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Abstract

Coastal areas are very dynamic geomorphological systems where changes may occur at diverse temporal and spatial scales, mostly related to erosion, as a result of the complex interplay between natural (e.g. waves, tides, storms, tectonic and physical processes, sediment transport) and anthropogenic pressures (e.g. land use changes, touristic activities). Against this background, coastal authorities are faced with the increasingly complex task of balancing coastal development with risk management. The Integrated Coastal Zone Management (ICZM) approach represents a valuable tool to resolve these conflicts, providing a structured framework and principles to mitigate impacts due to short and long-term uses and provide support to sustainable and integrated shoreline management. In the frame of the task 3.1 '*Census of needs/mapping of existing system for coastal management*', this report provides an overview of the main territorial and environmental features of the Italian and Greek TRITON pilot cases. Moreover, available dataset to inform the case studies, including data from on-going and former projects (e.g. EUROSION, START, PEGASO), open-source web data portals (e.g. Copernicus) and data supplied by national and local authorities are described, also providing details on their metadata. This information will be capitalized in both TRITON pilot cases within the application of risk-based methodologies to evaluate coastal erosion processes and provide support to cross border operational plan for ICMZ implementation across Greece and Italy.

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Acronyms

ARPA: *Azienda Regionale per la Protezione Ambientale* (Regional Environmental Protection Agency)
CAMS: Copernicus Atmosphere Monitoring Service
CLC: CORINE Land Cover
CMEMS: Copernicus Marine Environment Monitoring Service
DEM: Digital Elevation Model
DSAS: Digital Shoreline Analysis System
DTM: Digital Terrain Model
EC: European Commission
ECMWF: European Centre for medium-range Weather Forecasts
EMODNET: European Marine Observation and Data Network
EPR: End Point Rate
ESA: European Space Agency
EU: European Union
EUMETSAT: European Organization for the Exploitation of Meteorological Satellites
GDP: Gross Domestic Product
GEBCO: General Bathymetric Chart of the Oceans
GIS: Geographic Information System
GPCC: Global Precipitation Climatology Centre
HYPE: Hydrological Predictions for the Environment
ICZM: Integrated Coastal Zone Management
IPCC: Intergovernmental Panel on Climate Change
IQR: Interquartile Range
ISPRA: *Istituto Superiore per la Protezione e la Ricerca Ambientale*
ISTAT: *Istituto Nazionale di Statistica* (Italian National Institute of Statistics)
MMU: Minimum Mapping Unit
NSM: Net Shoreline Movement
OECD: Organisation for Economic Co-operation and Development
PPTR: *Piano Paesaggistico Territoriale Regionale* (Regional Territoral Landscape Plan)
PRC: *Piano Regionale Coste* (Regional Coastal Plan)
SCP: Semi-Automatic Classification Plugin
SPM: Suspended Particulate Matter
UF: *Unità Fisiografiche* (Physiographic Unit)
UNESCO: United Nations Educational, Scientific and Cultural Organization
USGS: United States Geological Survey
WLR: Weighted Linear Regression

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1. Introduction

Climate change is causing serious threats on natural and human systems worldwide (IPCC, 2018). In particular, climate-related impacts will be especially relevant in coastal areas, where a dense interaction between terrestrial and marine systems occurs (IPCC, 2013). According to the IPCC scenarios, coastal areas, and related ecosystems, will be increasingly exposed to erosion, as a direct consequence of rising sea levels and changing patterns of extreme events (MATTM, 2017). The expected physical impacts (e.g. sea-level rise, storms, floods), already affecting low-lying coastal areas, are projected to increase in the future leading to more severe environmental effects (IPCC, 2013). Examples are biodiversity loss, reduced species survival and species shift which, in turn, will affect ecosystems services flow and generate socio-economic damages, including disruption of urban areas and infrastructures (UNDP, 2011; IPCC, 2014a).

Located at the land-sea interface, coastal areas are dynamic environments in which natural and anthropogenic processes interact at diverse temporal and spatial scales, modifying their geomorphological, physical and biological characteristics (Mills et al., 2005). Natural effects include shoreline interactions with incident waves, tides, storms, tectonic movements, as well s physical processes linked to the sediment transport by rivers (Dolan et al., 1981). The processes of coastal erosion and accretion have always existed and have contributed, over time, to shape the coastal landscape by creating a wide variety of types of coastline (e.g. cliff, sandy and rocky coast, etc.). Coastal erosion can be a slow (years, decades or centuries) or rapid onset (days or weeks) process: it normally has a long term trend, due to the continuous wave motion, but it can be as well rapid, as a consequence of an extreme flood event (Mentaschi et al., 2018). This process can also be accelerated by anthropogenic pressures: as example, the damming of streams can lead to a decrease of sediments transport since they would result trapped behind dams; the extraction of natural resources from the seabed (sand and gas) and water abstraction from groundwater may cause ground subsidence.

In this context, due to the this complex interplay between natural and human-made pressures, the Mediterranean region is already experiencing a number of environmental impacts, including erosion and degradation of coastal ecosystems, triggering efforts to improve short-term coastal management (Nicholls and Hoozemans, 1996). Even though the Mediterranean Sea is not expected to be subjected to sea level rise as the oceans, the region is considered to be a climate change hot-spot due to its specific physical, environmental and socio-economic features. In fact, the Mediterranean region is characterized by low lying coastal areas particularly prone to storm surge flooding events and rising sea level, as sea water can't be stopped by steep slope or dunes providing natural defense to water intrusion (ETC/ACC, 2010; Anzidei et al., 2014, 2017). Moreover, there are multiple areas of anthropization linked to land use changes and increasing demographic

development, thus depicting a scenario of severe damages to properties and destruction of habitats (Antonioli et al., 2017; Marsico et al., 2017).
Against this background, coastal authorities are faced with the challenging task of balancing coastal development with risk management. An integrated approach to coastal management is needed to face coastal erosion processes, merging both technical and scientific studies to identify, on one side, the main causes contributing to coastal imbalance and to design, on the other, the most appropriate monitoring actions for understanding the trends and the required structural measures, following the order of priority resulting from the level of risk. The Integrated Coastal Zone Management (ICZM) approach represents a valuable tool to face these kinds of environmental issues, providing a structured framework and principles to mitigate impacts due to short- and long-term uses, and support strategies for sustainable and integrated shoreline management. However, even though the ICZM Protocol has been signed in 2008 (UNEP/MAP/PAP, 2008), its implementation is still fragmented across the Mediterranean region.
Drawing on this need, the overall objective of the Triton project is to reduce the consequences of coastal erosion by bridging the policy-implementation gap in the ICZM in the area of intervention (IT-GR), improving the integration of coastal zone policies within broader spatial planning and socio-economic policies. The Apulian and Western Greece shorelines, in the area of intervention of the project, are facing significant erosion impacts due to natural and man-induced causes, calling for targeted interventions and adaptation strategies based on risk analysis and management.
In the frame of the task 3.1 '*Census of needs/mapping of existing system for coastal management*' this report briefly describes the main territorial and environmental features of the Italian and Greek TRITON pilot cases, also providing details on the dataset, from open-source web data portals (e.g. Copernicus, EUROSION) and supplied by national and local authorities, available at the case study level (Section 2). As summarized in the conclusions (Section 3), these information will be exploited in both TRITON pilot cases within the application of risk-based methodologies, allowing to evaluate shoreline evolution against different climate change and management scenarios and provide support to cross border ICMZ in the area of intervention (IT-GR).

2. Coastal erosion processes: main terminologies and theories

The "coast", also known as the "coastline" or "seashore", is the area where land meets the sea or ocean, or a line that forms the boundary between the land and the ocean or a lake. A precise line named a "coastline" cannot be determined due to the continuous variation of sea level according to waves and winds and to the continuous displacement of materials. The term "coastal zone" refers to a region where interaction of the sea and land processes occurs. The coast and its adjacent areas on and offshore are an important part of a local ecosystem, social and economic chain. The high level of biodiversity creates a high level of biological activity, which has attracted human activities for thousands of years. Most part of the world's people live in coastal regions. Many major cities are on or near good harbors and have port facilities. Some landlocked places have achieved port status by building canals. The coast is a frontier that nations have typically defended against military invaders, smugglers and illegal migrants. Fixed coastal defenses have long been erected in many nations, coastal countries typically have a navy and some form of coast guard, in Italy *Marina Militare Italiana*, *Guardia Costiera*, *Capitaneria di Porto*, respectively.

Coasts, especially those with beaches and warm water, attract tourists. In many island nations such as those of the Mediterranean, Indian Ocean, South Pacific and Caribbean, tourism is central to the economy. Coasts offer recreational activities such as swimming, fishing, surfing, boating, and sunbathing. Growth management can be a challenge for coastal local authorities who often struggle to provide the infrastructure required by new residents. The coastal evolution is the product of morphodynamic process that occurs in response to change in external conditions (*Wright and Thom, 1977)*.

The **structure of the coasts** is very heterogeneous, and its shape depends on several factors such as the soil material, the exposure to the atmospheric agents, the anthropic pressing and the human activities. A main difference can be remarked between rocky shore and sedimentary shore. A **rocky shore** is an intertidal area that consists of solid rocks. Their diversity depends, among other things, on cliff mineralogy, lithology, tectonic history, climate, waves and tides. Some rocky coasts consist of steep plunging cliffs; this is observed when subaerial erosion is minor compared to marine erosion or in cases of volcanic activity or tectonic subsidence. Cliffs which are degraded by subaerial weathering processes are more gently sloping. Such more rounded (often vegetated) cliffs, are called "bluffs". A common coastal cliff morphology is the slope-over-wall profile: a rounded weathered top and a vertical wall below (Figure 1). In many cases cliffs are fronted by shore platforms, which can be tens to many hundreds (or even thousands) of meters wide. These shore platforms result from cliff retreat; the outer edge marks the cliff position in the past – often millennia ago, in the case of erosion-resistant rock. Wave attenuation on the shore platform reduces cliff recession rates. Cliff and shore platform both retreat under erosive processes; the rate of cliff retreat strongly depends on the width of the shore platform. An equilibrium profile is reached when platform retreat and cliff retreat occur at the same pace.

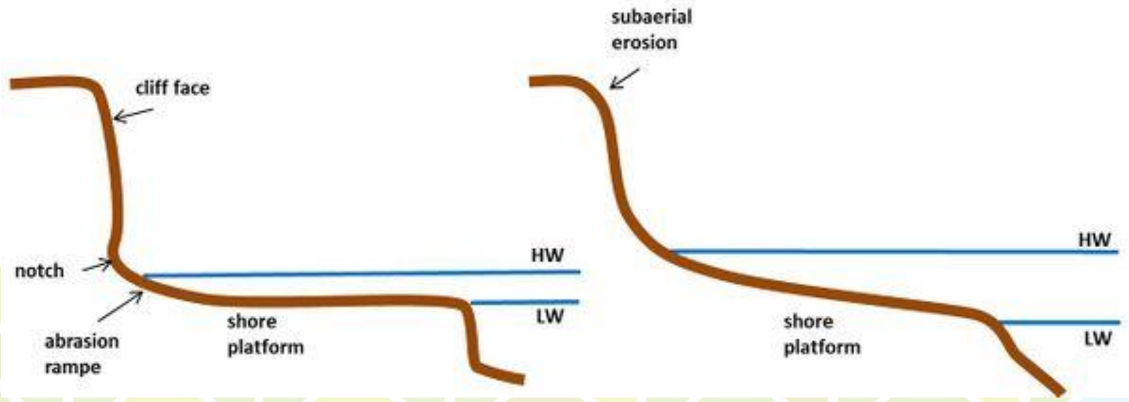

Figure 2: Structure of coastal areas

Cliff retreat depends on many factors: rock structure (massive, bedding, faulted, granular), rock lithology (permeability, solubility, hardness, jointing), hydraulic action (exposure to waves more or less loaded with debris, tides, currents) and subaerial weathering (by surface and subsurface runoff, freeze-thaw, chemical processes, biota). Hard rock cliffs retreat typically less than 1 cm/year, whereas soft cliffs (consisting of boulder clay, for example) retreat typically more than 1 m/year. Cliff retreat is often episodic, through rock-fall and toppling, after undercutting of the cliff base by wave quarrying, abrasion and weathering. Wave quarrying is the process of rock dissection by breaking waves, which produce shock pressures and air compression in joints and fissures. Wave abrasion is the process of rock scraping and shattering by abrasive material (rock fragments) moved forth and back by wave-orbital motion. Rock weathering is due to the mechanical action of alternate drying and wetting and salt crystallization in fissures, but also due to chemical processes (dilution) and biotic activity. Soft-rock cliffs may collapse by slumping or sliding events, which are often preceded by soil creep and triggered by rainwater infiltration. Debris fans at the cliff base after a slumping event are subsequently reworked by wave action; they are washed away or become part of the shore platform. Marine dissolution processes are an important cause of degradation of limestone cliffs, when acidic seawater (containing dissolved CO_2) and salt spray enter cracks, joints and fissures. Bio-erosion (by algae and by boring and grazing organisms) also contributes to erosion of calcareous rock. The resulting forms are termed "karst", featuring caves, arches and stacks.

Sedimentary shores or beaches are loose deposits of sand, including some gravel or shells, that cover the shoreline in many places. They make up a large portion of the world's ice-free coastlines. Beaches serve as buffer zones or shock absorbers that protect the coastline, sea cliffs or dunes from direct wave attack. It is an extremely dynamic environment where sand, water and air are always in motion.

The active coastal zone (sometimes also called active coastal profile) is the beach zone over which sand is exchanged in cross-shore direction by natural processes. The seaward limit corresponds to the closure depth, beyond which no significant longshore or cross-shore transports take place due to littoral transport processes, and the landward limit to a hard boundary (seawall, cliff...). In the case of a dune coast the active zone comprises part of the front dune that can be eroded by storm waves.

The beach can be divided into three main zones (Figure 2):

- **Backshore** is the area that goes from the landward limit (the foot of the cliff or the foot of the dunes) until the limit of waves under normal conditions. Therefore, the backshore is inly exposed to waver under extreme events;
- **Foreshore or beach face** is the part of the shore/beach which is wet due to the varying tide and wave run-up under normal conditions, i.e., excluding the impact of extreme storm waves and storm surge. This means that the foreshore in morphological terms extends further up on the beach than the shoreline.
- **Shoreface** or **nearshore** is part of the active coastal zone, situated seaward of the shoreline. This zone extends seaward from the foreshore to the closure depth. The littoral zone is the zone in which littoral morphodynamical processes take place, related mainly to longshore sediment transport and cross-shore sediment transport. The width of the instantaneous littoral zone varies dependent of the wave conditions. In the general context, the littoral zone is defined as the zone corresponding to the yearly wave climate;

  The nearshore can be divided into:
  - Breaker areas where the breakers begin to occur;
  - Surf zone;
  - Swash zone is the area closest to the shore

Beyond shoreface, offshore zone is individuated.

The **coastline classification** is based on three main categories (EEA, 2016):

Compared to the type of beach that is being created, they can be classified into:

- **Dissipative**, i.e. with a slight slope and a large area of fringes;
- **Intermediate,** with moderate slopes;
- **Reflective**, with pebble beaches where the waves break near the shore.

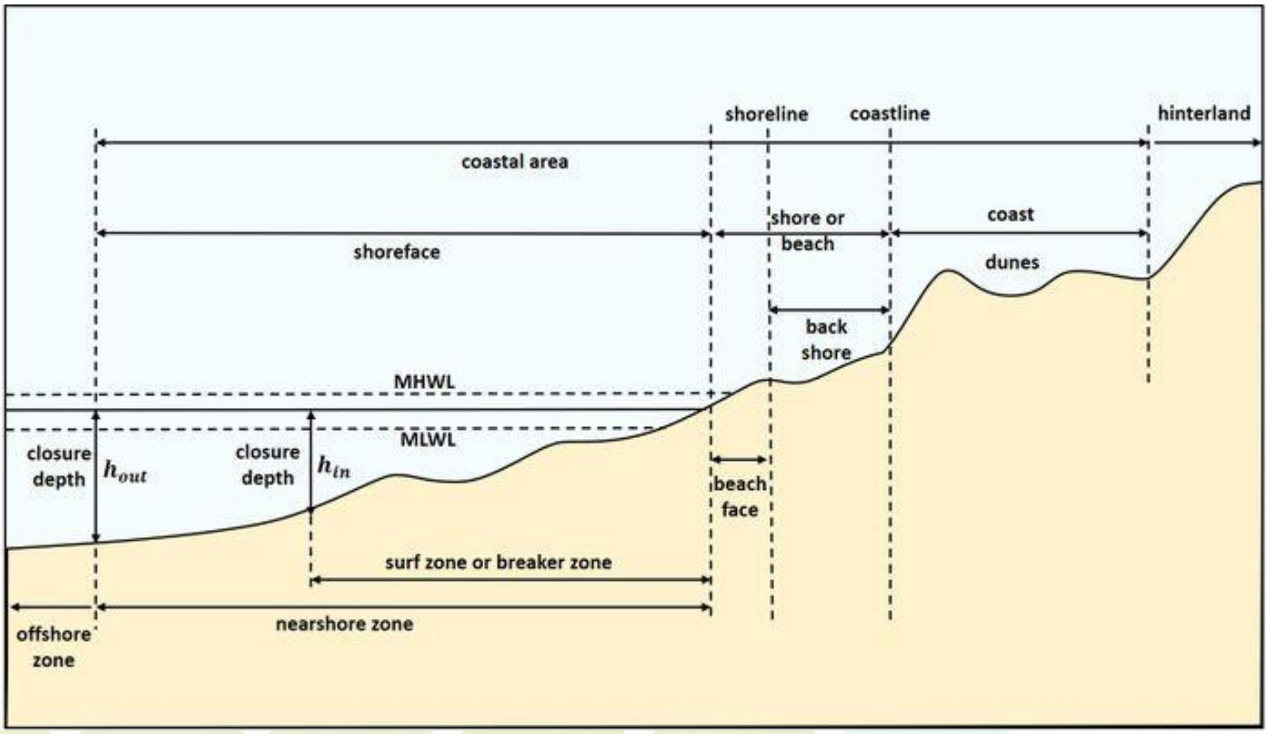

Figure 3: Zonal classification of coastal areas

The transition between sea and land (shoreline) is never a fixed line along sandy coasts. Seen at a short time scale (seasonal and intra-seasonal time scale), the shoreline continuously shifts in landward and seaward direction. This is a well-known and intriguing feature of the natural behaviour of our coasts. Seen over a longer time scale, many coasts all over the world show a structural, gradual and continuous accreting or eroding tendency, although stable coasts also occur. Pure natural (autonomous) reasons, or man-induced reasons may cause this behaviour.

