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CO-EVOLVE

Promoting the co-evolution of human activities and natural systems for the development of sustainable coastal and maritime tourism

Deliverable 3.2.1

Coastal morphodynamics in Mediterranean touristic areas under climate change conditions

Activity 3.2

Threats to co-evolution - Mediterranean scale: Climate changes and morphological stability

WP3

CNR - ISMAR

Authors

Federica Rizzetto and **Carmine Vacca**

Istituto di Scienze Marine

Consiglio Nazionale delle Ricerche

Arsenale - Tesa 104, Castello 2737/F

30122 Venezia (Italy)

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Table of content

1. Introduction

This report represents “*Deliverable 3.2.1 - Coastal morphodynamics in Mediterranean touristic areas under climate change conditions*”, which is one of the two outputs expected from the “*Activity 3.2 - Threats to co-evolution - Mediterranean scale: Climate changes and morphological stability*”. The Activity 3.2 is aimed at identifying threats to the morphological stability of the Mediterranean touristic coastal areas and at developing a methodology of analysis applicable not only at MED scale, but also at NUTSII and NUTSIII scales (EUROSTAT, 2015) and to the study of the pilot areas, whose selection was based on the criteria that, in each site, geomorphological characteristics, hydrodynamic processes, climate conditions and human impact are different.

Mediterranean touristic coasts have been identified according to the definitions and classifications proposed by the working group responsible for Deliverable 3.16. They exhibit various threats that require hazard identification and risk assessment to define correct future planning and mitigation strategies.

The research is carried out through the review of existing data, which allows updating the knowledge about the present erosion trends, the future possible trends considering the foreseen relative sea-level rise scenarios, hazard and risk according to the Directive 2007/60/EC, the key anthropogenic and natural drivers, and the vulnerability factors that could threaten the co-evolution of human activities and natural systems in touristic coastal zones.

Even if the study is performed from MED to NUTS II and NUTS III scale (EUROSTAT, 2015), it is more detailed in the EU member countries mainly due to the greater availability of data.

The first deliverable of the activity, described in this report, is an overview of coastal morphodynamics in Mediterranean touristic areas in the light of climate conditions. It allows defining the present state of the art that has to be considered as “starting point” for the future analyses and data interpretation expected from the following deliverable (*Deliverable 3.2.2 - Mapping of coastal morphodynamics descriptors in Mediterranean touristic areas*).

2. Importance of the in-depth analysis of coastal morphodynamics, climate and oceanographic conditions for tourism, beach management and planning activities

Coastal areas are sensitive transition spaces between land and sea, in which terrestrial and marine environments influence each other. As they stretches across different countries characterized by dissimilar socio-economic reality, transboundary policies have to be put into practice to reach a coherent and effective approach to coastal management (Pranzini & Wetzel, 2008).

The Mediterranean Sea has one of the most threatened coasts in the world. Owing to their economic value, its beaches must be defended from the natural and anthropogenic processes that affect the littorals, have impacts over natural resources and can influence tourism. Tourism represents one of the main uses of the coast and a substantial value for economy from local to national scale; so, it has to be guaranteed.

In the Mediterranean littorals, social and economic interests, as well as the protection of natural environments and ecosystems, must agree with the strategies required by the Integrated Coastal Zone Management (ICZM) Protocol, which was signed in 2008 in Madrid and entered into force in March 2011. “Integrated Coastal Zone Management” means a dynamic process for the sustainable management and use of coastal zones, taking into account at the same time the fragility of coastal ecosystems and landscapes, the diversity of activities and uses, their interactions, the maritime orientation of certain activities and uses and their impact on both the marine and land parts (ICZM Protocol, Art. 2f). Consequently, the ICZM Protocol allows the Mediterranean countries to improve the management and protection of their coastal zones and to deal with the emerging coastal environmental challenges, such as climate change.

Hazards have to be also evaluated according to the Directive 2007/60/EC on the assessment and management of flood risks.

The needed actions require an accurate and updated knowledge of the ongoing processes, in particular of those responsible for changes of beach morphology (Pranzini & Wetzel, 2008). For example, shoreline evolution regulates shape, width and extension of the emerged beach (i.e. the coastal area with the highest economic value), therefore it must be studied in detail, as well as all processes responsible for its modifications. Coastline retreat (i.e. erosion) represents one of the main threats to the beach-based tourism and receives particular attention because it is responsible for land loss and consequent negative impacts on economic activities. Consequently, studies of coastal morphodynamics are surely necessary to define the evolutionary trends of the littorals and to understand if policy interventions for stabilizing shorelines can be sustainable in the long period.

Climate change has a great impact on coastal evolution as it causes modifications both on weather conditions and hydrodynamic processes (e.g., sea-level rise, increase of storm surges, increase of frequency and height of tides). Moreover, climate and weather are important factors in tourists' decision making, as well as safety, and influence the successful operation of tourism businesses (Becken, 2010), destination choice and, as a consequence, tourist flows. For this reason, in the last decades, increasing attention has been paid to how climate change might affect tourist destinations (Wall & Badke, 1994) and how these might adapt to minimise risks and maximise opportunities (Becken & Hay, 2007).

Even if tourism depends on a healthy environment and the sustainable use of natural capital, activities are often concentrated in already densely populated areas, leading to vast increases in water demand, more waste and emissions from air, road and sea transport at peak periods, more risks of soil sealing and biodiversity degradation, eutrophication and other pressures (European Commission, 2014). The impacts of climate change could exacerbate the above mentioned pressures on these areas. However, in other cases, climate change could also be considered positively, as it could be responsible for more favourable future conditions (Becken, 2010).

3. Material and methods

The first part of the activity was based on the collection of available studies on coastal morphology and driving physical processes in the Mediterranean touristic littorals. All partners were involved in this action.

The collected material was organized into a GIS (Geographic Information System) database to make easier data management, analysis and interpretation and to allow the realization of thematic maps summarizing the results obtained from this study.

3.1 Data collection (studies, projects, networks, initiatives)

Published and unpublished products of previous and on-going researches (e.g., reports, maps, articles, project outcomes, networks, initiatives), containing the relevant information on the geomorphological characteristics of the coasts, their evolutionary trends over the last decades, climate and oceanographic conditions (e.g., storms, waves, tides), human activities, and other anthropogenic and natural drivers responsible for coastal dynamics, were selected.

