventions seem to have either initiate and/or enhanced erosion, which locally accounts several meters, despite the non-intense nearshore hydrodynamic conditions. Coastal erosion and shoreline retreat are expected to be increased due to Climate Change and the potential future Sea-level rise (Photos by Mertzani As.-July 2019)

(a)

(b) 

Fig. 11. Aerial photographs of the old Delta (Foto 11a) and the new Delta (Foto 11b) of Spercheios River to the Maliakos and the surrounding marine ecosystems (Code Number 1PhthiGRWetl- NATURA 2000 SiteCode: GR2440002). 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. To the right (northwest) of old Delta, is distinguished the new estuary, after the diversion to the north of the main river channel. As shown in the aerial photographs of Fig. 11, intensification and development of agriculture and artificial river diversion projects and channelization, included among the multiple anthropogenic pressures and interventions that have been encountered as of now in the protected area of the delta. (Source of the aerial photographs: TripInView/Geotag Aeroview 2014)

4. CONCLUSIONS

A significant segment in low elevation coastal zones in Greece is in a fragile equilibrium. This is mainly because of man-made interventions that were carried out without preliminary studies regarding the long-term consequences of these activities. Characteristic examples of these are the protected wetlands that exist in Greece such as those in the Delta and the river mouth areas of the Sperchios, Alfeios, Arachthos, Louros, Inois rivers, and the small town of Tolo.

The intensification of human activities on these areas, such as, wetland draining, exsiccation of lagoons and lakes, river engineering works, dam construction, intensification and development of agriculture projects, construction of motorways, construction of harbor structures, such as harbours, jetties, seawalls, groins, and breakwaters, rapid urbanization processes, holiday home building and tourist facilities, massive tourism and intense coastal development, water pollution, uncontrolled water abstraction from surface and underground water tables, and removal of coastal vegetation, combined with the Climate Change, influence the local natural environment and the geomorphological evolution processes on the coastal zone, and constitute the main causes of the destabilization of the ecological balance of the coastal zone. Sea-level rise could erode and inundate coastal ecosystems and disrupt wetlands, Urban and peri-Urban areas.

Climate Change and the consequent Sea-level rise within the range of 0.5–1.0 m will cause significant shoreline retreat in low elevation coastal zones, under investigation, in Greece. In most cases in the under investigation areas, coastline retreat is due mostly to the combination of marine erosion and to the process of inundation which accompanying Sea-level rise. Main cause of these phenomena could be their coastal geomorphology, which is characterized by the presence of erodible sand dunes and sand barriers, and lowland areas.

The mismanagement and overexploitation of the vulnerable coastal environment over the last decades, lacking proper planning, threatens to destroy the coastal zone, a key pillar of the economy (tourism, recreation, shipping, fishing) and a major environmental resource for Greece.

The coastal space is a multifactorial system that needs special protection and rationally designed interventions for the "coexistence" of anthropogenic activity with the coastal ecosystem.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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