The description of **coastal erosion** phenomenon is based on the settlement of two main definitions:

- **a)** the loss or displacement of land along the coastline due to the action of waves, currents, tides, wind-driven water, waterborne ice, or other impacts of storms. In this case, landward retreat of the shoreline, measured to a given spatial datum, is described over a temporal scale of tides, seasons, and other short-term cyclic processes.
- **b)** alternatively, it is defined as the process of long-term removal of sediment and rocks at the coastline, leading again to loss of land and retreat of the coastline landward.

The coastal erosion may be caused by hydraulic action, abrasion, impact and corrosion by wind and water, and other forces, natural or unnatural.

The **sedimentary balance of the coast** is the sum of the processes concerning the shoreline conceived as the meeting point between earth and water. This an environment effect in which erosion processes (material removal due to waves and tides, coastal currents and wind) and sedimentation (contribution of material from rivers or from nearby stretches of coastline) can occur. The sedimentary balance heavily affects the shape of the coast in the following terms:

a) if the sedimentary balance is negative, i.e. erosion is prevalent, the coast will generally have narrow and steep backshore and the profile could be characterized, according to the features of land, by cliffs and bluffs;
b) if the sedimentary balance is positive, that is, depositional phenomena prevail, the coast will be low and characterized by wide shores; in this case we can also distinguish different possibilities:
    - open coastlines, when there is a clear and linear separation between water and land;
    - protected shorelines when after a first land line emerges other bodies of water more or less connected with the sea (this is the case of the lagoons).

According to one principle of classification, an **emergent coastline** is a coastline which has experienced a fall in sea level, because of either a global sea level change, or local uplift. Emergent coastlines are identifiable by the coastal landforms, which are above the high tide mark, such as raised beaches. In contrast, a **submergent coastline** is one where the sea level has risen, due to a global sea level change, local subsidence, or isostatic rebound. Submergent coastlines are identifiable by their submerged, or "drowned" landforms, such as rias (drowned valleys) and fjords. According to a second principle of classification, a **concordant coastline** is a coastline where bands of different rock types run parallel to the shore. These rock types are usually of varying resistance, so the coastline forms distinctive landforms, such as coves. **Discordant coastlines** feature distinctive landforms because the rocks are eroded by ocean waves. The less resistant rocks erode faster, creating inlets or bay; the more resistant rocks erode more slowly, remaining as headlands or outcroppings.

On rocky coasts, coastal erosion results in fracture zones with varying resistance to erosion. Softer areas become eroded much faster than harder ones, which typically result in landforms such as tunnels, bridges, columns, and pillars. Over time the coast generally evens out. The softer areas fill up with sediment eroded from hard areas, and rock formations are eroded away. Accordingly, abrasion commonly happens in areas where there are strong winds, loose sand, and soft rocks, since the mechanical action of other rock or sand particles yields grinding and wearing away of rock surfaces.

A remarkable part of the sediment deposited along a coast is the result of erosion of a surrounding cliff, or bluff. The following formations can be observed in a rocky coast:

- **Sea cliffs** retreat landward because of the constant undercutting of slopes by waves. If the slope/cliff being undercut is made of unconsolidated sediment it will erode at a much faster rate than a cliff made of bedrock. A natural arch is formed when a headland is eroded through by waves.

- **Sea caves** are made when certain rock beds are more susceptible to erosion than the surrounding rock beds because of different areas of weakness. These areas are eroded at a faster pace creating a hole or crevice that, through time, by means of wave action and erosion, becomes a cave.
- **Stack** is formed when a headland is eroded away by wave and wind action.
- **Stump** is a shortened sea stack that has been eroded away or fallen because of instability.
- **Wave-cut notches** are caused by the undercutting of overhanging slopes which leads to increased stress on cliff material and a greater probability that the slope material will fall. The fallen debris accumulates at the bottom of the cliff and is eventually removed by waves.
- **Wave-cut platform** forms after erosion and retreat of a sea cliff has been occurring for a long time. Gently sloping wave-cut platforms develop early on in the first stages of cliff retreat. Later, the length of the platform decreases because the waves lose their energy as they break further offshore.

3. Description and characterization of the TRITON pilot cases

3.1 The Apulia region shoreline, Italy

Apulia Region is located on South East part of Italy bordering the Adriatic Sea in the east, the Ionian Sea to the southeast, and the Strait of Otranto and Gulf of Taranto in the south. Its southern portion known as Salento, a peninsula, forms a high heel on the "boot" of Italy. The North Eastern part well known as Gargano area is named “Spur” of Italy due to its shape.

The region comprises 19.345 km² (7.469 square miles), and its population is about 4 million. As depicted in Figure 3, it is bordered by the other Italian regions Molise to the North, Campania to the West and Basilicata to the South-West. On external border it is surrounded by Croatia, Montenegro, Greece, and Albania, across the Adriatic and Ionian, respectively. The highest peak of the region is *Mount Cornacchia* (1.152 meters above sea level) within the *Daunian Mountains*, in the north along the Apennines. Apulia Region hosts two national parks, the *Alta Murgia National Park* and *Gargano National Park*. Outside of national parks in the North and West, most of Apulia and particularly Salento is geographically flat with only moderate hills.

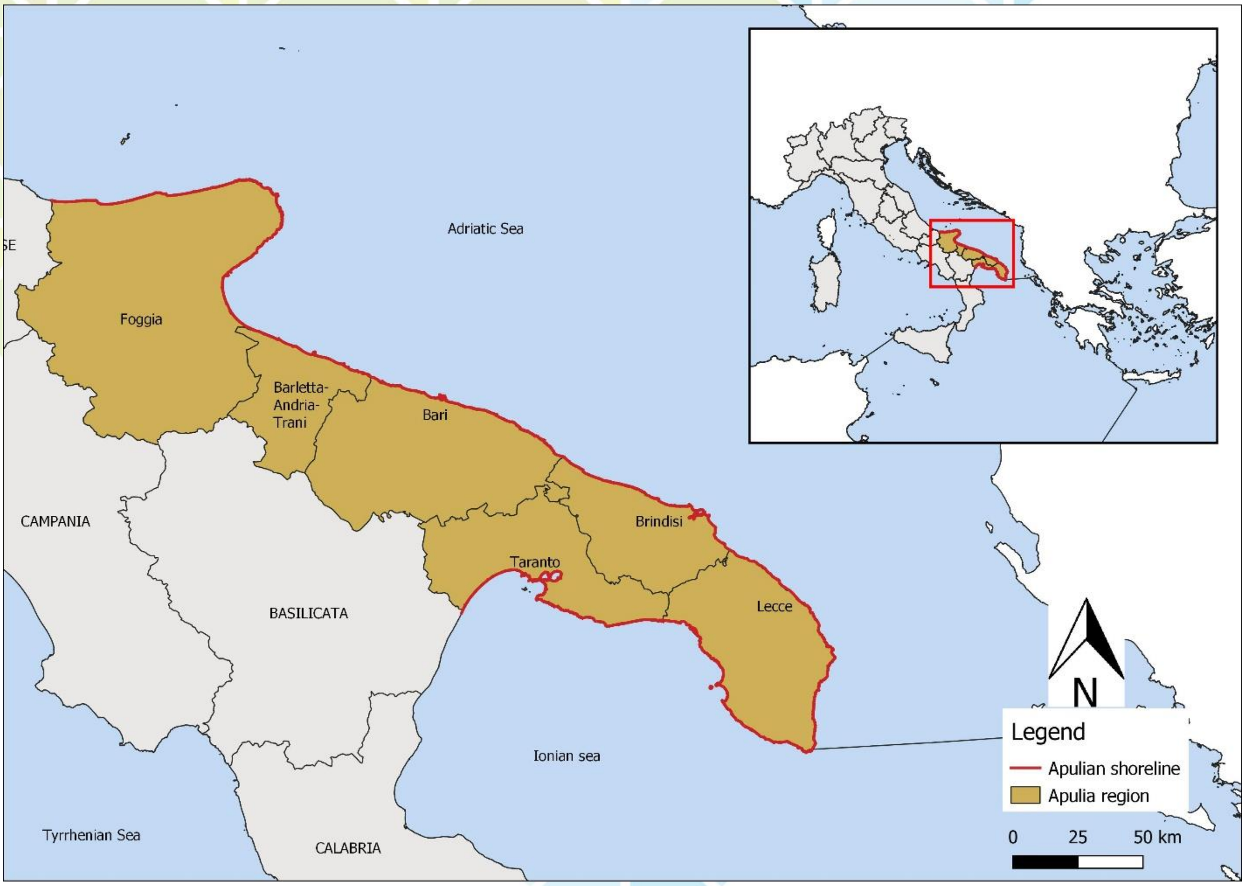

Figure 4: *Case study area of the Apulian shoreline*

The climate is typically Mediterranean with hot, dry and sunny summers and mild, rainy winters. Snowfall, especially on the coast is rare but has occurred as recently as January 2019 (following on from snow in March 2018 and January 2017). Apulia is among the hottest and driest regions of Italy in summer, with temperatures sometimes reaching up to and above 40 °C in Lecce and Foggia.

Apulia's coastline is longer than that of any other mainland Italian regions, representing the 12% of the national shoreline. Specifically, the Apulian coastline is long 970 km and it is composed by:

- 33% of sandy beaches for a length of 310,2 km;
- 33% of rock coasts for a length of 310,2 km;
- 21% by cliffs for a whole extension of 197,4 km;
- 5% artificial structures for an extension of 47 km;
- 8% other typologies for a whole extension of 75 km.

The pie-chart in Figure 4 shows the sedimentary classification of the Apulia Region Coastline updated to November 2018. The classification adopted by the Apulia Region is based on the classification issued by the "*Italian Coastal Typology for the European Water Framework Directive*" (Brondi et al., 2003).

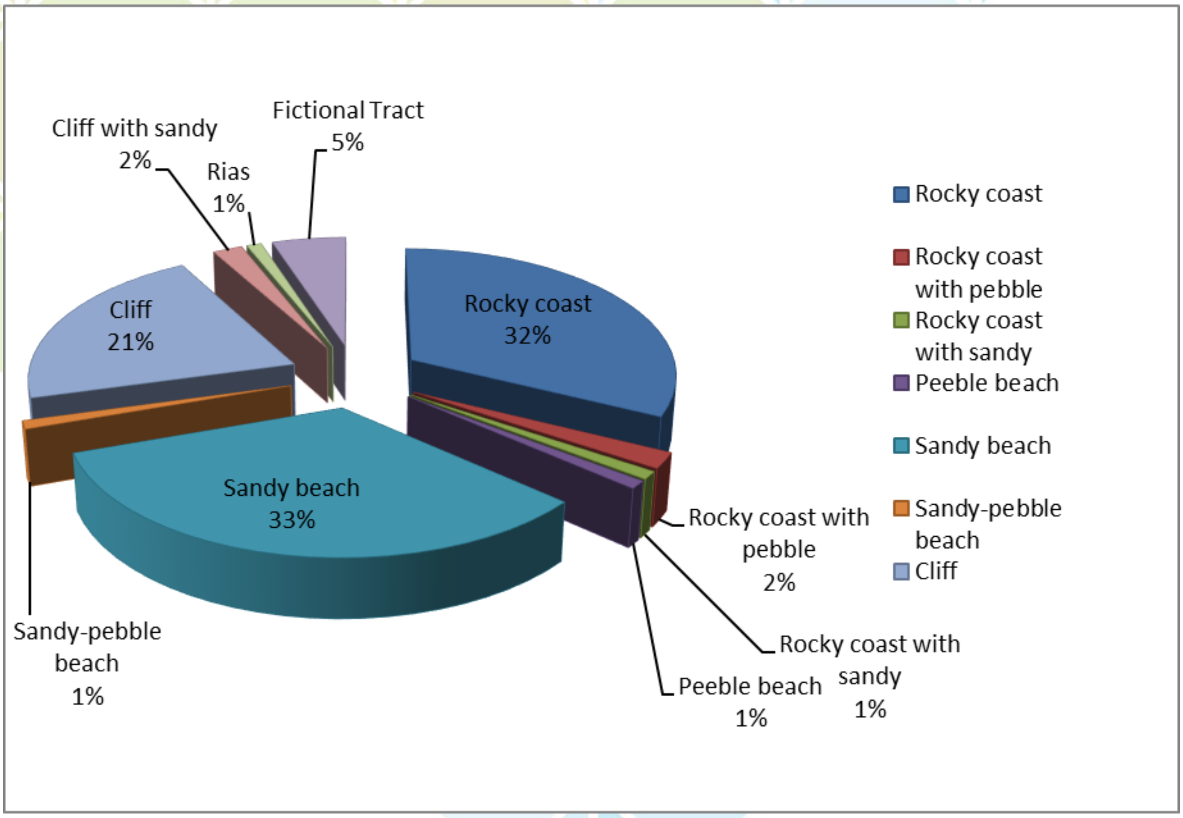

Figure 5*: Sedimentary classification of the Apulia Region Coastline (updated in November 2018)*

The coastal areas, particularly on the Adriatic and in the southern Salento region are frequently exposed to winds of varying strengths and directions, strongly affecting local temperatures and conditions, sometimes within the same day. The Northerly Bora wind from the Adriatic can lower temperatures, humidity and moderate summer heat while the Southerly Sirocco wind from North Africa can raise temperatures, humidity and occasionally drop red dust from the Sahara. On some days in spring and autumn, it can be warm enough to swim in Gallipoli and Porto Cesareo on the Ionian coast while at the same time, cool winds warrant jackets and sweaters in Monopoli and Otranto on the Adriatic coast.