The collection was carried out from Mediterranean to NUTSIII scale, allowing the morphodynamic analysis of the coasts at different levels of detail.

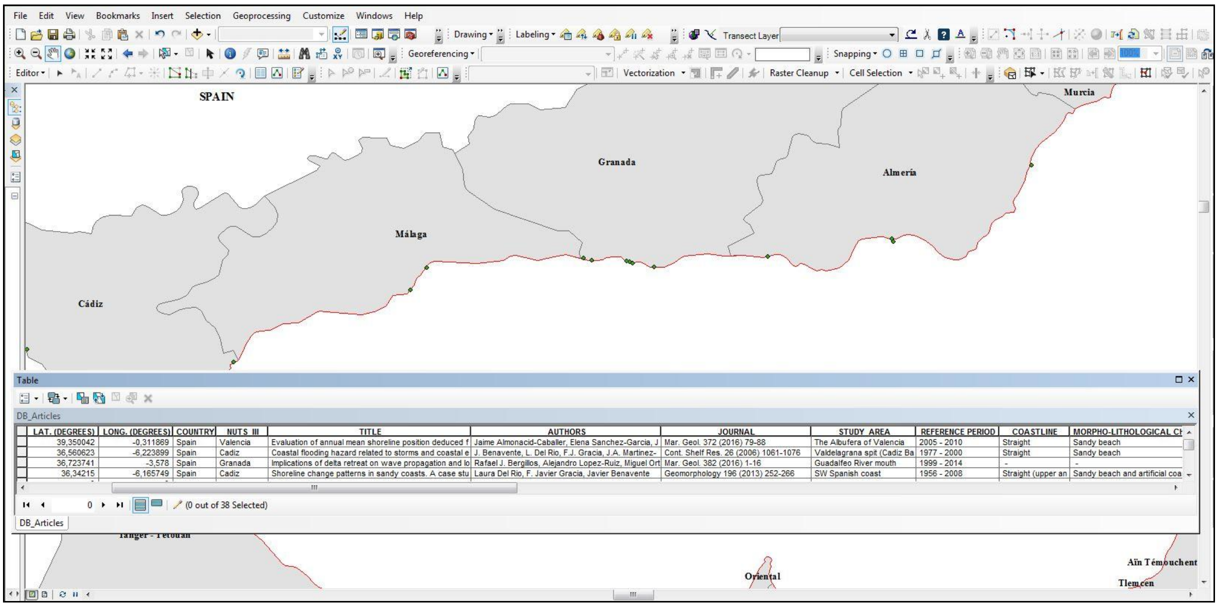


Figure 1: Example of table that summarizes all data derived from the literature used to perform the analysis. Each study location is represented by a green point on the map. The point location map and the table have been realized using the software ArcGIS 10.2.2.

For each document, a brief summary of the content (e.g., study area, type of information, data quality, and reference period) was produced (Fig. 1).

3.1.1 Data from projects

Until now, the outcomes of the following national and international projects have been taken into account:

- ADRIPLAN (2013-2015), ADRiatic Ionian maritime spatial PLANning.
  Source: http://adriplan.eu/
- BEACHMED-e (2005-2008), Strategic management of beach protection for sustainable development of Mediterranean coastal zones.
  Source: http://www.beachmed.eu/
- CAMP Italy Project (2014-2016), Coastal Area Management Programme for Italy.
  Source: http://www.camp-italy.org/
- CCTAME (2008-2011), Climate Change - Terrestrial Adaptation & Mitigation in Europe.
  Source: http://www.cctame.eu/
- ClimateCOST (2013-2016), the Full Costs of Climate Change.
  Source: http://www.climatecost.cc/
- CLIMSAVE (2010-2013) Climate Change Integrated Assessment Methodology for Cross-Sectorial Adaptation and Vulnerability in Europe.
  Source: http://www.climsave.eu/climsave/index.html
- COASTANCE (2009-2012), Regional action strategies for coastal zone adaptation to climate change.
  Source: http://www.coastance.eu/
- COASTGAP (2013-2015), Coastal Governance and Adaptation Policies in the Mediterranean.
  Source: http://coastgap.facecoast.eu/
- CONSCIENCE (2007-2010), Concepts and Science for Coastal Erosion Management.
  Source: http://www.conscience-eu.net/
- EUROSION (2002-2004), a European initiative for sustainable coastal erosion management.
  Source: http://www.eurosion.org/

- Med-IAMER (2014-2015), Integrated Actions to Mitigate Environmental Risks in the Mediterranean Sea.
  Source: http://www.medmaritimeprojects.eu/section/med-iamer
- MEDSANDCOAST (2014-2015), Modèles innovants de gouvernance des ressources sableuses des zones côtières-marines pour une défense stratégique des littoraux Méditerranéens.
  Source: http://medsandcoast.facecoast.eu/index.php?option=com_content&view=category&layout=blog&id=8&Itemid=101&lang=fr
- MEDTRENDS (2014-2015), The Mediterranean Sea: Trends, Threats & Recommendations.
  Source: http://www.medtrends.org/
- MICORE (2008-2011), Morphological Impacts and COastal Risks induced by Extreme storm events.
  Source: http://www.micore.eu/
- OURCOAST (2009-2011), commissioned to support and ensure the exchange of experiences and best practices in coastal planning and management.
  Source: http://ec.europa.eu/ourcoast/index.cfm?menuID=3
- PESETA I, II, III (2006-2017), Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis.
  Source: https://ec.europa.eu/jrc/en/peseta
- RESPONSE (2003-2006), Responding to the risks from climate change.
  Source: http://www.coastalwight.gov.uk/RESPONSE_webpages/r_e_theproject.htm
- RISK-KIT (2013-2017), Resilience-Increasing Strategies for Coasts – toolkit.
  Source: http://www.risckit.eu/np4/home.html
- RITMARE (2012-2016), The Italian Research for the Sea.
  Source: http://www.ritmare.it/
- SHAPE (2011-2014), Shaping an Holistic Approach to Protect the Adriatic Environment between coast and sea.
  Source: http://www.shape-ipaproject.eu/
- THESEUS (2009-2013), Innovative technologies for safer European coasts in a changing climate.
  Source: http://www.theseusproject.eu/

These projects provide the different types of information necessary to achieve the goal of the Activity 3.2 and to have a complete overview of the morphodynamic conditions of the Mediterranean littorals and related impacts and risks in the light of climate change. Data quality is generally good. They are mainly available as reports and maps, sometimes published as interactive web maps (web GIS), from MED to a local scale. However, as at a local scale each of the above mentioned projects does not focus on the same Mediterranean countries, collected data have not always the same distribution. Moreover, as these studies were carried out during different periods (probably using older data) and some of them were concluded more than five years ago, only a few can provide updated results.