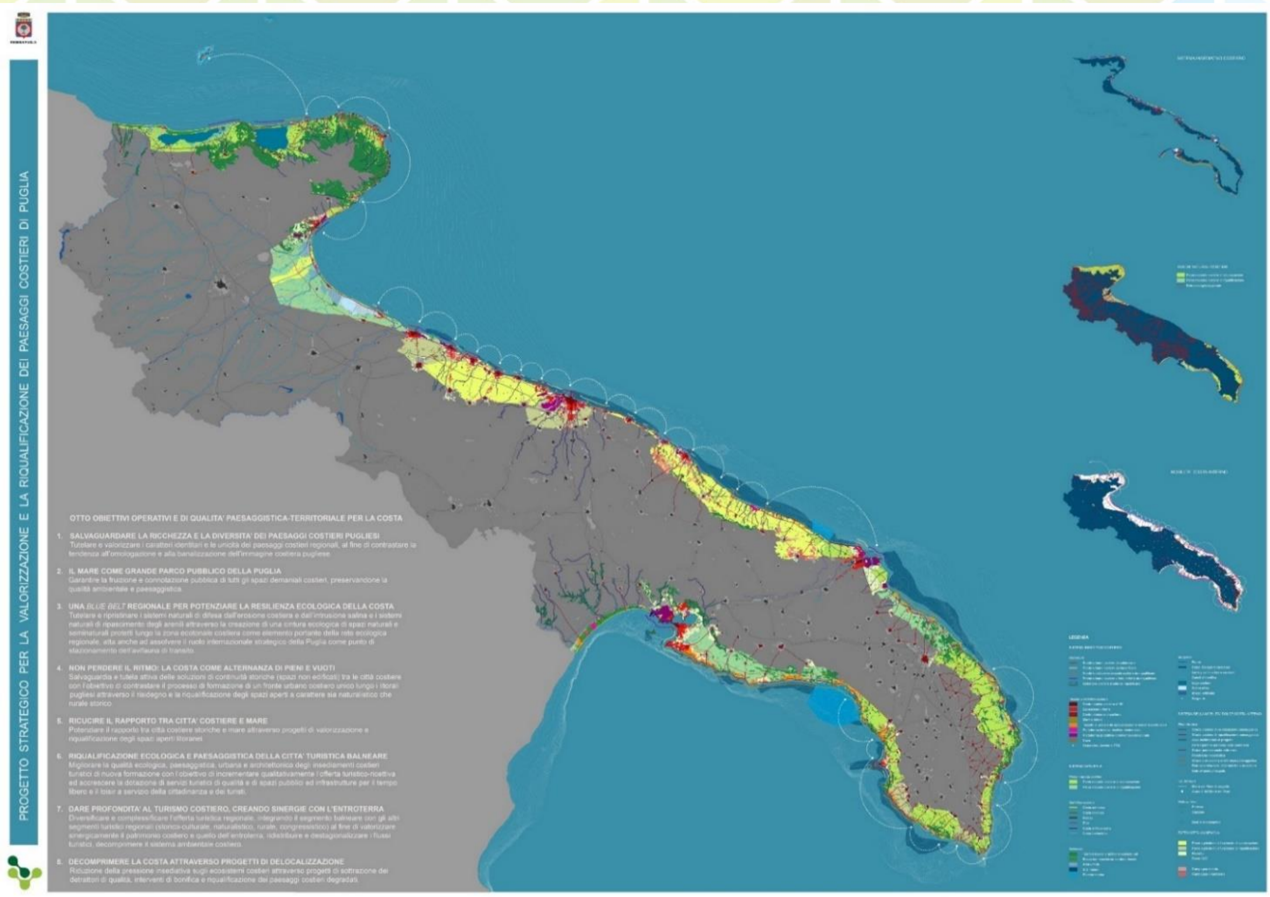

***Figure 6**: Strategic project for the enhancement and redevelopment of the Apulia coastal landscapes*

Since 1952 due to several reasons the Apulia shoreline started up to record phenomena of coastal erosion. The monitoring of Coastal Erosion in Italy started up in 1968 with De Marchi commission created by the Italian Government. The available studies on the coastal erosion support the ongoing legislative framework on Regional Coastal Plan (Regione Puglia and Politecnico di Bari, 2012), Municipality-level Coastal Plans (Regione Puglia, 2015) and the drafting of Regional Action Plan on Coastal Morphodynamism Evolution, are based on five previous studies:

a) Commissione De Marchi 1968 (Commissione Interministeriale De Marchi, 1968);
b) Atlante delle Spiagge Italiane (CNR-MURST, 1985-1997) (APAT, 2005);
c) P.O.R. Puglia 2000-2006 Regional Monitoring on Coastal Erosion (Regione Puglia, 2006);
d) MATT (Italian Ministry of Environment and Territory) Study on Coastal Management 2006 (Ministero dell'Ambiente e della Tutela del Territorio e del Mare, 2017);
e) Regional Action Plan on Coastal Management (2012) (Regione Puglia and Politecnico di Bari, 2012);

Based on the mentioned studies, which monitor the coastal erosion in the Apulia Region for a range of more than 50 years, it is possible to summarize the following main items on coastal erosion affecting Apulia Region:

1. Increasing of the state of suffering of most of the Apulian sandy beaches, mainly due to the increasing anthropic pressure, to the climatic variations that led to a change in the weather conditions;
2. Reduction of solid inputs, for the arrangement of cliffs and water courses;
3. Necessity of planning of integrated coastal management especially for physical conservation of sandy beaches, which today are subject to erosive phenomena of a structural nature.
4. Prevention of two main risks:
   - loss of state-owned public areas with high economic and environmental value;
   - destruction of natural defenses, in particular of dune systems, and of artificial defense works, with consequent potential flooding of the hinterland and damage to infrastructures and coastal settlements and industrial settlements.

Of course, it is obvious that the causes of these morphological changes are the result of a combination of factors, both natural and induced by human activities/behaviors, operating on different scales. Specifically, the studies related to the Apulia Region highlights as the most relevant natural factors are: wind and storms, coastal currents, sea level rise, soil subsidence and decrease in the solid contribution of rivers to the sea. Instead, the factors induced by man are several and include behavior such as use of the coastal strip for the construction of infrastructures and works for residential; industrial and recreational settlements; land use and vegetation alteration; the extraction of water from the subsoil; work to regulate watercourses for soil protection and for the accumulation and withdrawal of water resources for drinking, irrigation and industrial use; extraction of material (sand, gravel) from rivers; dredging, agricultural impact.

Thus, it is evident that coastal erosion and risks prevention need an integrated approach able to balance the different level of interest of stakeholders and in one shot the coastal management according to ICZM indications.

3.1.1 The Apulia region Legal Framework

At the European level, a specific legislation related to the Erosion and Coastal Management and Defence of the shoreline is not present, whereas there are conventions that examine general issues such as, for example, the protection of the sea, where the problem of coastal erosion plays a marginal role.
Also, in the national context, the legislation concerning coastal management is extremely fragmented, as it is not framed within a specific legislative framework.
In this context, with the Legislative Decree n. 112/98, the administrative tasks were assigned to the Regions, in terms of planning, integrated management of coastal defense interventions and coastal settlements, as well as the issue of state maritime concessions.
The Apulia Region, for the exercise of these functions, has equipped itself with sectorial management tools that can be summarized as follows:

- Regional Law n. 17/2015, for the protection and use of the coast;
- Regional Coastal Plan, approved by Resolution of the Regional Council of Apulia n. 2273 of 10/13/2011, which contains: 1) the reorganization and updating of technical and scientific knowledge on coastal dynamics; 2) the cognitive framework of environmental and landscape features; 3) the criteria and guidelines for the preparation of the Municipal Coastal Plans, as management tools for the relative coastal territory;
- Article 8 of the Apulia Regional Law n. 17/2007, which confers on the Province the release of the authorization pursuant to art. 109, paragraphs 2, 3 and 5, of Legislative Decree no. 152/2006 and to Article 21 of Law 31 July 2002, n. 179, in compliance with national technical regulations and regional guidelines on the immersion of sediments at sea;
- Resolution of the Regional Council of Apulia n. 410 of 10/03/2011, of approval of "Guidelines for identifying interventions aimed at mitigating the most critical situations of the low coasts of Puglia";
- Determination of the Director of the State Property and Heritage of the Apulia Region n. 371 of 16 June 2017, with which the "Guidelines for the Management of Beached Plant-derived Biomass" have been approved.

3.1.2 Hot-spot areas across the Apulia region shoreline

The present paragraph presents the description of the main criticalities affecting the Apulia shoreline, as analyzed in the 2005 -2017 timeframe, based on the database available from several contributors such as the *Region Apulia*, *Public Domain Department*, *Politecnico of Bari*, *Geologist Professional Orders*, *Italian Ministry of Environment*, *Regional Agency for Environment*, *ISPRA Italian Institute for Environmental Protection and Research*.

Specifically, within the study conducted as part of the Regional Coastal Plan for the years 1992, 2000 and 2005, an average setback of 4.6%, which is a lower value than the one reported by the APAT (Barbano et al., 2006) in the period 1950/2000 (equal to 21.4%, exceeding a 30 meters of coastline shift), was highlighted. These results indicate that the most intense erosive phenomena occurred before 1992, with a decreasing trend in the following period.

Despite the fact that the trend appears to be comforting, on the other hand coastal areas still in erosion generally coincide with those that have already suffered strong setbacks, so that further erosive actions, even if small, could determine the complete disappearance of the beach. The study also highlighted the main criticality of the erosion of sandy shores, defined as a function of three indicators: the historical evolutionary trend of the coast, the state of conservation of dune systems and the recent evolutionary trend, which records accurately the evolutionary situation along the timeline. This last indicator is highly important for regional coastal erosion monitoring system because it records accurately the evolutionary situation along the timeline. It has been implemented using the data on the retreat between the coastlines of 1992 and 2005. Taking into account the difference between shorelines of at least 10 m. Obviously, the stretches of coastline taken into consideration by the Regional Action Plan toward the highlighting of the effects of the erosive phenomenon are those characterized, in various ways, by the presence of the beach, and whose morphology is synthetically described in the following table 1.

Table 1*: Type of coastline analyzed in the frame of the Regional Action Plan on Coastal Management*

Type of coastline	Length (km)	Length (%)
Rocky coast with pebble beach	6,16	0,63
Rocky coast with sand beach	30,91	3,19
Pebble beach	9,73	1,00
Sand beach	319,48	32,92
Mixed sand-pebble beach	5,34	0,55
Cliff with sand beach	16,69	1,72
TOTAL	388,3	40

The Apulia Region, through the Regional Action Plan of 2012 and updated monitoring till 2017, analyzed the processes across different Physiographic Units (UF). In this regard it is useful to first recall the concept of U.F.- Physiographic Unit. The physiographic units identify stretches of coast where the solid transport, due to wave motion and coastal currents, is confined. In general, the U.F. is bounded by headlands and/or artificial elements (e.g. outer seawalls) whose conformations do not allow the entry and/or exit of sediments from the adjacent stretch of coast, i.e. there are greater depths than the "closure depth".

The Regional Action Plan on Coastal Management identifies 7 physiographic units, and according to the definition they encompass territories wider than the regional borders, extending from the first part from the Molo Sopraflutto in Termoli Port (Molise) till Roseto Capo Spulico (Calabria).

The seven Physiographical Units identified and the coastal municipalities belonging to them are:

U.F.1: Chieuti, Serracapriola, Lesina, Sannicandro Garganico, Cagnano Varano, Ischitella, Rodi Garganico, Vico del Gargano, Peschici, Vieste;

U.F.2: Vieste, Mattinata, Monte Sant'Angelo, Manfredonia, Zapponata, Margherita di Savoia, Barletta, Trani, Bisceglie, Molfetta, Giovinazzo, Bari;

U.F.3: Bari, Mola di Bari, Polignano a Mare, Monopoli, Fasano, Ostuni, Carovigno, Brindisi;

U.F.4: Brindisi, San Pietro Vernotico, Torchiarolo, Lecce, Vernole, Melendugno, Otranto;

U.F.5: Otranto, Santa Cesarea Terme, Castro, Diso, Andrano, Tricase, Tiggiano, Corsano, Alessano, Gagliano del Capo, Castrignano del Capo, Patù, Morciano di Leuca, Salve, Ugento, Alliste, Racale, Taviano, Gallipoli;

U.F.6: Gallipoli, Sannicola, Galatone, Nardo, Porto Cesareo, Manduria, Maruggio;

U.F.7: Maruggio, Torricella, Lizzano, Pulsano, Leporano, Taranto, Massafra, Palagiano, Castellaneta, Ginosa.

As analyzed in the frame of the PRC, Figure 6 depicts the evolution of the Apulian shoreline across the seven U.F. (retreating coast in red and advancing in green) between the 2005 -2017 timeframe and within a buffer zone of 10 m from the coastline. As can be observed, the first three U.F. (among the seven identified in the PRC), from the municipalities of Chieuti to Gallipoli, have experienced the greater differences in the shoreline evolution compared to the last ones.

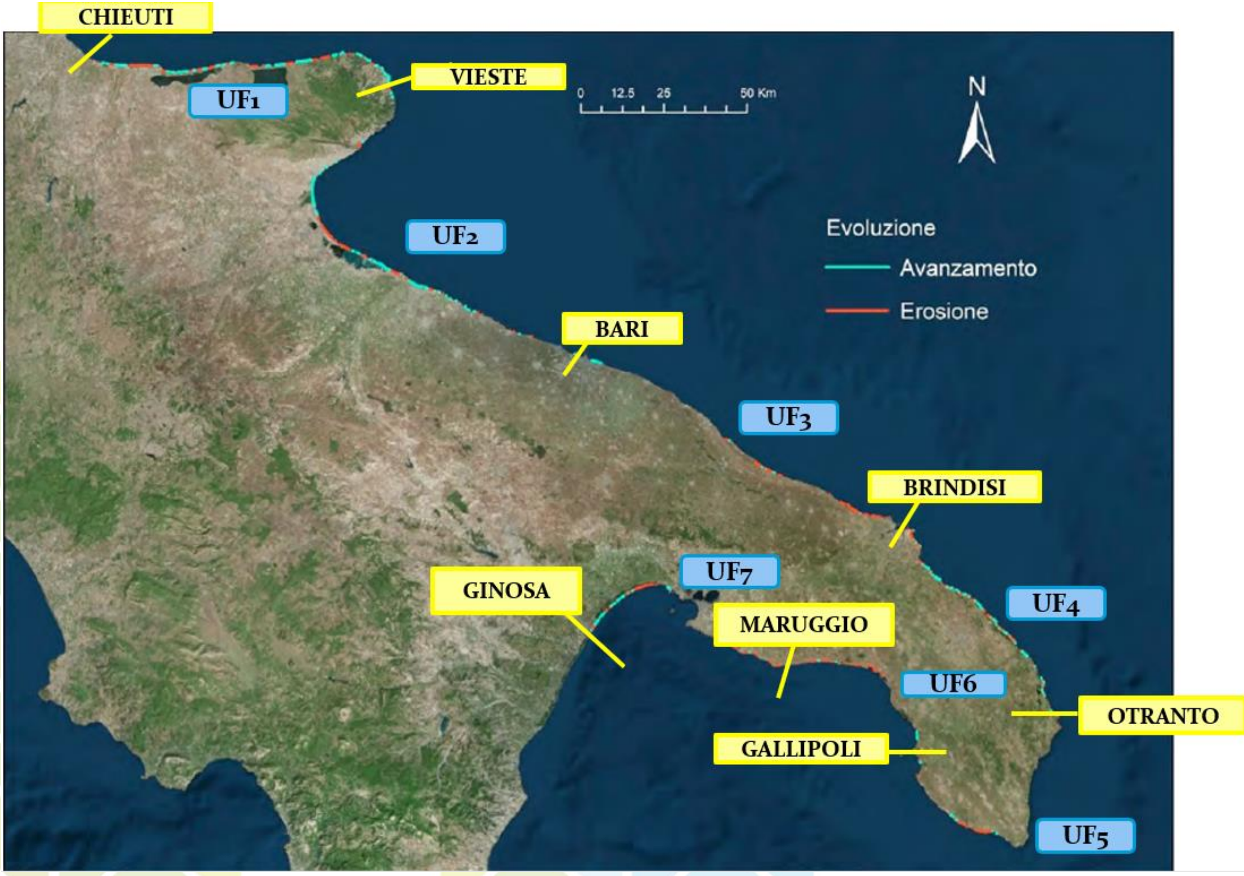

***Figure 7**: Shoreline evolution between 2005 and 2017 timeframe and within a 10m buffer zone from the coastline (Regione Puglia, 2018)*

Specifically, in the analyzed period (2005-2017) and 10m-wide buffer zone, 129 km of sandy coast (33.2%) were affected by erosion, 84 km (21.6%) advanced and 175 km (45.2%) remained almost stable. Table 2 reports the results ofthis analysis, highlighting the evolution trend for each U.F.. As can be observed, UF6 and UF7 (from Gallipoli to Ginosa), result less affected by the erosive phenomenon compared to the other physiographic units, since about the 70% of the sandy coast is stable or advancing. In UF3 (from Bari to Brindisi) and UF5 (from Otranto to Gallipoli), numerous retreating stretches were observed, so much as the percentage of stable or advancing coastline is just over the 50%. The same pattern can be recognized for the UF1 (from Chieuti to Vieste), with an overall situation less critical due to the higher rate of advancing coast (about 31%).

***Table 2**: Evolution trend of sandy coasts in the 2005-2017 timeframe (10m range)*

EVOLUTION 2005 – 2017 (10m range)							
Physiographic Unit	**Sandy coast (km)**	**Retreating (km)**	**Advancing (km)**	**Stable (km)**	**Retreating (%)**	**Advancing (%)**	**Stable (%)**
UF1	82.10	32.5	25.30	24.30	39.59	30.82	29.59
UF2	77.67	24.80	24.80	28.07	31.93	31.83	36.14
UF3	40.75	17.60	3.80	19.35	43.19	9.33	47.48
UF4	65.17	20.80	18.30	26.07	31.92	28.08	40.00
UF5	16.44	7.44	3.65	5.36	45.25	22.18	32.57
UF6	50.06	11.49	1.39	37.19	22.95	2.77	74.29
UF7	56.13	14.20	6.60	35.33	25.30	11.76	62.94
Total	**388.31**	**128.83**	**83.83**	**175.65**	**33.18**	**21.59**	**45.23**

As a more detailed analysis, the following Table 3 shows for each coastal municipalities of the Apulia Region the part of coast affected by retreat in a range of 10 meters.

***Table 3**: Retreating coasts per municipalities within the 2005-2017 timeframe (10m range)*

PROVINCE	**MUNICIPALITY**	**TOTAL LENGTH (m)**
FOGGIA	Chieuti	1736
	Serracapriola	7413
	Lesina	9593
	Sannicandro Garganico	233
	Cagnano Varano	1973
	Ischitella	1631
	Rodi Garganico	2927
	Vico del Gargano	2413
	Peschici	921
	Vieste	3666
	Mattinata	1593
	Monte S.Angelo	122
	Manfredonia	1787
	Zapponeta	9370
BARLETTA-ANDRIA-TRANI	Margherita di Savoia	5351
	Barletta	4501
	Trani	313
	Bisceglie	613
BARI	Molfetta	593
	Giovinazzo	375
	Bari	230
	Monopoli	939
BRINDISI	Fasano	3127
	Ostuni	3020

PROVINCE	MUNICIPALITY	TOTAL LENGTH (m)
	Carovigno	2945
	Brindisi	12746
	S. Pietro Vernotico	1204
	Torchiarolo	1001
LECCE	Lecce	7291
	Vernole	4236
	Melendugno	524
	Otranto	1437
	Salve	4562
	Ugento	2878
	Gallipoli	243
	Nardò	49
	Porto Cesareo	5216
TARANTO	Manduria	4023
	Maruggio	1955
	Torricella	639
	Lizzano	885
	Fraz. di Taranto	905
	Pulsano	893
	Massafra	2882
	Palagiano	4775
	Castellaneta	1776
	Ginosa	1459
TOTAL Km		**129**

In addition to the 10-meters analysis, as depicted in Figure 7, a more in-depth evaluation with a 30-meter range was also developed, in order to identify high level criticalities focusing exclusively on retreating coast already identified within the 10-m range analysis (129 km of Apulia shoreline).

These are areas well-known for suffering high criticalities, and the presence of erosive processes had already been amply demonstrated in the course of previous studies, such as the Commissione De Marchi, Atlas of Italian beaches, P.O.R. Puglia and MATT.

Table 4 shows the values of retreating, advancing and stable sandy coasts for the 30 meters-wide buffer zone.

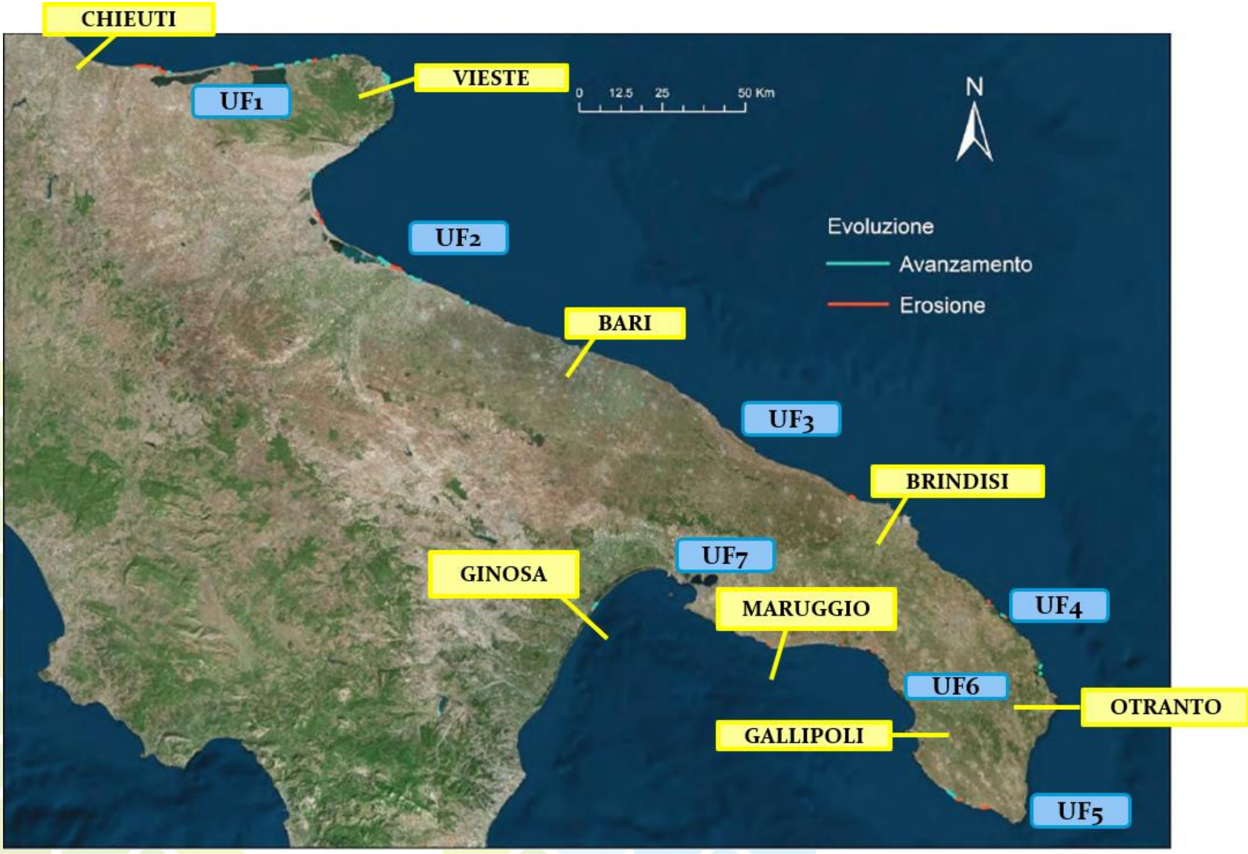

***Figure 8**: Retreating and advancing coast evolution between 2005 and 2017 (30m range) (Regione Puglia, 2018)*

***Table 4**: Evolution trend of sandy coasts in the 2005-2017 timeframe (30m range)*

EVOLUTION 2005 – 2017 (30m range)							
Physiographic Unit	**Sandy coast (km)**	**Retreating (km)**	**Advancing (km)**	**Stable (km)**	**Retreating (%)**	**Advancing (%)**	**Stable (%)**
UF1	82.10	13.1	10.6	58.40	15.96	11.91	71.13
UF2	77.67	6.5	8.9	62.27	8.37	11.46	80.17
UF3	40.75	1.7	0	39.05	4.17	0	95.83
UF4	65.17	1.8	2.1	61.27	2.76	3.22	94.02
UF5	16.44	3.8	2.9	9.74	23.11	17.64	59.25
UF6	50.06	1.6	0	48.46	3.20	0	96.80
UF7	56.13	1.3	1.7	53.13	2.32	3.03	94.65
Total	**388.31**	**29.8**	**26.2**	**332.31**	**7.67**	**6.75**	**85.58**

As a more detailed analysis, the following Table 5 shows, for each coastal municipalities of the Apulia Region, the length and surface of retreating coasts within a 30 meters range.

***Table 5**: Retreating coasts per municipalities within the 2005-2017 timeframe (30m range)*

Province	Municipality Location	UF	Erosion Type	Length (M)	Area (M²)	Type of Coastline
FOGGIA	**Serracapriola** Foce Fortore	1	Coastal Process	5287,9	168049,8	Sandy
	Lesina Sud di Acquarotta	1	Coastal Process	2909,4	58533,9	Sandy
	Cagnano Varano Sud di Capoiale	1	Coastal Process	2370,5	49867,9	Sandy
	Rodi Garganico Est del porto	1	Coastal Process	1987,2	28370,2	Sandy
	Vieste Torre di Porto Nuovo	1	Integrate Dynamics	572,4	14109,5	Sandy
	Manfredonia Ippocampo	2	Coastal Process	1546,4	31851,9	Sandy
	Zapponeta Foggiamare	2	Coastal Process	1378,5	19450,3	Sandy
BARLETTA-ANDRIA-TRANI	**Margherita di Savoia** Foce Ofanto	2	Coastal Process	3629,1	177960,0	Sandy
BRINDISI	**Brindisi** Apani	3	Coastal Process	1752,5	26381,9	Rocky with sandy beaches on foot
LECCE	**Vernole** Riserva Naturale Le Cesine Pantano Grande	4	Coastal Process	1059,6	18187,9	Sandy
	Lecce Nord Darsena di S. Cataldo	4	Coastal Process	775,4	8301,2	Sandy
	Salve Pescoluse	5	Coastal Process	2203,5	25456,7	Sandy
	Ugento Torre Mozza	5	Coastal Process	1585,6	44796,2	Sandy

Province	Municipality Location	UF	Erosion Type	Length (M)	Area (M^2)	Type of Coastline
	Porto Cesareo Sud di Bacino Grande	6	Coastal Process	1168,2	14641, 7	Sandy
TARANTO	**Manduria** Palude del Conte	6	Coastal Process	436,1	12106, 8	Sandy
	Torricella Torre Ovo	7	Coastal Process	638,7	4760,9	Rocky with sandy beaches
	Ginosa Foce Galaso	7	Mouth dynamic	699,6	6070,4	Sandy
TOTAL in km and km²				**29,8**	**0,71**	

The increase in the length of the coastline in erosion can be only partially attributed to the extension of the phenomenon to stretches closest to beaches already presenting critical situations (e.g. Foce Fortore, Foce Ofanto, Lecce, Cesine, Torre Mozza). More often has been observed the appearance of new coastal stretches suffering a retreating trend (eg. Rodi Garganico, Torre Canne, Torre Guaceto, Porto Cesareo, Salve, Aco Ionico) (Regione Puglia, 2018).

3.1.3 Available data at the case study level

The implementation of risk-based methodologies requires the collection and processing of a huge amount of heterogeneous information, including data from climate and hydrodynamic models to characterize hazard scenarios, as well as land-use dataset supporting the identification and characterization of potentially exposed targets and their vulnerabilities. Accordingly, with the main aim of evaluating coastal erosion risks in the Apulia shoreline case study, an in-depth research and collection of GIS-based dataset was performed, paying specific attention on their spatial resolution and homogeneous coverage for the area of concern. A variety of physical and environmental data, as well as data on main natural (e.g. currents, storms, winds) and anthropogenic drivers (e.g. localization of settlements and infrastructures, agricultural activities) were retrieved, in order to spatially characterize the main stressors contributing to coastal erosion processes in the case study and identify potentially exposed targets. Data collected for the Apulia region shoreline are summarized in the Table 6, detailing metadata based on the following criteria: a) Data type, b) Spatial domain, c) Year of data release/update, d) Spatial resolution, e) Timeframe and Scenario, f) GIS data format and g) Literature reference or dataset link to web-based platforms.

As a first-pass screening of available data for the case study, European open-source web data portals were explored. Specifically, topographic data (i.e. Digital Elevation Model EU-DEM), as well as socio-economic information concerning the land use pattern (e.g. Corine Land Cover map, localization of main infrastructures) were retrieved from the Copernicus services (e.g. Land Monitoring, Urban Atlas; www.copernicus.eu). Moreover, other relevant geological (e.g. soil types), environmental (e.g. protected areas under the Natura 2000 directive) and base map data (i.e. coastline and administrative boundaries) were collected from the data catalogue of the European Environmental Agency (EEA; www.eea.europa.eu), making available a wide array of data for environmental assessment and management. As far as climate forcing contributing to coastal erosion processes is concerned, EU-scale data were collected from the Joint Research Centre Data Catalogue, providing extreme storm surge level and extreme sea level scenarios for the historical period (1969-2004) and future timeframe (2009-2099), according to the RCP4.5 and 8.5 emission scenarios, developed in the frame of the LISCoAsT project (Large Scale Integrated Sea-level and Coastal Assessment Tool; https://data.jrc.ec.europa.eu/collection/LISCOAST). The main source of data concerning the population distribution and age has been the data portal of the Italian National Institute of Statistics (ISTAT; http://dati.istat.it), providing GIS and tabular-based data updated at the 2018 (ISTAT, 2018). More detailed geological and geomorphological information (e.g. coastal types), as well as local scale topographic data for the Apulian shoreline (i.e. Laser Imaging Detection and Ranging – LIDAR data) were instead retrieved from the National Geoportal (www.pcn.minambiente.it) of the Italian Minister of the Environment.

***Table 6**: Metadata of the dataset available for the implementation of risk-based methodologies in the Apulia shoreline case study*

Data type	Spatial domain	Year	Spatial resolution	Time-frame Reference period	GIS Data Format	Reference/Link
Basemap data						
Administrative Boundaries	World	2015	/	/	Shape	http://gadm.org
Coastline	Europe	2015	/	/	Shape	https://www.eea.europa.eu/data-and-maps/data/eea-coastline-for-analysis-1
European Reference Grid	Europe	2011	1 km, 10 km, 100 km (plus 15 km buffer)	/	Shape	https://www.eea.europa.eu/data-and-maps/data/eea-reference-grids-2
Bathymetry	Adriatic Sea	2018	200 m	/	Raster	http://www.emodnet-bathymetry.eu/metadata-amp-data/composite-dtms-catalogue-service#/metadata/SDN_CPRD_145_DTM_CNR-ISMAR-22
Topographic data						
Digital Elevation Model (EU-DEM v1.1)	Europe	2016	25 m	/	**GeoTIFF**	http://land.copernicus.eu/pan-european/satellite-derived-products/eu-dem/eu-dem-v1.1
LIDAR	Italy	2016	15 cm	/	Shape	http://www.pcn.minambiente.it/mattm/en/online-the-new-procedure-for-the-request-of-lidar-data-and_or-interferometric-ps/
Climate forcing						
Sea level	Apulia region				Raster	https://start.linksmt.it/web/guest/coste
Sea temperature	Apulia region				Raster	https://start.linksmt.it/web/guest/coste
Sea salinity	Apulia region				Raster	https://start.linksmt.it/web/guest/costeS
Sea surface currents	Apulia region				Raster	https://start.linksmt.it/web/guest/costeS
Wave height and direction	Apulia region				Raster	https://start.linksmt.it/web/guest/coste
Marine circulation along main ports	Apulia region				Raster	https://start.linksmt.it/web/guest/coste
Extreme Sea Level and Extreme Storm Surge Level	Europe	2017	~ 11 km	Historical: 1969-2004 Future: 2009-2099 under RCP8.5, 4.5	NetCDF	http://data.jrc.ec.europa.eu/dataset/jrc-liscoast-10012
Geomorphological data						
Erosion of the coast	Apulia region			5/10/15 years		https://start.linksmt.it/web/guest/coste
Shoreline trend	Europe					https://www.eea.europa.eu/data-and-maps/data/geomorphology-geology-erosion-trends-and-coastal-defence-works
	Italy	2010	1:2000	/	Shape	http://www.pcn.minambiente.it/geoportal/catalog/search/resource/details.page?uuid=%7BC49FEE18-000C-4B37-B062-E76BCAD5104F%7D
Environmental data						
Protected areas	Europe	2017	/	/	GeoTIFF	https://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-13
Transportation of sediments	Apulia region					https://start.linksmt.it/web/guest/coste

Data type	Spatial domain	Year	Spatial resolution	Time-frame Reference period	GIS Data Format	Reference/Link
Soil type	Europe	2006	1 km x 1 km	/	Raster	https://esdac.jrc.ec.europa.eu/content/european-soil-database-v2-raster-library-1kmx1km
Biodiversity/ Natura 2000	Europe	2018		/	Raster	https://www.eea.europa.eu/data-and-maps/data/natura-10
Nationally Designed Areas	Europe	2017	/	/	Shape	https://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-12#tab-gis-data
Socio-economic data						
Land cover	Europe	2018	500 m	CLC2018	GeoTIFF	https://land.copernicus.eu/local/urban-atlas
Urban Atlas	Europe	2012		/	Raster	https://land.copernicus.eu/local/urban-atlas/urban-atlas-2012/view
Settlement	Europe	2012 (released in 2017)	2.5 m pixel	2006-2012	Raster	https://land.copernicus.eu/pan-european/GHSL/european-settlement-map/esm-2012-release-2017-urban-green
Population and building census	Italy	2018	/	2018	Shape	https://www.istat.it/it/archivio/104317#accordions
Population projections	Italy	2018	/	2017-2065	Shape	http://dati.istat.it/Index.aspx?DataSetCode=DCIS_PREVDEM1

Other useful data were retrieved by exploring European and national projects dealing with the analysis of coastal erosion processes and ICZM (e.g. EUROSION, PEGASO, etc.). Among these, the largest amount of data concerning climate related forcing were retrieved from the web-data portal of the START project (*SisTemi di rApid mapping e contRollo del Territorio costiero e marino*; https://start.linksmt.it/), a national project aimed at providing a decision support system for coastal and port monitoring and planning activities along the Apulian coasts as well as an early warning system for climate extreme events. Specifically, the web-GIS of the project makes available a wide array of information including sea and morphological observational data, sea forecast (i.e. height, period and direction of waves, sea temperature, surface currents, wave height and direction, marine circulation along the ports, sea level, sea surface salinity) and atmospheric data (i.e. air temperature, winds to 10 meters, surface pressure, cloud cover, precipitation).

Another relevant source of data has been the web-data portal of the EUROSION project (www.eurosion.org), providing EU-scale environmental data (e.g. sediment flows, shoreline erosion trend, areas of high ecological value), socio-economic information (e.g. localization of main infrastructures and coastal artificial protections, land cover and land cover changes since 1975) and base-map layers (i.e. maritime and shoreline boundaries). Finally, other local-scale data were acquired from the Regional Coastal Plan (PRC) of the Apulia region, making available in the web-data portal of the region (www.sit.puglia.it/portal/portale_pianificazione_regionale/PRC) the GIS-based maps used for the analysis of shoreline evolution in the 2005-2017 timeframe (e.g. shoreline boundaries, hydrological network, land-use).