3.1.2 Data from scientific articles

Hundreds of articles focused on the Mediterranean touristic coastal areas and regarding the topics of the Activity 3.2 were collected. After reading the papers, about six hundred works were selected on the basis of their content, data quality and reference period (Fig. 2). They mainly describe the results of studies carried out both on small areas and long stretches of coasts and provide very interesting multidisciplinary data useful to improve the present analysis. Thematic maps, data tables and in-depth investigations are common. However, despite the great availability of articles and the good data quality, these studies have an irregular and patchy spatial distribution and are based on information collected during different reference periods. So, they do not always allow updating homogeneously the project outcomes listed in the previous paragraph. In any case, owing to the incomplete data coverage, update turns out to be discontinuous along the entire Mediterranean coast.

3.1.3 Data from other sources

Other reports realized by national and international authorities and working groups, in the framework of initiatives aimed at risk assessment and coastal zone management in view of climate change, were selected.

3.2 Data archiving: the GIS database

Selected material was organized into a GIS database, which represents a MED-level data repository containing information about coastal morphodynamics and oceanographic and climate conditions, necessary to analyse and identify threats to touristic activities.

This database was created using the Geographic Information System software “ArcGIS 10.2.2”; it has given the possibility to store, georeference and compare data, analyse spatial information and create maps. It represents an important tool for the immediate interpretation of the beach system dynamics and for coastal planning in view of future climate changes and sea-level rise. Consequently, it provides fundamental support to coastal protection, urban organization, management of coastal tourism, environmental restoration, and habitat protection.

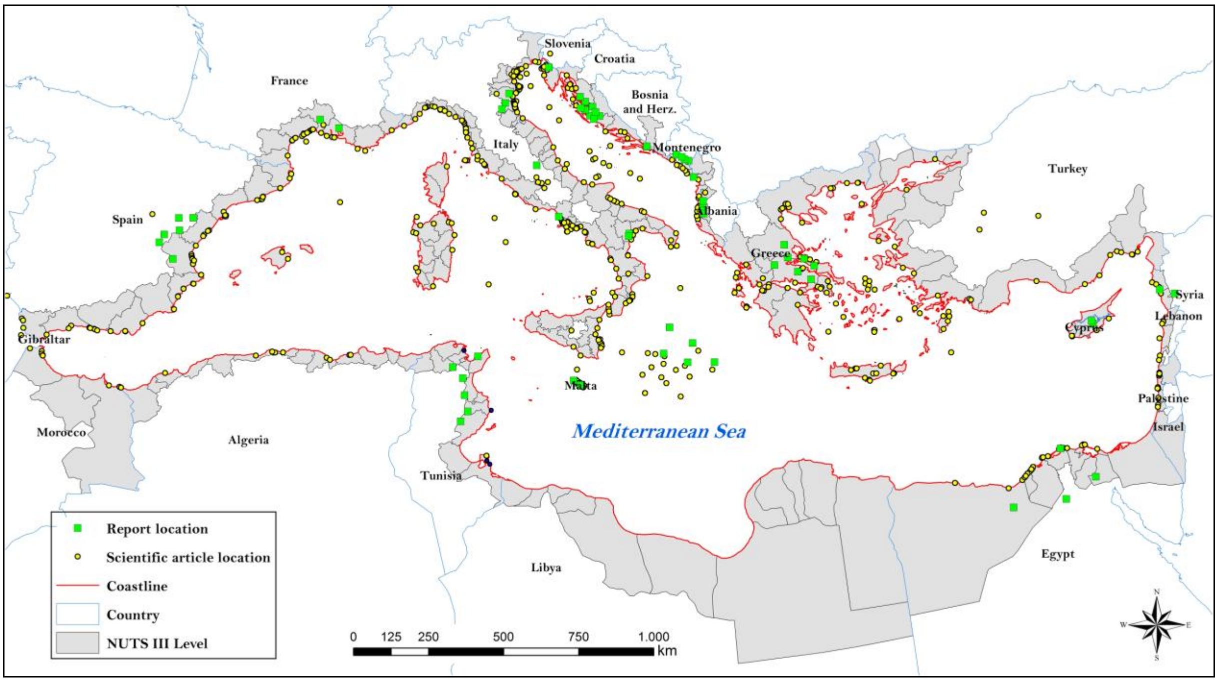
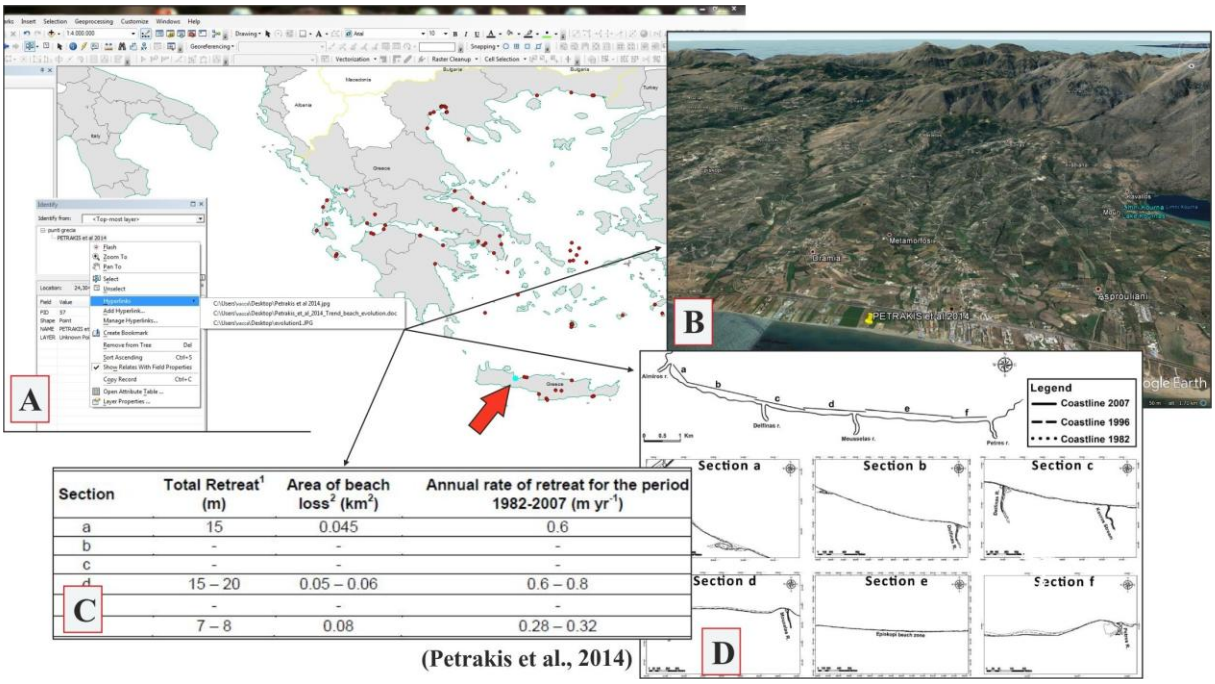


Figure 2: Distribution of the selected literature along the Mediterranean coasts. The points located in the sea represent studies performed at Mediterranean scale, whereas those placed inland refer to researches carried out at NUTS 0 and NUTS I scale.

In the geodatabase, spatial and alphanumeric data are organized in order to represent the main following variables for coastal setting and processes (Fig. 3):

- beach characteristics (geomorphology, lithology, sedimentology),
- coastal evolutionary trends,
- subsidence/uplift,
- coastal defence measures,
- hydrodynamic conditions,
- climate conditions,
- other driving physical natural processes and human activities/interventions that affect the littorals,
- land-use,
- touristic activities,

- coastal hazards.



Section	Total Retreat[1] (m)	Area of beach loss[2] (km^2)	Annual rate of retreat for the period 1982-2007 ($m\ yr^{-1}$)
a	15	0.045	0.6
b	-	-	-
c	-	-	-
d	15 – 20	0.05 – 0.06	0.6 – 0.8
	-	-	-
	7 – 8	0.08	0.28 – 0.32

Figure 3. Other contents of each article/report that can be displayed by selecting a point on the map (A). Hyperlinks allow providing additional information, for example the location of the study area on Google Earth (B) or data about coastal morphodynamics from the selected research, such as information about coastline advance and retreat, available as data tables (C) and/or maps (D).

The GIS database also provides an important framework for integrating existing multidisciplinary data produced at local, regional, national and MED scales and for reporting to the national and international authorities the status and evolutionary trends of the Mediterranean coasts, the anthropogenic processes that affects the littorals, and the beach behaviour in relation to climate change.

Results coming from the integrated data analysis will allow defining all the factors that could threaten touristic activities.

4. State of the art

4.1 Overview of morphodynamics and vulnerability in touristic European coasts

4.1.1 Spain

The Mediterranean coasts of Spain are mainly characterized by stretched sandy littorals, deltas and lagoons. The presence of canyon heads (Garcìa et al., 2006; Ribó et al., 2011; Durán et al., 2013; Ortega-Sánchez et al., 2014; Puig et al., 2017) has a direct influence on the shelf dispersal system as they collect large amounts of sediments and transport them offshore along preferred pathways.

The coastal strip plays a fundamental role in Spanish economy. Coastal tourism has largely developed over the last 60 years (García-Ayllón, 2016), producing a rapid urbanization that has been also responsible for significant morphological modifications of the littorals (García-Ayllón, 2015). Owing to the economic importance of the coast, in the last decades many studies have been carried out to assess hazard and risk and particular attention has been focused on evolutionary trends of the shore in the light of climate conditions and hydrodynamic processes (e.g., Jimenez & Sánchez-Arcilla, 2004; Fatoric & Chelleri, 2012; Jabaloy-Sánchez et al., 2014; Lobo et al., 2014; López et al., 2016; López et al., 2017; Tenza-Abril et al., 2017). Due to coastal morphology and to the exposure to extreme climate events, Spanish littorals are often affected by storm-induced flooding, which are responsible for high erosion rates (see, for example, Jiménez et al., 2012). As a consequence, in 1999 the regional government approved the Special Plan against flood risk, which was reviewed in 2010 (Castillo-Rodríguez et al., 2016), to mitigate this phenomenon.

4.1.2 France

The Mediterranean coast of France is mainly characterized by wetlands, lagoons, estuaries and sand beaches.

Along these littorals, erosion is mostly due to a lesser river sediment input related to a decrease in the frequency of major floods, catchment reforestation, dam construction and dredging activities, as it appears from the EUROSION project results.

The expected climate change will worsen two existing coastal hazards, i.e. erosion and temporary inundation caused by storm waves, and will create a new hazard, i.e. permanent inundation due to sea-level rise, which occurs over long time scales and is considered irreversible (Le Cozannet et al., 2011). As the French coasts are highly anthropized, all these hazards represent serious threats to population, urban environment, tourism and other economic activities. In particular, after the storm Xynthia occurred on February 27-28, 2010, French people fear that in the future climate change can be responsible for similar periodic catastrophic flooding.

Studies aimed at assessing the effects of rising sea-level on the variations of the shoreline position, both on pocket-beaches and open beaches of the French coast, have shown that, on open-beaches exposed to the swell (e.g., Camargue), sea-level rise is not the major cause of coastal erosion and does not represent the most severe risk (Brunel & Sabatier, 2007; 2009). Moreover, in this case, the cross-shore processes of overwash “assist” the shoreline retreat and compensate for sea-level rise. On the other hand, rising sea level plays an important role in the erosion process - and consequent narrowing - of pocket-beaches protected from wave action and with limited back-shore areas (e.g., the beaches of Provence), causing important socio-economic impacts.