3.2 The Messolonghi shoreline, Greece

The study area of the present report is situated along the shoreline of the Municipality Ieras Poleos Messolonghiou. It belongs geographically to the western Greece, in the south of the prefecture of Aitoloakarnania, one of the regional units of Greece. It is part of the geographic region of Central Greece and the administrative region of Western Greece. More precisely, the study is focused in the southern coastline of the Municipality Ieras Poleos Messolonghiou situated at the north-western part of the Patraikos Gulf (Western Greece). The study area includes the Messolonghi lagoon system, covering an area of 11,200 ha, the Aitolikos Lagoon with a total area of 1,400 ha, as well as other lagoons, such as Kleisova in the east (3000 ha) and west of the Gournopoulo and Palaeopotamos (800 ha) (Figure 8). This complex lagoonal system is among the largest in the Mediterranean Sea, with a surface of about 150 km2 and has been formed through the siltation action of adjacent rivers, the Acheloos and Evinos (Leonardos & Sinis, 1998). The silled deep basin (about 27.5 m), Etolikon lagoon, lies at the northern part of this complex and is of tectonic origin. The lagoon is connected with the typically shallow Messolonghi lagoon (maximum depth ~1.5 m), through a 1.2 m deep and 170 m wide sill (Gianni & Zacharias, 2012). The Messolonghi lagoon comprises the central and southern part of the lagoon system and connects to the south with the Patraikos Gulf. The Kleisova lagoon is located at the eastern part of this complex and is characterized by a great number of saltworks which occupy an area of 12.4 km^2.

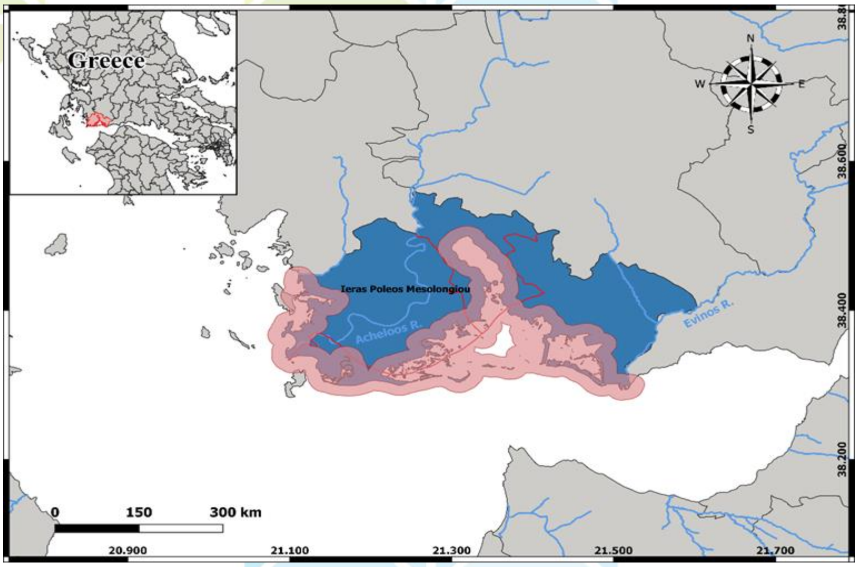

Figure 9: Map of the boundaries of the Municipality Ieras Poleos Messolonghiou, with highlighted the coastal study area

In addition, the area of interest was divided into four sub-areas focusing on the coastlines of each area for further investigation, as is shown in Figure 9. This division was based on the specific characteristics of each sub-area since Louros and Alikes (Tourlida and Alikes beach) sites are characterized by sandy beaches, Louronisides site (Prokopanistos, Schinias, Komma) has many fish farms, while Evinos estuary has a very dynamic and complex coastline system. Furthermore, all sub-areas were divided into smaller cells according to Copernicus Marine Environmental Monitoring Service (CMEMS) models' discretization. The coordinates of the center of each cell was fed to an innovative algorithm tool in order to retrieve historic oceanographic and meteorological data along the coastlines of the TRITON Greek study area.

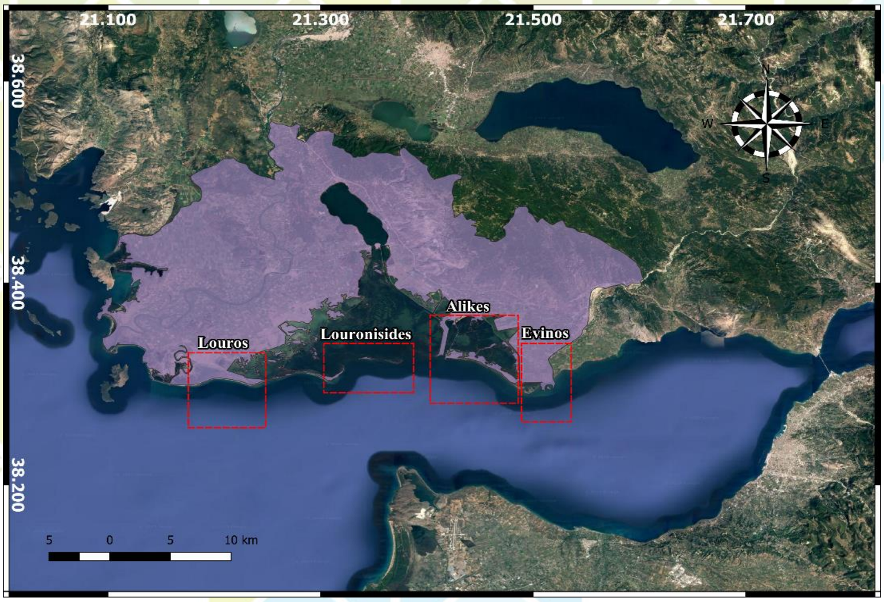

***Figure 10**: Sub-areas as divided along the study area (coastline of the Municipality Ieras Poleos Messolonghiou)*

Sub- areas characteristics are described into the following Table 7.

***Table 7**: Geographic description of TRITON Greek study areas.*

Site Name	Length (km)	Western point Latitude	Western point Longitude	Eastern point Latitude	Eastern point Longitude
Louros	4.90	38°17'55.25"N	21°10'51.42"E	38°17'54.66"N	21°14'3.39"E
Louronisides					
Prokopanistos	2.40	38°18'9.23"N	21°18'21.86"E	38°19'5.79"N	21°19'16.08"E

Schinias	1.50	38°19'29.74"N	21°20'10.71"E	38°19'30.75"N	21°21'7.28"E
Komma	1.73	38°19'25.27"N	21°21'39.38"E	38°19'25.53"N	21°22'33.96"E
Alikes					
Tourlida	0.42	38°19'29.02"N	21°25'3.95"E	38°19'30.08"N	21°25'16.05"E
Alikes	7.20	38°19'30.44"N	21°25'16.96"E	38°17'41.45"N	21°29'12.80"E
Evinos	3.51	38°17'25.78"N	21°29'45.11"E	38°18'37.22"N	21°31'24.04"E

3.2.1 Available data at the case study level

In this study, data from several databases were retrieved and utilized for the intervention area. More precisely, meteorological data (such as wind speed, wind direction and precipitation) were retrieved from Copernicus Atmosphere Monitoring Service (CAMS) and Global Precipitation Climatology Centre (GPCC). Oceanographic data (such as currents, waves and water temperature) were retrieved from Copernicus Marine Environmental Monitoring Service (CMEMS) and the mass concentration of particulate (inorganic) matter in seawater (SPM) and chlorophyll-a concentration were derived from level 3 satellite images (MODIS, Sentinel).

Geomorphology

Messolonghi study site is characterized from a system of coastal lagoons connected to the Patraikos Gulf with several straights. Moving to the inland the topography of the study area is characterized as flat agricultural land and the altitude is increased at several kilometers from the coastline to the hinterland where hills and low mountains are formed (Lagkadinou, 2005).

Moreover, several small plains with small slopes created by the silt depositions from rivers Evinos and Acheloos, such as the plains of Evinochori, Neochori and Katochis and larger slopes occurred at the foothills of the hills such as Ag. Elias, Chrysovergion, Kefalovrysos, Agrilia, Ag. Thomas etc. and at the foothills of Mountain Zygos (Mount Arakinthos).

At the higher altitudes of the study area, Varasova mountain (982 m) and Elliniko mountain (652 m) and the Psili Panagia hill (601 m) are observed while several hills with lower altitude are also observed (Lagkadinou, 2005).

Bathymetric data

The bathymetry of the study area was derived from the EMODnet Hydrography portal (http://www.emodnet-hydrography.eu). This portal was initiated by the European Commission as part of the development of the European Marine Observation and Data Network. EMODnet bathymetry is composed of a multitude of datasets from a multitude of data providers. Users of the resulting grid and associated datasets need to be able to evaluate at the grid node level the quality of the bathymetric data and product they will be using.

For each maritime region bathymetric survey data and aggregated bathymetry data sets have been collated from public and research organizations. These have been processed and quality controlled and used to produce the regional Digital Terrain Models (DTMs). Thereafter, these have been integrated into the EMODnet DTM for European seas.

The 2018 DTM version has a grid size of 1/16 × 1/16 arc minutes, where each grid cell has the following information:

- x, y coordinates,
- minimum water depth (m),
- average water depth (m),
- maximum water depth (m),
- standard deviation of water depth (m),
- number of values used for interpolation over the grid cell,
- interpolation flag (identification of extrapolated cells),
- average water depth smoothed by means of a spline function (m),
- an indicator of the offsets between the average and smoothed water depth as the percentage of the water depth,
- reference to the prevailing source of data with metadata.

The DTM values have been determined from 4 possible sources of data:

- Bathymetric survey data: high resolution data sets from single and multibeam surveys that are referenced via the CDI Data Discovery and Access service,
- Digital Terrain Model data: composite data sets produced and delivered by a number of external data providers such as Hydrographic Offices derived from their internal bathymetric database and based upon historic surveys. The aggregated data sets are referenced via the Sextant Catalogue service,
- Satellite Derived Bathymetry data: composite data sets produced from Landsat 8 images, in particular for the coastal stretches in Greece and Spain. The SDB data sets are referenced via the Sextant Catalogue service,
- GEBCO 2014 30” gridded data, used to complete area coverage in case there are no survey data or composite data sets available to the partners.

According to EMODnet bathymetry the coastal zone of the study area is characterized by small depth in the breaking zone (under 10 m). This data can be found in Figure 10 where maximum depth is in the area southern of Evinos site (about 110m). Moreover, further analysis on retrieved bathymetry data shows low seabed slope which is estimated around 2% in the near coast area (Figure 11).

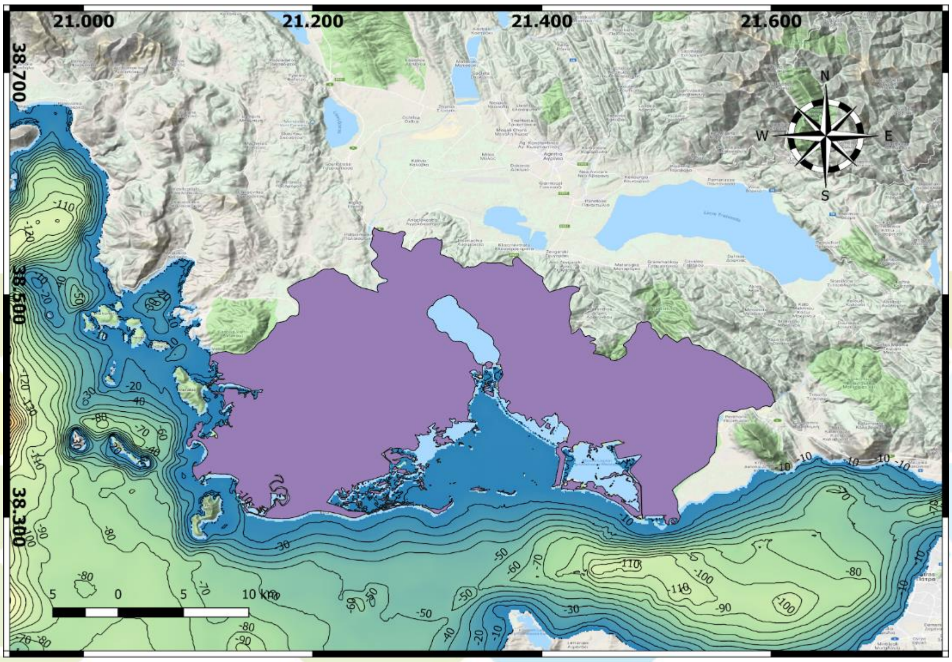

Figure 11: Bathymetry of the Patraikos Gulf and the area close to the Municipality Ieras Poleos Messolonghiou

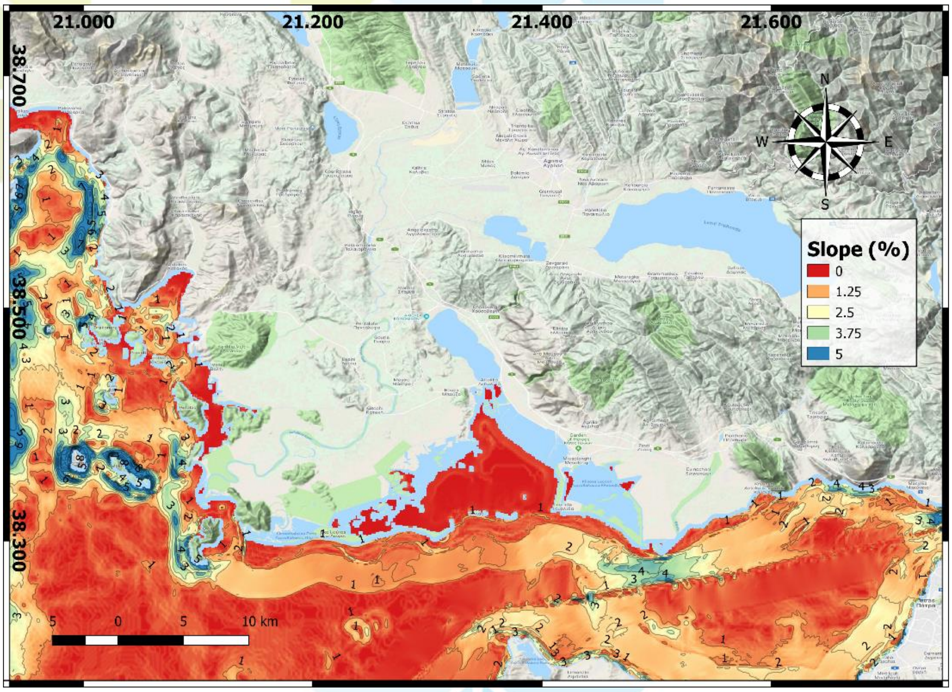

Figure 12: Bottom slopes calculated from bathymetric data. Patraikos Gulf and the area close to the Municipality Ieras Poleos Messolonghiou

Land cover data

CORINE Land Cover (CLC) is one of the most well-known and used products retrieved from the Copernicus Land Monitoring Service. There are many editions previously produced (1990, 2000, 2006 and 2012) but in the present study 2018 edition was used. It consists of an inventory of land cover in 44 classes. CLC uses a Minimum Mapping Unit (MMU) of 25 hectares (ha) for areal phenomena and a minimum width of 100 m for linear phenomena. The time series are complemented by change layers, which highlight changes in land cover with an MMU of 5 ha. Different MMUs mean that the change layer has higher resolution than the status layer. Due to differences in MMUs the difference between two status layers will not equal to the corresponding CLC-Changes layer. It is produced with assistance from the European Environment Agency's Eionet network that contributed their own data, collected mainly by visual interpretation of high-resolution satellite imagery. In a few countries semi-automatic solutions are applied, using national in-situ data, satellite image processing, GIS integration and generalization. CLC has a wide variety of applications, underpinning various Community policies in the domains of environment, including agriculture, transport, spatial planning, etc.

According to the updated version of the CORINE Land Cover 2018, the coastal zone of the Municipality Ieras Poleos Messolonghiou is consisted by a system of coastal lagoons and sandy beaches. The agricultural lands located close to Acheloos and Evinos river basins are characterized as permanent irrigated land (212). Additionally, 20% of the Prefecture is covered by forests consisting of oak trees at 31%, broadleaf and broadleaf trees at 50% and fir trees at 19%.

In the are close to the coastal zone of the study area, from west to east, salt marshes are situated close to Acheloos riverbanks (code 421), and sandy beaches and dunes (code 331) are formed in the front coastal zone separating Patraikos Gulf from the complex coastal lagoons system (code 521) of Messolonghi Lagoon (Figure 12). The main land use in the prefecture of Aitoloakarnania is for agricultural and livestock production. The irrigated areas of the prefecture are 513,500 acres with total irrigation water needs 340 hm3, covered mainly by Lake Lysimachia and Acheloos River. An extensive irrigation network, as well as direct pumping of water from the water deposits is being used. These permanent irrigated areas can be found close to the two rivers of the study area (Acheloos and Evinos river) with areas of 4,749.87 ha and 125.35 ha, respectively.