However, shoreline retreat can be also due to storm events, which particularly affect low-lying coasts causing not only beach and dune erosion, but also significant migration of nearshore bars, overwashes and even breaches of coastal barriers, as well as damage to coastal defences and coastal infrastructure (Gervais et al., 2012).

4.1.3 Italy

Owing to the physical setting of Italy, Italian coasts display various morphological and lithological types, from rocky littorals and cliffs to low sandy beaches. An interesting classification is proposed by Ferretti et al. (2003), who identified twelve types of coasts. Most of them are experiencing high human pressures, mainly due to urbanization and tourism.

As Italian littorals are characterized by various orientations, they are exposed to different hydrodynamic processes and weather conditions. So, in the framework of this activity, the coasts have been arranged into three groups: (1) Adriatic coasts, (2) Ionian and southern Tyrrhenian coasts, and (3) northern and central Tyrrhenian coasts.

(a) Adriatic coasts

The Adriatic coasts are mainly characterized by low sandy beaches commonly affected by significant erosion processes (Simeoni & Bondesan, 1997). Human activities have been largely responsible for these phenomena owing to an improper land use and misguided and incorrect coastal management and planning. Urbanization, construction of roads and railways, building of extensive defence structures, extraction of sediments from the riverbeds are just some of the most important causes that have produced drastic modifications on the littorals, either irreversible or rather difficult to correct.

Owing to their geomorphological characteristics, the North Adriatic beaches are highly vulnerable to the impacts of the ongoing climate change (e.g., storm surges, increase of strength and frequency of high tides, accelerated sea-level rise). With reference to the evaluation of coastal risks and the effects of climate change on the evolution of the coasts, Torresan et al. (2012) proposed a vulnerability assessment methodology for the estimation of the sensitivity of the North Adriatic littorals. The study was carried out at a regional scale taking into account qualitative and quantitative spatial attributes, representing environmental and socioeconomic vulnerability indicators of multiple coastal receptors to climate change. The results of the analysis included the realization of vulnerability maps for multiple coastal receptors (i.e. beaches, river mouths, wetlands, terrestrial biological systems, protected areas, urban and agricultural areas) in relation to each climate-related impact (i.e. sea-level rise, inundation, storm-surge flooding and coastal erosion).

The low-lying coast of the Northern Adriatic Sea is also very sensitive to land- and sea-elevation changes (Carbognin et al., 2009; Bitelli et al., 2010). Subsidence is due to both natural and anthropogenic processes: natural processes include sediment compaction and deformation of substratum, whereas anthropogenic subsidence is due to ground fluid removal. In the north Adriatic coast, the combined effects of the lowering of the land-surface elevation and sea-level rise have threatened the industrial areas, the urban zones, and the surrounding vast reclaimed marshland, which have became more prone to being submerged. This has resulted in a more serious risk of flooding and inundation, particularly in view of the ongoing climate change.

In the second half of the 20th century, anthropogenic subsidence also represented a serious problem for the Venice Lagoon preservation. Starting in the 1970s, it was strongly reduced or stopped after the halt of groundwater withdrawals (Carbognin et al., 2009). In this area, because of its high vulnerability exposure, the process has been, and is still, largely studied (e.g., Stozzi et al., 2009; 2010; Tosi et al., 2009; 2010; 2012, 2014; 2016; Kourkouli et al., 2014; Teatini et al., 2012; 2014).

Similar conditions of land subsidence have been detected in the Po river delta (e.g., Simeoni & Corbau, 2009; Fabris et al., 2014), in the Ravenna area (Teatini et al., 2005) and close to the Bevano river mouth (Taramelli et al., 2015).

As regards the Emilia-Romagna region, sandy beaches, having an average width of 70 m and generally protected by offshore breakwaters, represent the dominant coastal landscape (Armaroli et al., 2012). The littorals are currently experiencing a deficit in their sediment budget owing to a decrease in human-induced fluvial sediment transport from the 1970s onwards. The rapid coastal development occurred in the last 50 years has exacerbated this problem, also increasing the risk of sea ingression. In the last 30 years, the Emilia-Romagna coastline has been in a “frozen state”, except for the zones near Comacchio, owing to human interventions (coastal defences and widespread beach replenishments). Moreover, significant effects on the morphological modifications and damages along the Emilia-Romagna coastline have been produced by storms and flooding (Armaroli et al., 2012; Pescaroli & Magni, 2015; Sekovski et al., 2015).

Other studies on coastal evolutionary trends and vulnerability have been carried out both at a regional and at a local scale along the Abruzzo, Molise, Puglia littorals (e.g., Damiani et al., 2003; Aucelli et al., 2009; Indiveri et al., 2013; Tarragoni et al., 2015b). Results coming from all these works show that coastal erosion represents one of the major threats to the coast, largely enhanced by anthropogenic processes and worsened by the ongoing effect of climate change.

(b) Ionian and southern Tyrrhenian coasts

Different types of littorals, from cliffs to low sandy beaches, characterize the Ionian and southern Tyrrhenian coasts.

Analyses of morphodynamics and future impacts of climate change, as well as assessment of vulnerability and risk, have been performed in the last decades by various authors. The joint interpretation of the results has allowed reconstructing the evolution of the coast and understanding the causes of its modifications, also in a climate change perspective. In particular, interesting studies related to these topics were carried out along the Basilicata (e.g., Aiello et al., 2013; Greco & Martino, 2014; 2016), the Calabria (e.g., Blois, 2008; Bellotti et al., 2009; Morelli et al., 2009, D’Alessandro et al., 2011) and the Sicily littorals (e.g., Anfuso & Martínez Del Pozo, 2009). In general, they have shown the evolutionary trends of the coast, highlighted the effects of protection measures and predicted coastline evolution.

Unlike other Italian coastal stretches, the littorals of the Ionian and southern Tyrrhenian seas could also be exposed to waves produced by tsunamis.

Due to the increasing number of population and economic activities, information obtained from these researches is used for the correct management of the coastal environments and the development of plans aimed at their protection and preservation.

(c) Northern and central Tyrrhenian coasts

The Tyrrhenian coasts of Italy are characterized by cliffs, rocky littorals, pocket beaches and well-developed sand/gravel beaches.

In the Liguria region, cliffs are frequently affected by slope instability (Brandolini et al., 2006; 2009; 2013). In particular, several landslide-prone zones have been identified and appeared to be due to the presence of a deep-seated gravitational slope deformation. These processes, which can be also triggered by running waters and wave motion, represent a geomorphological risk for the road and railway networks, the stability of buildings and the safety of people, including swimmers and those in boats in the seaward sector.

Slope instability is a major issue for the cliffs of the Tuscany region too (Marchetti et al., 2008; Sciarra et al., 2014). Moreover, Tuscanian beaches are commonly threatened by erosion, as shown by Cipriani et al. (2013) and Tarragoni et al. (2015), who studied the shoreline evolution of the Ombrone river delta, by Cipriani et al. (2011a), who analysed the Follonica Gulf, and by Cipriani et al. (2011b), who investigated seventeen small beaches located along the coast of the Elba Island.

Erosion also largely occurs along the Tyrrhenian coasts of central Italy and the littorals of Sardinia, where the studies aimed at analysing this process and its effects on coastal activities and at assessing vulnerability are quite well distributed.

4.1.4 Slovenia

Slovenian littorals are mainly characterized by rocky coasts, bays and salt-pans. Sea floods are common and occur every year (Kolega, 2006). The damage produced by these events depends on their frequency and extent. Sea floods are caused by high tides (due to a combination of meteorological and hydrological factors), strong south winds and drops in air pressure. They are more frequent in autumn and winter and rather rare in spring. They represent a serious threat to the different coastal land uses; so, it is necessary to analyse and monitor flooding events for a proper spatial planning. In fact, Slovenian littorals are quite attractive for new buildings, tourism and other economic activities and a great number of inhabitants could be particularly endangered during flooding. In the future, these scenarios could worsen owing to climate change and the consequent sea-level rise.

Moreover, since the mid-1950s the Slovenian coast has been subjected to constant changes due to the increase of population and the development of various economic activities, in particular those derived from the expansion of commercial ports and tourism.

4.1.5 Croatia

Croatian coast is mainly characterized by rocky littorals; coarse grained beaches, fine grained beaches and wetlands are also present. Over the last decades, anthropogenic impact has strongly modified the natural setting of the coastal areas owing to an increase of population and industrialization (Juračić et al., 2009). A number of small ports and man-made structures, such as breakwaters and groynes built to prevent erosion, have modified beach equilibrium. Moreover, these constructions might have an adverse effect on the littorals.

Coastal vulnerability varies as it depends not only on the modifications in weather conditions and hydrodynamic forcing induced by climate change, but also by the high variability of the lithological and geomorphological characteristics of the littorals (Juračić et al., 2009; Benac et al., 2014). In the future, climate change responsible for further sea-level rise and increased storminess could make Croatian littorals more vulnerable to flooding and erosion. Coastal flooding due to current climate variability is already an issue for Croatia. In the 21st century, the impacts of sea-level rise and socio-economic development could increase flood risks substantially if no adaptation measures are taken (Hinkel et al., 2015).

At present, coastal risk mapping and coastal zone management along the climate-sensitive shoreline of Croatia are in initial stages (Ružić et al., 2014).

4.1.6 Montenegro

In terms of coastal landforms, Montenegro shows a great variability, ranging from sandy littorals to rocky coasts, mainly characterized by steep limestone mountains rising from the sea level to an elevation of ca. 800 m a.s.l. and corresponding to a ria coast (Frankl et al., 2016).

The coastal region is the most developed and most inhabited part of Montenegro and is recognized by its natural attractions and cultural heritages (Javno Preduzeće za upravljanje Morskim Dobrom, 2013). As such, it is of special importance for the development of tourism and also considered attractive for living; for this reason, a continuous migrations from the country toward the coast is occurring.

The coastal area of Montenegro, as it is a part of Eastern Adriatic, is exposed to risks deriving from natural disasters, such as earthquakes and floods, which could be exacerbated by climate change. Recently, erosion has been noticed on several beaches, but not along the coastal stretches characterized by stable rocky cliffs.

4.1.7 Albania

The Albanian coastal region may be divided into two stretches: the north one is characterized by an approximately 40 km wide plain, whereas the south strip is mountainous (Kurt & Dinçer, 2012). Locally, there are some small hills in verity heights between 200 m and 300 m (Ciavola et al., 1999; Mathers et al., 1999). The presence of low-lying coastal landscapes is strongly related to the large sediment load presently discharged by the rivers into the sea (Simeoni et al., 1997).

At present, Albanian littorals are characterized by accumulation along the Adriatic coastline and erosion along the Ionian seaside (Frasheri et al., 2011).

The economic importance of the coast is growing, leading to an increase of urbanization and tourism. This development is producing anthropogenic, often irreversible, modifications. Owing to these recent rapid transformations, it is essential to analyse coastal evolutionary trends and improve the knowledge of the natural processes and anthropogenic actions that affect the littorals. The main need is the control of human activities, since wrong coastal management policies can have detrimental effects on the economy (Simeoni et al., 1997). Moreover, as residential areas are usually on low coastal territories, potential sea-level rise could have serious impacts as it could be responsible for flooding and, consequently, for the loss of currently emerged zones (Kurt & Dinçer, 2012). As a result, this process could adversely affect social and economic life without a correct and proper land-use planning.

At present, the ongoing climate change is also making its adverse impact on erosion and hydrodynamic processes (Frasheri et al., 2011).

4.1.8 Greece

The Greece coast is characterized by a wide variety of morphologies, i.e. rocky littorals, cliffs, pocket beaches, sand/gravel/cobble beaches and wetlands mainly associated with deltas.