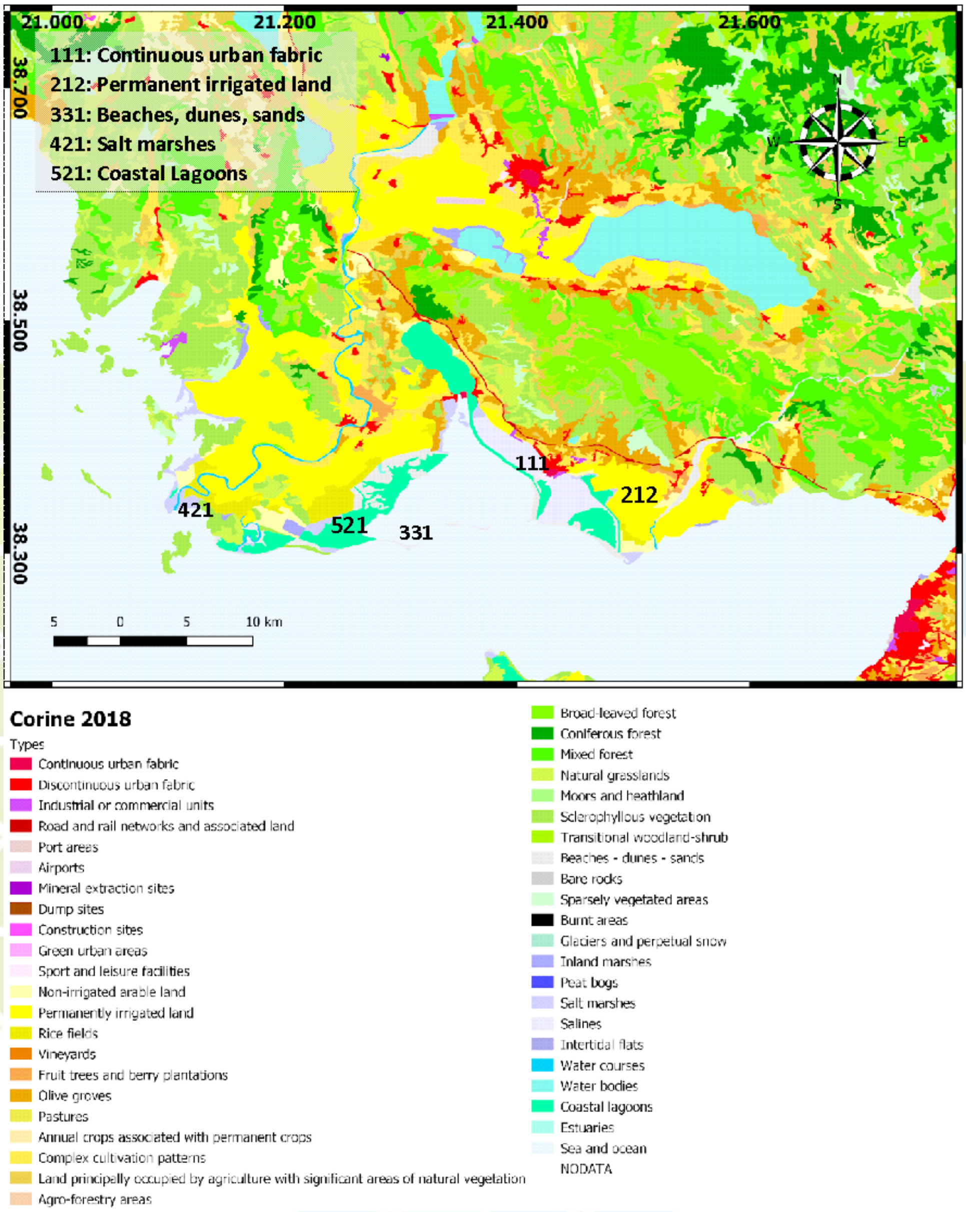

***Figure 13**: Corine land cover of the Municipality Ieras Poleos Messolonghiou*

River discharge data

The main hydrological systems of the study area are the water catchment areas of the two major rivers: Acheloos and Evinos. The total catchment area of the Municipality Ieras Poleos Messolonghiou is estimated around 3,500 km^2. The system is primarily discharged into the Acheloos and Evinos basins, as well as to the lakeside and lowland sources of Trichonida and to the seaside or submarine sources. The total estimated underground runoff is around 70 m^3/s (Kourmoulis, 1984;

Koutsogiannis et al., 1995; Papaspyropoulos, 1981). From the literature, Acheloos is the river with the highest discharge compared to the rest Greek rivers. It flows through the prefecture of Aitoloakarnania with a total length of 220 km before it empties into the Ionian Sea. Evinos is a 92 km long river in the eastern section of the study area, which flows in a southwestern direction and it empties into the Patraikos Gulf, 10 km southeast of Messolonghi town. Moreover, in the water district of the prefecture of Aitoloakarnania there are also the natural lakes Trichonida and Lysimachia, as well as smaller lakes (Ozeros and Amvrakia) that feed the study area (Ministry of Environment and Public Works, 1995).

Discharge data for these two rivers were retrieved from the database which has been developed from SHMI, Hydrological Predictions for the Environment (HYPE). HYPE model is a dynamic, semi-distributed and process-based hydrological and nutrient transport model (Lindström et al., 2010) which can be used to assess water quantity and quality on small and large scale. E-HYPE, created by regulating HYPE model for pan-European, calculates water balance, hydrological processes (snow, glaciers, soil moisture, flow path, contribution of groundwater and lakes) and sea discharges for the area from the British Isles to the Ural Mountains, Norway to the Mediterranean (9.6 million km^2). E-HYPE is an operational high-resolution model that generates data with a daily time step. The internal model components are checked and calibrated with observational data in different areas. E-HYPE models the flow in daily time scale and provides topographical, precipitation, temperature, evapotranspiration, land cover, soil type, lake, river network-basins and flow data used in modeling from global/continental databases and satellite products. E-HYPE is an open-access web service, from where any user can easy download daily flow rates (m^3/s) for any sub-basin across Europe. The model which is being used to study the effects of climate and land-use change on water resources, can also be considered in operational runoff forecasting studies for the early warning service and the hydropower sector. Using reliable quality input data, the model undergoes calibration and verification processes according to sound scientific principles (Arheimer et al., 2011). As can be shown in the Figure 12 below, the study area consists of seven sub-basins. Six of them outflow to the coastal zone of the Municipality. As mentioned above, river discharge data for these sub-basins were retrieved from E-Hype model database for the period 1981 to 2010 and were further processed and analyzed (Figure 13). Based on Figure 13, Acheloos discharge is almost 5 times higher than that of Evinos river flow, with a minimum value of 35 m^3/s during the summer months. Furthermore, due to the damming of Evinos river, discharge is near-zero during the summer months.

In addition, physicochemical parameters were retrieved from the same database, such as water temperature and nutrients (Figures 14 - 19). Despite the higher discharge values of Achellos river, flowing towards the Patraikos Gulf, the nutrient fluxes from R. Evinos have constant higher values, with the minimum values in most records being much higher than those of R. Acheloos.

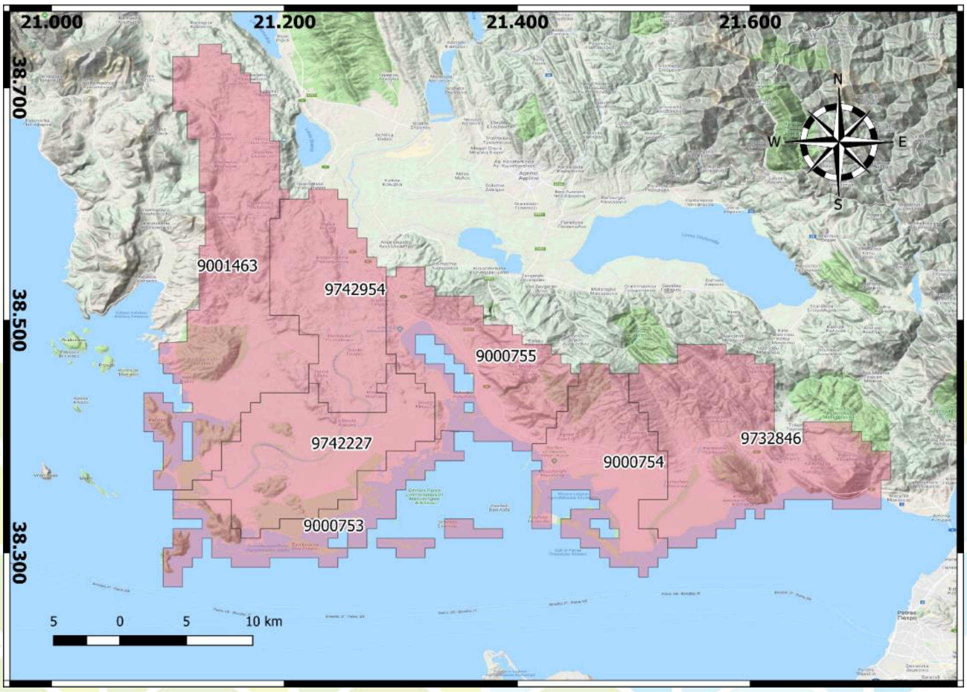

***Figure 14**: Hydrological Sub-basins as defined on HYPE model in the area of the Municipality Ieras Poleos Messolonghiou*

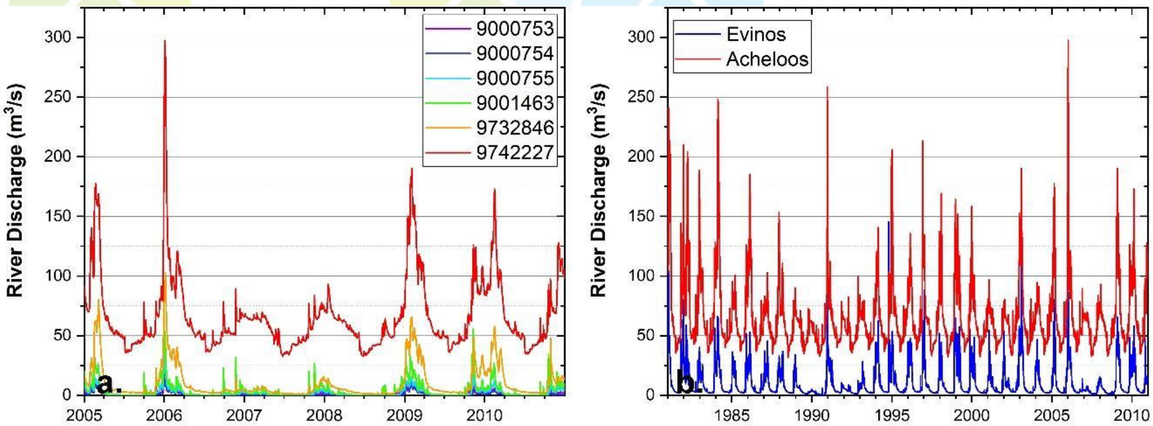

***Figure 15**: Temporal variability of daily discharge of a) each sub-basin as retrieved from HYPE database and b) of Acheloos and Evinos rivers*

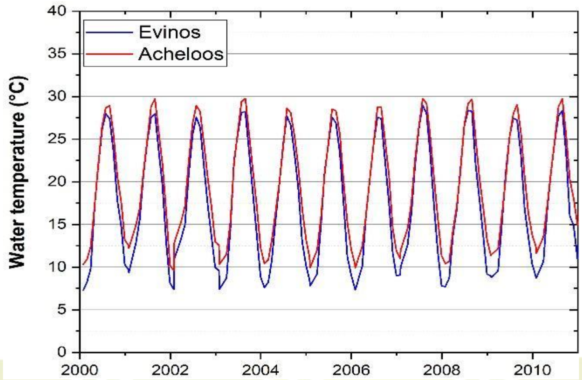

Figure 16*: Temporal variability of daily Water Temperature of Acheloos and Evinos rivers for the period 2000-2010*

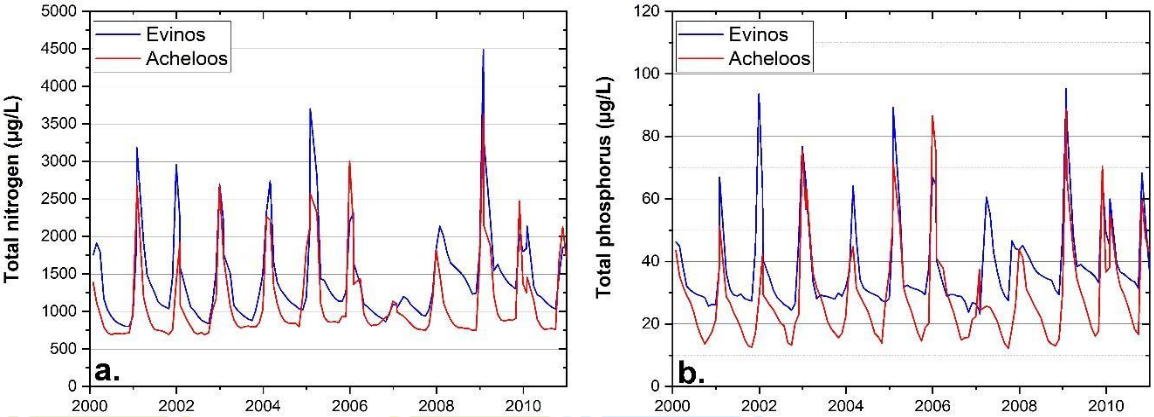

Figure 17*: Temporal variability of a) daily Total Nitrogen and b) daily Total Phosphorus Concentrations of Acheloos and Evinos rivers for the period 2000-2010*

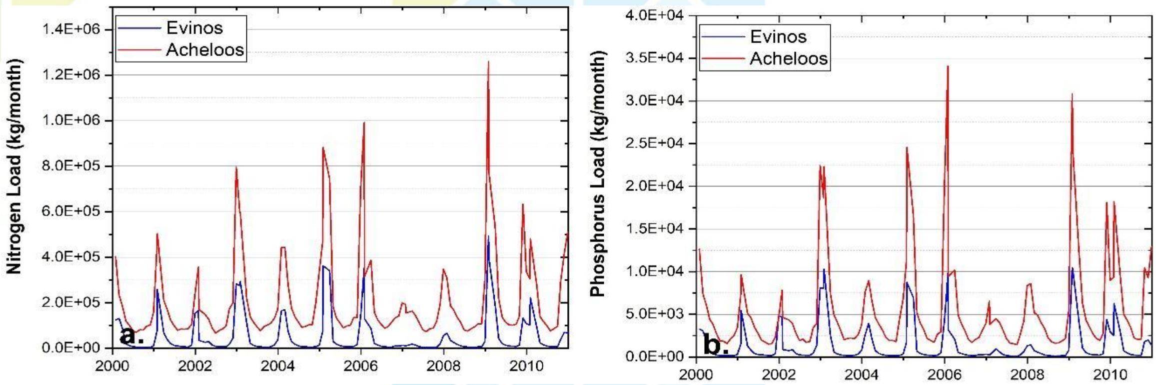

Figure 18*: Temporal variability of a) daily Nitrogen Load and b) daily Phosphorus Load of Acheloos and Evinos rivers for the period 2000-2010*

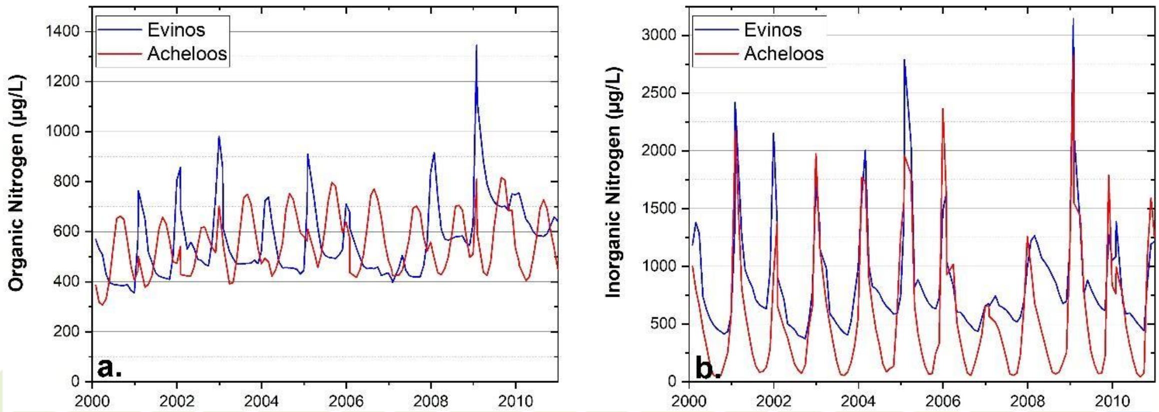

Figure 19: Temporal variability of a) daily Organic Nitrogen and b) daily Inorganic Nitrogen of Acheloos and Evinos rivers for the period 2000-2010

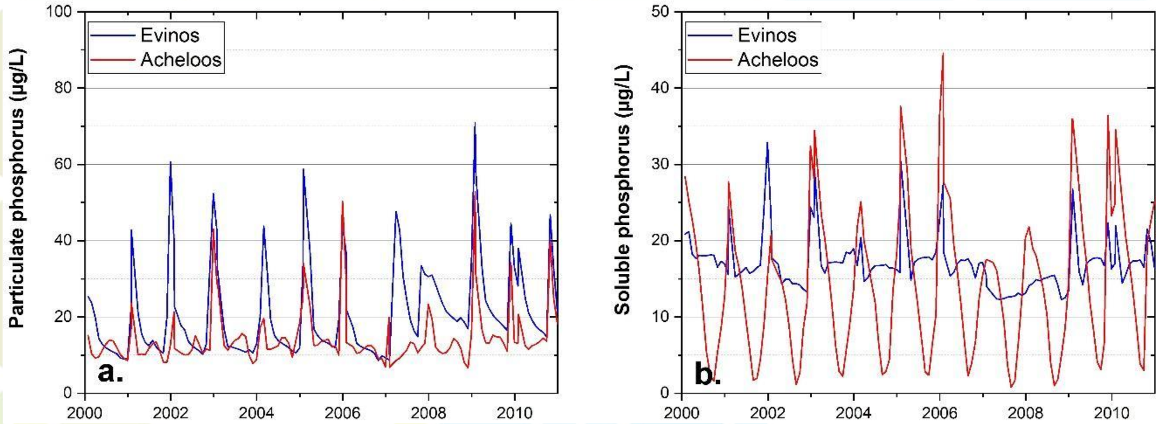

Figure 20: Temporal variability of a) daily Particulate Phosphorus and b) daily Soluble Phosphorus of Acheloos and Evinos rivers for the period 2000-2010

Oceanographic data

Physical and marine biogeochemical components are useful for coastal water quality monitoring and pollution control. Sea level rise is a key indicator of climate change and helps to assess coastal erosion. Currents and waves play a crucial role for the determination of the impact of water circulation in coastal erosion. Sea surface temperature elevation has direct consequences on marine ecosystems and appearance of tropical cyclones. Chlorophyll-a and Suspended Particulate Matter (SPM) are two of the most significant datasets for monitoring the impact of the rivers in the study area. Therefore, the retrieval of these datasets appears to be necessary to understand the underlying processes in a cost-effective manner. The retrieval of most of these datasets is through the Copernicus Marine Environment Monitoring Service (CMEMS), part of the Copernicus Program, which is an EU Program managed by the European Commission (EC) and implemented in partnership with the Member States, the European Space Agency (ESA), the European Organization for the

Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for medium-range Weather Forecasts (ECMWF), EU Agencies and Mercator Ocean. The Program aimed at developing a set of European information services based on satellite Earth Observation and in-situ (non-space) data.

The Copernicus Marine Environment Monitoring Service (CMEMS) provides regular and systematic information about the physical state and dynamics of the ocean and marine ecosystems for the global ocean and the European regional seas. This data covers the analysis of current condition, short-term forecasts of the conditions a few days in advance and the provision of retrospective data records (re-analysis datasets). Many of the data delivered by the service (e.g., water temperature, salinity, sea level, currents, wind and sea ice) also play a crucial role in the domain of weather, climate and seasonal forecasting. As mentioned above, basic datasets from CMEMS were retrieved and analyzed in order to determine the processes responsible for the sediment transport along the coastal zone of the Municipality Ieras Poleos Messolonghiou. More precisely, oceanographic data such as sea surface currents (velocity and direction), wave (direction, significant wave height and period), concentration of suspended materials (SPM) and the sea surface temperature were retrieved for the period 1987-2019 (depends on the dataset). The retrieval of the datasets is based on the discretization of the waves dataset, as referral points, to describe each of the sub-areas of the study site, but each dataset has its own points based on the discretization defined by CMEMS database. In the following Figure 19 these referral points and the four sub-areas can be seen.

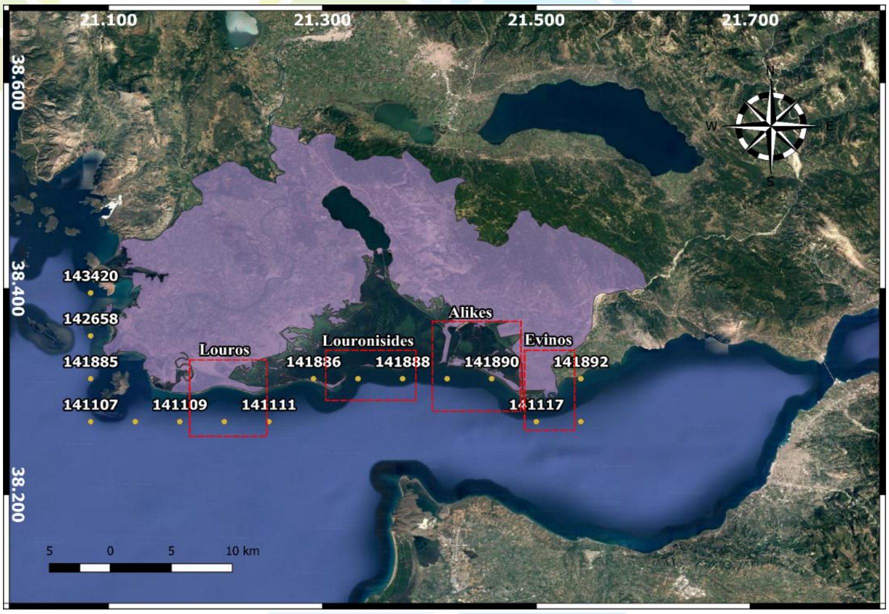

***Figure 21**: Sub-areas as divided in the present study. The points refer to the center points of CMEMS grid discretization*

Currents data

By transporting heat and energy, ocean currents play a major role in shaping the climate of Earth's in many regions. Surface currents (restricted to the upper 400 m of the ocean) are generally wind-driven and develop their typical clockwise spirals in the northern hemisphere and counter-clockwise rotation in the southern hemisphere (for warm currents).

Therefore, surface currents for the period 2006-2019 were retrieved from the CMEMS database based on the referral points that were defined before and on the coarser resolution grid obtained from the CMEMS database. Retrieval was automatized using scripts that retrieve data from each of the referral points.

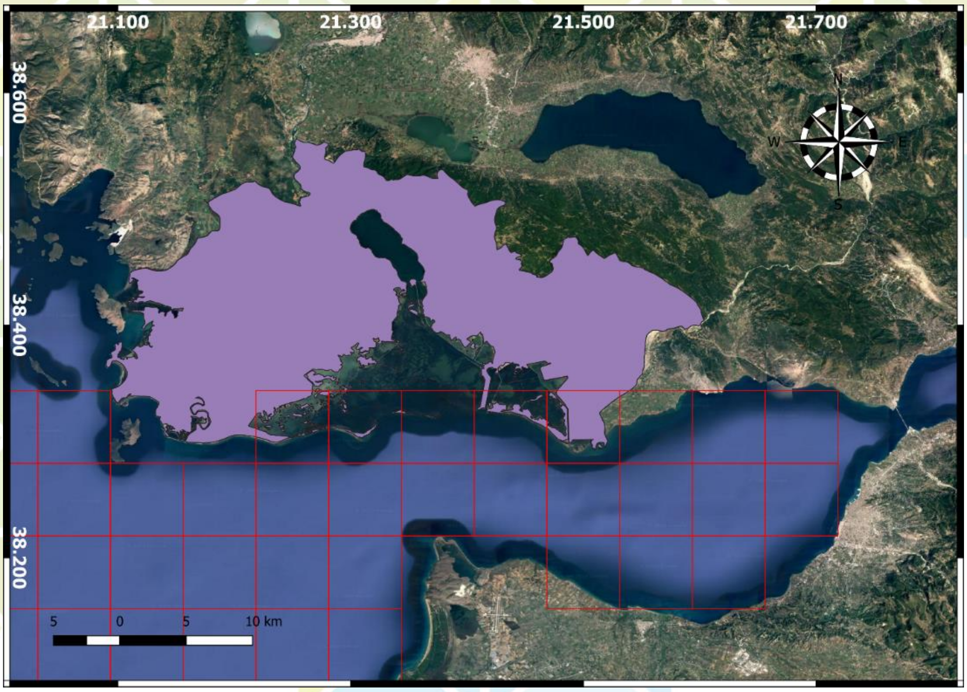

***Figure 22**: Discretization of the study area according to CMEMS currents database*

Subsequently, further analysis, based on innovative tools that were created for this dataset, was applied. Specifically, data were divided in four time periods following the respective data collected from satellite imagery for the determination of the coastal erosion. In Figure 22 the prevailing circulation patterns, as sea surface currents (SSC) and the average sea surface currents speeds during four different time periods a) 2006-2009, b) 2009-2012, c) 2012-2015 and d) 2015-2019, is shown.

Typically, in Patraikos Gulf the sea currents move from west to east, with the higher surface current speed to be observed at the center of the gulf, although in inner Patraikos Gulf the sea surface currents move to SSE with lower speeds. Along the southern coastline of the Municipality Ieras

Poleos Messolonghiou the SSC moves from east to west with a typical current velocity around 2 m/s (Figure 22).

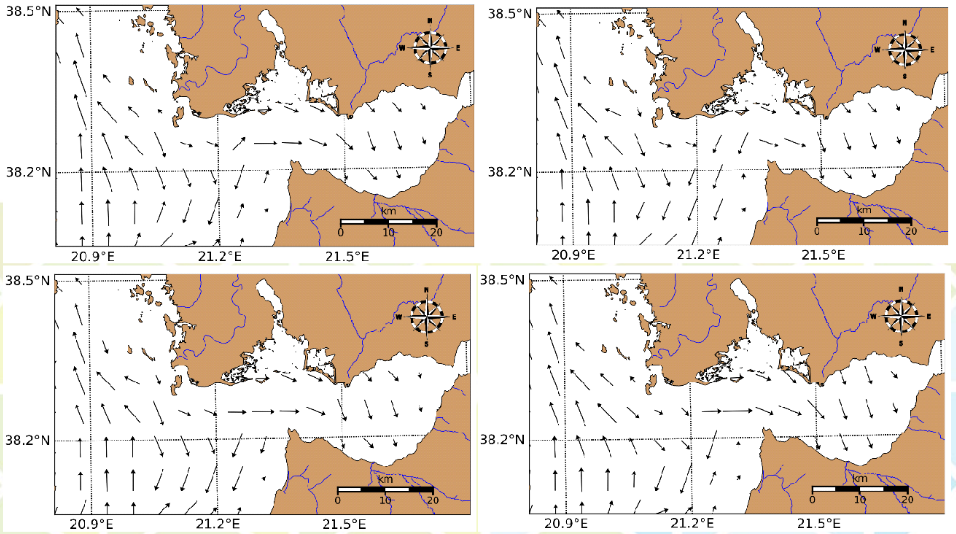

Figure 23: Prevailing sea surface currents as calculated by algorithms, utilizing the CMEMS water flow data for the area close to the coastal zone of the Municipality Ieras Poleos Messolonghiou. The length of each arrow defines the magnitude of current speed.

Wave data

Wave products (significant wave height, wave propagation direction and wave period) for the period 2006-2019 were retrieved from CMEMS database, based on the referral points that were defined before. The wave products are the integrated parameters computed from the total wave spectrum (significant wave height, period, direction, Stokes drift etc.). As can be seen in the Figure 23, the data points selected were located along the coastal zone of the study area. The data retrieval was based on scripts that automatically retrieve data for each of the referral points. Subsequently, further analysis, based on innovative tools that were created for this dataset, was applied.

More precisely, wave-roses of data for each single CMEMS cell was produced and a Peaks Over Threshold analysis (POT) was applied in order to estimate the average wave height and the extreme wave values at all CMEMS cells. In addition, wave data were used for the calculation of the wave characteristics at the nearshore and breaker zone aiming to compute the longshore Incident Wave Energy.

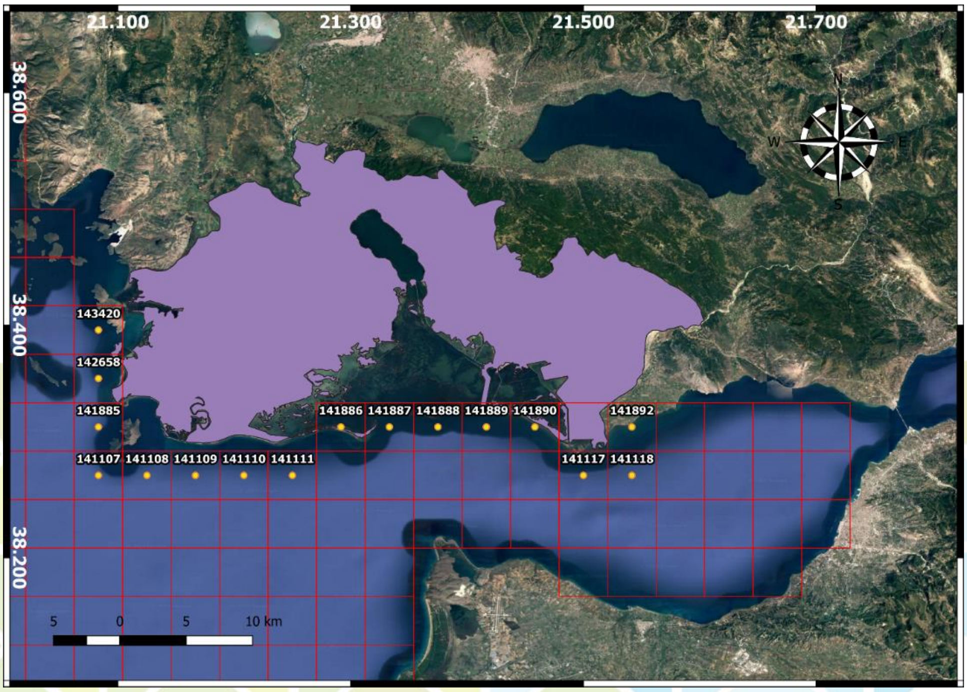

***Figure 24**: Discretization of study area according to CMEMS waves dataset. The retrieved data refer to the central point (yellow points) of each coastal grid cell.*

3.3 The Gulf of Patras, Greece

The Gulf of Patras lies in the Western Greece and links the Gulf of Corinth (East) with the Ionian Sea (West). Specifically, the Gulf is a branch of the Ionian Sea, bracketed between two sills: one lying along an imaginary line from Tourlida (Messolonghi lagoon) to Cape Araxos, at the border between the Ionian Sea and the Gulf of Patras; and the second one at the Straits of Rio–Antirio connecting the Gulf of Patras with the bay of Nafpaktos, located at the entrance of the Gulf of Corinth (Fourniotis and Horsch, 2015). In the Northern part the gulf is bounded by the shore of Aetolia-Acarnania in continental Greece, and the South by Achaea in the Peloponnese peninsula (Fourniotis and Horsch, 2015). It is 40–50 km long, 10–20 km wide, and has an area of about 350–400 km2 (Figure 24). The only major port is located in the municipality of Patras placed on the South-East coast of the Gulf, and was constructed in 2010. It connects the region with the main Greek islands (e.g. Cephalonia), and the rest of Europe (e.g. Ancona, Brindisi). Due to the large oil deposits underlying the sea floor, as well as the on-going increase in industrial and transport activities, the Gulf of Patras is expected to be the focus of attention in the coming years, both in terms of coastal development and oil spills and ship-related pollution (Makatounis et al., 2018). According to the Hellenic legislative framework, the gulf of Patras is characterized as a water body at risk.

Figure 24: The Gulf of Patras

3.3.1 Available data at the case study level

In this study, data from several databases were retrieved and utilized for the intervention area.

- Hydrological data, sea-water quality data and data concerning the Natura sites were retrieved from the Hellenic geodata base (http://geodata.gov.gr/).
- Meteorological data (such as wind speed and wind direction) were retrieved from the Hellenic National Meteorological Network (HNMN).
- Bathymetry data were retrieved from the digital database C-MAP of DHI (2014), which includes measurements of the Hellenic Navy's Hydrographic Service, and from bathymetric measurements performed in the framework of the TRITON research project (analytical details are given in the deliverable D4.3).
- Wave and Current data were calculated by preforming a numerical analysis with the use of the bathymetric measurements performed in the framework of the TRITON research project (analytical details are given in the deliverable D4.3).
- Coastal erosion morpho-sedimentological data, evolutionary erosion trend data and coastal erosion defense works data were retrieved from the European Environmental Agency, the EUROSION database and the detailed investigation performed in the framework of the TRITON research project.

Natura sites and hydrological data

The Hellenic site http://geodata.gov.gr was selected as the basic platform for the retrieval of all necessary information concerning rivers, sea-water quality and Natura sites existing in the intervention area. In Figure 25 all these data are presented. Concerning the Natura sites, the following sites exist in the area of interest:

- Habitats Directive Sites (pSCI, SCI or SAC)

PARAKTIA THALASSIA ZONI APO AKR. KYLLINI EOS TOUMPI - KALOGRIA (GR2330007), Area: 11,106.19 ha.

LIMNOTHALASSA KALOGRIAS, DASOS STROFYLIAS KAI ELOS LAMIAS, ARAXOS (GR2320001), Area: 5,770.75 ha.

LIMNOTHALASSA KOTYCHI, BRINIA (GR2330006) Area: 1,280.14 ha.

- Birds Directive Sites (SPA)

YGROTOPOI KALOGRIAS-LAMIAS KAI DASOS STROFYLIAS (GR2320011), Area: 6,525.13 ha.

LIMNOTHALASSA KOTYCHI - ALYKI LECHAINON (SiteCode: GR2330009) Area: 2,342.99 ha.