The map of seismicity (M . 4) of the Mediterranean basin in the time span 1900-2012 (International Seismological Centre, on-line catalogue, 2001, http://www.isc.ac.uk/) shows that Greece (in particular the Aegean Islands) is a highly seismic zone. So, tsunami risk is also high and the related consequences may be particularly severe because of the short distances between the tsunamigenic sources and the nearest exposed coasts (Anzidei et al., 2014). Tectonics also plays an important role in these areas, as a rise in sea level can be offset or amplified by tectonic uplift or subsidence, respectively (Hellenic Republic - Ministry of Environment, Energy and Climate Change, 2014). Along the Hellenic Arc, in the central and eastern Mediterranean, the few available GPS sites show a transition from near-null movements in northern Greece to uplift in Crete, with values decreasing to the east (Anzidei et al., 2014). Subsidence can also be locally caused by human-induced processes; the case studies of the runaways area of the Macedonia airport and the village of Perea, the city of Katerini (a greatly agricultural town and a tourist destination due to its proximity to archeological sites) and the industrial area of Oreokastro, NW of the city of Thessaloniki, represent some examples of sinking zones owing to the excessive groundwater withdrawal (Raspini et al., 2013b; Svigkas et al., 2015; 2017).

The coasts of Greece are highly vulnerable to erosion owing to various factors, such as their geomorphological setting, the mean wave heights, the mean tide ranges and the relative sea-level rise (Petrakis et al., 2014b). Almost, 28% of the coastal area in Greece is under retreat. The highest trends are observed on beach zones and low-lying coastal (including deltaic) plains (Alexandrakis et al., 2010). Taking into consideration that (i) about 40% of the total population in Greece lives within a coastal strip of a few kilometres from the shoreline (Pranzini & Williams, 2013), (ii) the coast accommodates the majority of the industrial activity (>85%), including tourism, (iii) about 90% of the touristic activities are connected to the coastal areas and (iv) the coastal plains (including deltas) form most of the fertile agricultural land of Greece, the study of the past, present and future trends of coastal erosion is essential for the socio-economic growth of the involving communities (Alexandrakis et al., 2010; Petrakis et al., 2014b). Hence, coastal zone evolution and integrated coastal zone management schemes incorporating the potential impact of a future and accelerating sea-level rise are of great importance for Greece (Alexandrakis et al., 2010). In particular, this impact will be more severe in beach zones and low-lying littorals than in other types of coasts owing to their morphological characteristics.

Many studies aimed at analysing coastal vulnerability at a local scale were performed by various authors (e.g., Gaki-Papanastassiou et al. 2010; Chalkias et al., 2011; Karymbalis et al., 2012; Kontogianni et al., 2012; Papoulia et al., 2013; Alexandrakis, 2014; Alexandrakis and Poulos, 2014; Monioudi et al., 2014; Alexandrakis et al., 2015). They often highlighted the economic damages caused by the losses of coastal areas due to sea-level rise and also evaluated the effects of beach erosion on tourism.

4.1.9 Cyprus

Cyprus is an island country, the third largest island in the Mediterranean Sea, after Sicily and Sardinia, both in terms of area and population (Department of Environment Ministry of Agriculture, Natural Resources and Environment, 2013).

The Troodos Mountains cover most of the southern and western portions of the island, whereas the Kyrenia Mountains extend along the northern coastline; the Kyrenia range has lower elevation and occupies a more restricted area.

The coastline displays a great variety of morphological features. Beach materials vary from loose sand and gravel to cemented sandstone and rock formations; the former type of littoral, composed of "soft" materials, is usually narrow and erodible (Loizidou, 2000). In particular, about 30% of the Cyprus coastline is currently subjected to increasing erosion, enhanced both by urbanization and pressure of tourism, which is the major economic activity (90% of the tourist industry is concentrated in coastal areas). In the low-lying region of Larnaca, located in the south coast of the island, erosion (mostly due to human activities) constitutes a greater threat than flooding (Department of Environment Ministry of Agriculture, Natural Resources and Environment, 2013). This area represents the most vulnerable territory of Cyprus.

In general, the implementation of the measures proposed within the Shoreline Management Project, which started in the period 1993-1995 within the framework of the European Union Program MEDSPA and under the guidance of Delft Hydraulics, has already locally given some results (Loizidou, 2000). In particular, actions to reduce risk from coastal storm flooding and inundation, to control erosion and to improve beach conditions must be adopted to favour tourism and other activities on the littorals (Department of Environment Ministry of Agriculture, Natural Resources and Environment, 2013). Even though in the coming years the coastal zone of Cyprus is not expected to become very vulnerable to sea flooding, in view of the foreseen climate change low-lying areas could become significantly prone to sea-level rise impacts and could be threatened by inundation risk and greater exposure to storms (Department of Environment Ministry of Agriculture, Natural Resources and Environment, 2013).

4.1.10 Malta

The coasts of Malta are mainly characterized by vertical cliffs, indented bays, clay slopes, boulder rocks and pocket beaches (Briguglio L., 2000; Biolchi et al., 2014). The Maltese

Islands have an undulating tilt towards the northeast, thus producing two types of coastline: a gently sloping rocky coast on the north-eastern side and a steep cliff-dominated coastline on the southwest and west side of the Islands (Borg, 2004). The structural setting of the north-western coast, characterised by the superimposition of deeply-jointed limestones on clayey materials, is responsible for local instability that causes a wide variety of landslides of different type, size, state and rate of activity (Devoto et al., 2013).

In general, erosion is mainly visible where human intervention occurred in the form of development or incompatible actions (Borg, 2004); so, human intervention is considered the main factor that accelerates erosion. Modifications of the coast have been produced by infrastructure development and urbanisation, which have led to loss of specific habitats, such as sand dunes and saline marshlands. In limestone coastal cliffs, the rate of erosion may accelerate owing to both destabilisation caused by engineering works and increased load over the underlying rock.

Sandy beaches in the Maltese Islands are very limited, constituting around 2.5% of its coastline (Borg, 2004). Some of them are important for their heritage value as they have archaeological and historical remains. As sandy beaches give an economic benefit to the tourism and recreation industry, erosion represents a threat to the development of these activities.