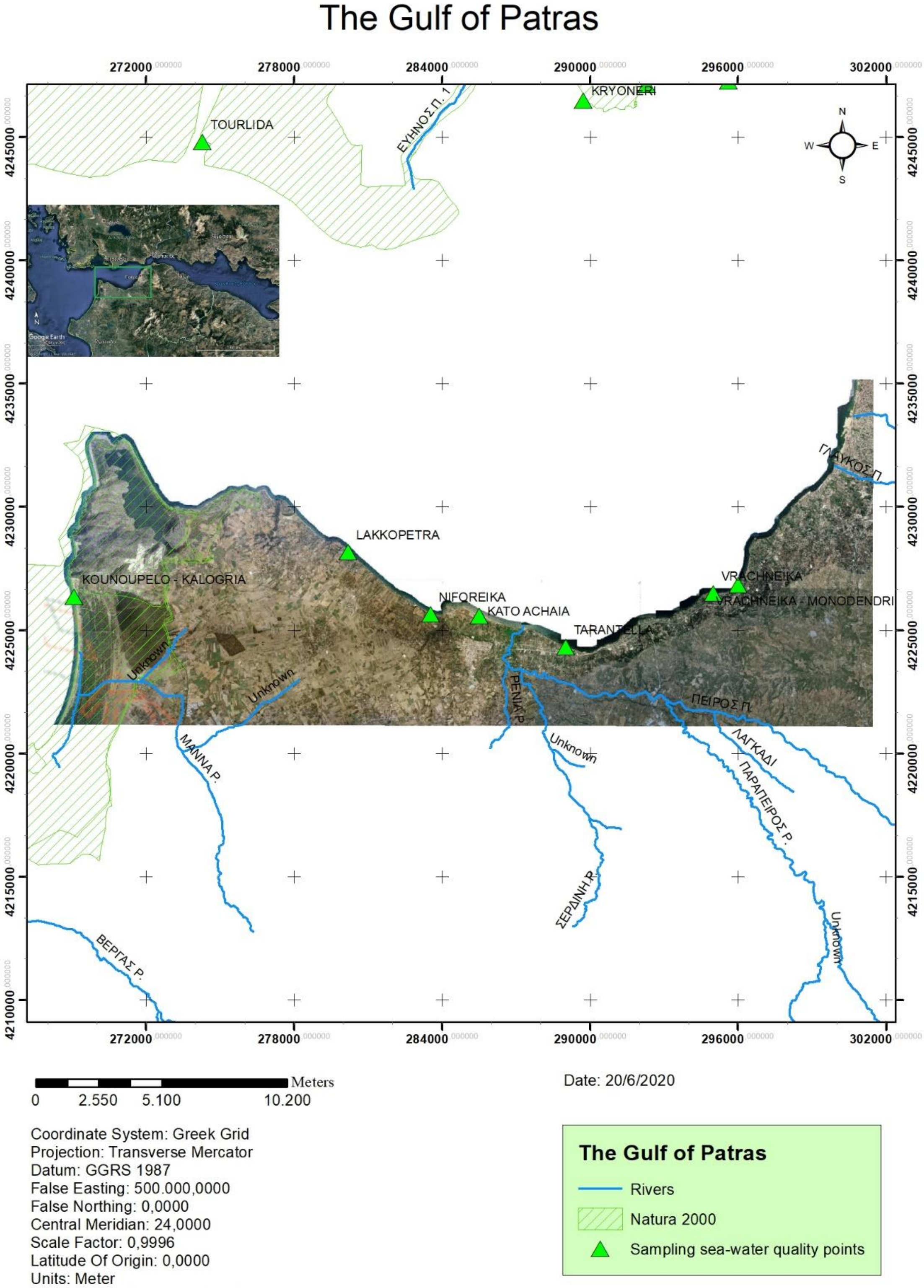

Figure 25: *Map of the Gulf of Patras presenting the main rivers, the Natura sites, and the sea-water quality sampling points*

Meteorological data and wave development in the Gulf of Patras

The characteristics of the waves in the deep waters of the coastal zone of the gulf of Patraswere calculated using wind data taken from the HNMN meteorological stations at Nafpaktos (from 1/1/1977 to 31/12/2011) and Araxos. Using numerical simulation of wind-induced wave generation, growth and propagation of waves were performed in the Gulf of Patras and the Ionian Sea between the islands of Kefallonia and Zakynthos and the Gulf of Patras. Afterwards, the SW module solved numerically the wave action equation in a computational mesh of the bathymetry of the specific region.

The bathymetry data were derived from the digital database C-MAP of DHI (2014), which includes measurements of the Hellenic Navy's Hydrographic Service, and from bathymetric measurements performed in the framework of the TRITON research project (analytical details are given in the Deliverable D4.3).

In the present work, the computational field, shown in Figure 25, was discretized with 181,406 triangular cells in an unstructured computational mesh with resolution from 100 m in shallow waters to 300 m in deep waters. The input data for the module SW are the computational mesh and the wind characteristics with 1-year return period. The module SW was set to compute the steady state of the wave propagation.

Typical results of wave height, direction and velocity distribution for the northeastern wind, are shown in Figure 27**:**. From the results of all wind directions, the wave height and direction in deep waters offshore of the coastal zone of the pilot area of the Gulf of Patras and deep waters were found. These data were used as input data in the numerical simulations of wave propagation, wave-generated currents, sediment transport and bed morphodynamic evolution in the specific coastal zone, as it is described in detail in the Deliverable D4.3.

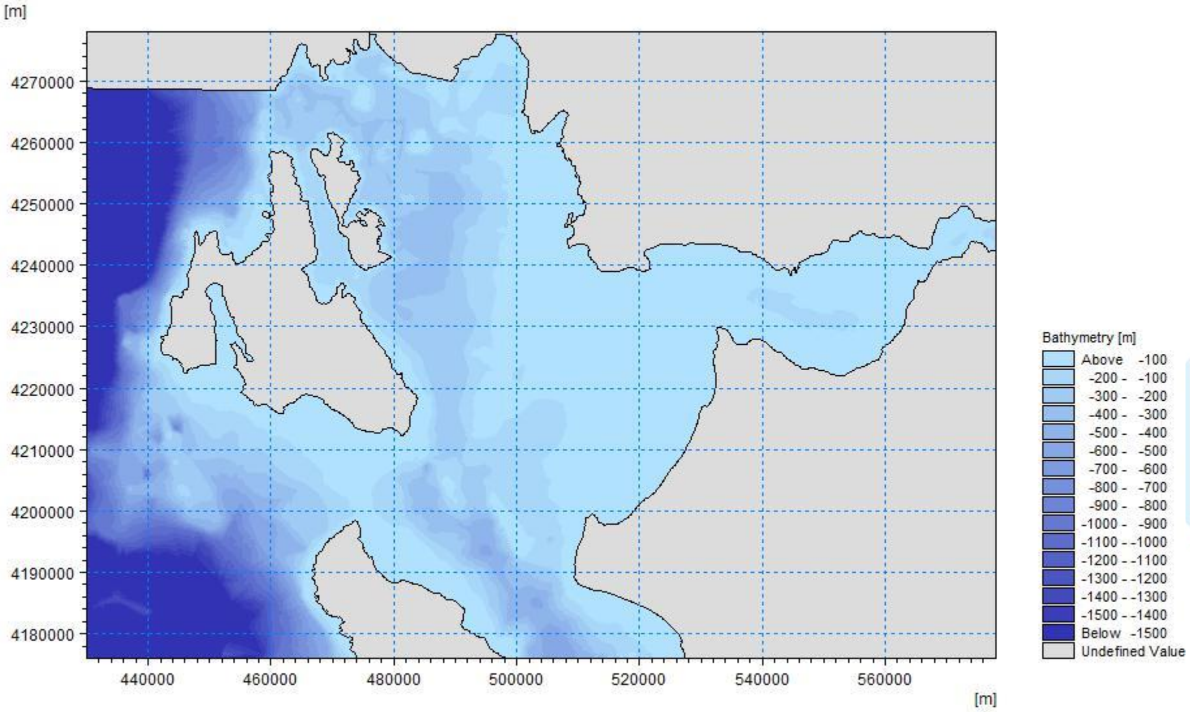

Figure 256: *The bathymetric computational mesh of the Ionian Sea west of the Gulf of Patras, which was used the numerical in simulations of wind-induced wave generation, growth and propagation.*

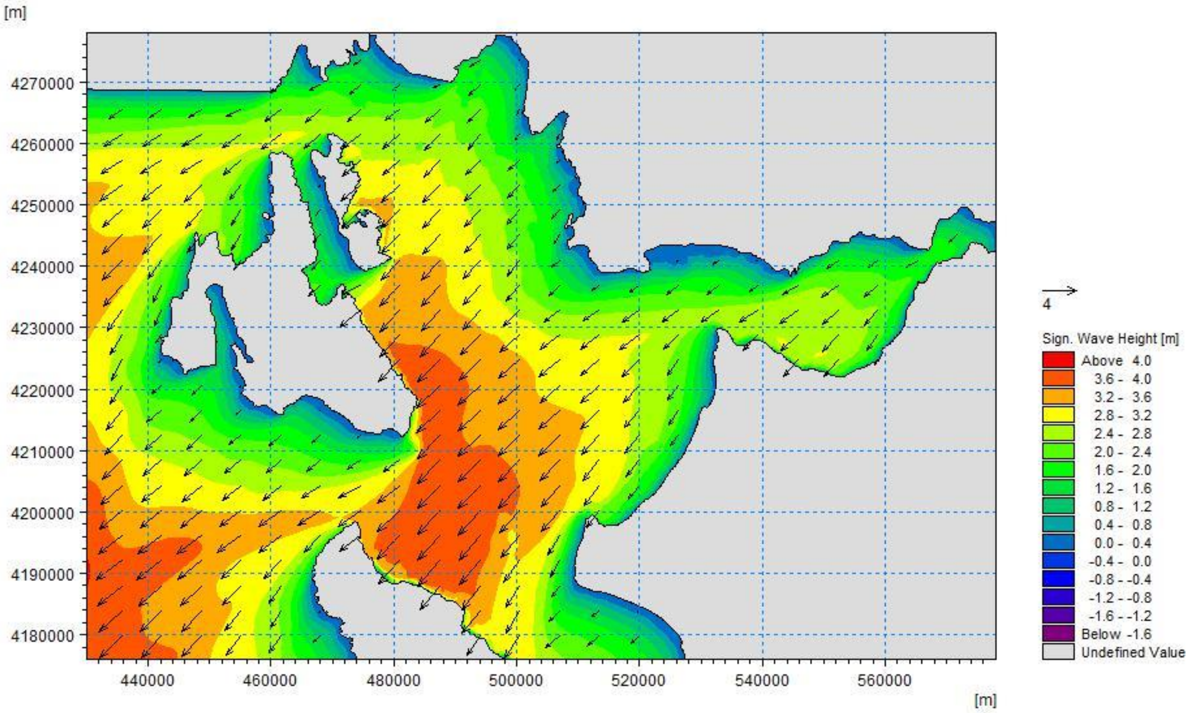

Figure 27: *Wave height, velocity and direction distribution in the area of the Ionian Sea west of the Gulf of Patras due to the action of northeastern winds.*

Coastal erosion data in the Gulf of Patras

Three levels of information were retrieved form the EUROSION database:

a) Coastal erosion morpho-sedimentological data (cemo);
b) Evolutionary erosion trend data (ceev);
c) Coastal Erosion Defense Works data (cedw).

<u>a) Coastal erosion morpho-sedimentological data (cemo)</u>

The following morphological structures are present in the area of intervention and are presented in Figure 28:

- ✓ Conglomerates and cliffs subject to erosion with a presence of rock waste and sediments (sand or pebbles) on the strand;
- ✓ Developed beaches with a length of >1 km with strands made of coarse sediments consisted by gravels or pebbles;
- ✓ Developed beaches with a length of >1 Km long with strands fine to coarse sand;
- ✓ Harbour areas.

<u>b) Evolutionary erosion trend (ceev)</u>

The trend of erosion in the area of interest can be divided to the following categories (Figure 28):

- ✓ Stable: Evolution almost not perceptible at human scale;
- ✓ Aggradation probable but not documented.

<u>c) Coastal Erosion Defense Works (cedw)</u>

All this information is illustrated in Figure 28 and was used as a basic information for the later detailed investigation performed in the framework of the TRITON research project.

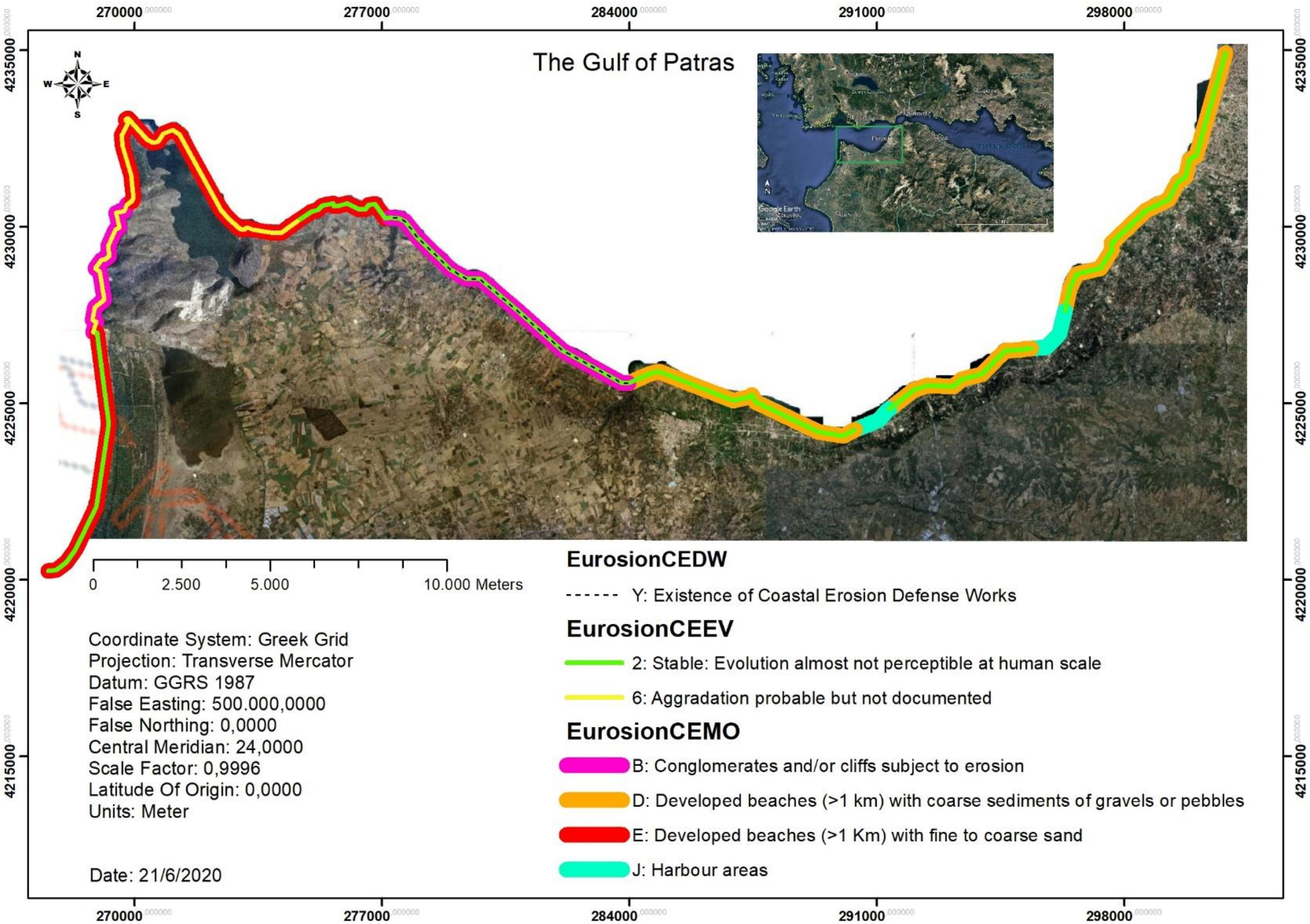

Figure 28: *Coastal erosion morpho-sedimentological data (cemo), Evolutionary erosion trend data (ceev) and Coastal Erosion Defense Works data (cedw) in the gulf of Patras*

4. Conclusions

In the frame of the task 3.1 "*Census of needs/mapping of existing system for coastal management*", this deliverable introduces the TRITON pilot cases: the Apulia region shoreline in Italy as well as the Messolonghi coastal area and the gulf of Patras in Greece, providing details on their main territorial and environmental characteristics, including information on main issues related to coastal erosion processes in place on these areas. Specifically, the report is mainly structured in two sections: i) the first one briefly introduces the main terminologies and theories useful for a better understanding of coastal erosion processes and related management practices; ii) the second one focuses on the TRITON IT-GR pilot cases, describing the geographical context where they are placed, the land use/cover, geological and geomorphological patterns characterizing their shoreline, also identifying critical hot-spots stretches presenting high criticalities in terms of erosive processes. This part presents the available dataset as well to inform the case studies, including data from on-going and former projects (e.g. EUROSION, START, PEGASO), open-source web data portals (e.g. Copernicus) and local-scale information supplied by national and local authorities.

These information will be capitalized in both TRITON pilot cases within the application of tailored risk-based methodologies and filed investigations (WP4) allowing to evaluate, at the local scale, the shoreline evolution trend against different climate changes scenarios (e.g. sea level rise, increase of coastal flooding events) and management options (e.g. implementation of artificial protection along the coast, or nature based solutions to reduce longshore wave power). Resulting output from these analyses are expected to provide important information to support robust decision-making and to provide the means for dynamic adaptive policy pathways in the context of cross border ICZM implementation in the intervention area across Greece and Italy.

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