Owing to its favourable topography, good drainage and negligible land movement, Malta is not particularly vulnerable to sea-level rise (Attard et al., 1996). However, certain areas, such as the low-lying coastal zones located in the southeast part of Malta could be severely affected (Briguglio, 2000). Consequently, tourism could be negatively impacted owing to the risk of flooding that could be also exacerbated by the increase of storm activity as a consequence of climate change.

However, storm waves already play a crucial role in assessing the present coastal vulnerability and risk of the island. In fact, the Maltese coasts are seasonally affected by extreme storm waves generated by NE and NW winds. In the past, similar effects have been also produced by tsunami events (Tinti et al., 2004; Galea, 2007; Bertolaso et al., 2008; Pino et al., 2008).

Seawater flooding is rather uncommon in Malta Island, but it can sometimes occur when there is a combination of high tide and heavy rainfall or as a result of atmospheric gravity waves (MRA-Malta Resources Authority, 2013).

4.2 Overview of morphodynamics and vulnerability in touristic Asian coasts

4.2.1 Syria

The Syrian coasts are mainly characterized by rocky littorals, cliffs and sand bays (Sanlaville et al., 1997). These areas are suffering from an increasing number of natural and man-made disasters, such as earthquakes, flash flooding, climate change. Sea-level rise represents one of the main threats to the coastal environment (Saleh and Allaert, 2014). The Syrian coastal area is vulnerable to this process, but not at the same level in all regions (Faour et al., 2013). The most vulnerable zones are flat and low-lying coastal plain, deltaic and estuaries coastal plains and sandy shores. This assessment was based on the evaluation of the Coastal Vulnerability Index that took into account main factors acting on the coastal area (i.e. erosion/accretion patterns, topography, subsidence and relative sea-level rise).

According to Saleh and Allaert (2014), it is possible to reduce these impacts and damages by adopting suitable disaster mitigation strategies, achieved through an integrated system of geographical and environmental data collection, management tools and simulations that also allow risk assessment and creation of a proper awareness of this hazard.

4.2.2 Lebanon

The coast of Lebanon is characterized by small sand and gravel beaches, cliffs and rocky littorals.

The coastal zone is currently the most populated area of the Lebanese territory (Abou-Dagher et al., 2012). In fact, even if it represents only 8 % of the total area of the country, it encompasses 33 % of its total built-up area (Dar Al-Handasa & IAURIF, 2004).

In general, the coast is experiencing increased anthropogenic pressures responsible for high rates of erosion. In particular, the analysis of the evolutionary trend of the northern littorals has demonstrated that the majority of erosion occurred between 1962 and 1994 and was followed by stabilization (Abou-Dagher et al., 2012). Extensive sea-filling activities, started in 1970 and continued until 2007, caused the destruction of intertidal and littoral habitats and led to modifications of coastal morphology and dynamics. The study carried out by the previous authors allowed the identification of the main causes of coastal damage in order to propose suitable measures to prevent further degradation and to preserve the coastal environments and their resources.

4.2.3 Israel

The Israeli coast is characterized by rocky littorals, cliffs and sandy beaches.

Studies focused on specific coastal sites have been carried out to reconstruct local evolutionary trends, in relation to anthropogenic interventions as well. Zviely et al. (2006; 2007; 2009) estimated longshore sand transport along the Mediterranean coast of Israel and defined the related long-term evolution. In particular, from the end of the 18th century to 1928, when human intervention was negligible along Haifa Bay's coast, a significant shore advance was observed. On the contrary, a dramatic change in sedimentological regime occurred between 1928 and 2006 as a consequence of the construction of Haifa Port's main breakwater (1929-1933), which blocked the longshore sediment transport entering the Bay. So, the coastal expansion trend ceased and was replaced by erosion (Zviely et al., 2009).

Man-made disturbances along the Israeli coast during the 20th century (ports, marinas, detached breakwaters, sand mining) have undoubtedly altered coastal morphology and affected the fragile environment, but until now their impacts seem to be largely contained and localized (Zviely et al., 2007).

Other investigations on coastal erosion and the effects of sea-level rise along the Mediterranean Israeli coast were performed by Rosen (2009, 2011). They were used to establish a national policy document in relation to coastal cliffs collapse and erosion due to natural and anthropogenic processes, including global warming, sea-level rise and reduced return period of extreme events (Rosen, 2011).

In the future, coastline retreat, presently caused by the lack of longshore sediment transport, could be exacerbated by the expected climate change. Studies aimed at analysing the effects of sea-level rise and extreme events are important to identify areas at risk, taking into account land use as well. An interesting example is represented by the analysis of Lichter and Felsenstein (2012) that has allowed the estimation of the different levels of inundation and flooding under varying natural hazards scenarios and of the costs in terms of capital stock at risk.

4.3 Overview of morphodynamics and vulnerability in touristic African coasts

4.3.1 Libya

The Mediterranean coast of Libya is characterized by rocky littorals, cliffs and long sandy beaches, which are manly replaced by pocket beaches along the eastern stretch. The coastal zone is currently the most populated area of Libya and its beaches represent gathering places.

Based on the findings of the Intergovernmental Panel on Climate Change (IPCC) and the Arab Forum for Environment and Development (AFED), the coast of Libya can be considered one of the most vulnerable zones of the Arab region to sea-level rise (Tolba & Saab, 2009), as this process will be responsible for flooding and consequent serious implications on the coastal shape, resources and tourism. Increasing storm surges due to climate change could have negative impacts as well (Dasgupta et al., 2007).

4.3.2 Tunisia

The coastal morphology is characterized by the presence of rocky littorals, cliffs, sand/gravel beaches, wetlands, and lagoons.

Beach erosion and coastal flooding due to current climate variability are already serious issues for Tunisia (Hinkel et al., 2015; Louati et al., 2015). Tourism, which is a significant source of income for the country, is one of the main activities that suffer from these processes. Many studies on specific coastal sites have been carried out to analyse the evolutionary trends of the littorals (e.g., Bouchahma & Wanglin, 2012; Louati et al., 2015) and to assess coastal vulnerability and risk (see, for example, Rizzi et al., 2016). All of them teach that in the 21st century, the impacts of climate change and consequent sea-level rise will be substantial if no adaptation measures are taken. Increasing sea level will have various direct and indirect socio-economic consequences (Republic of Tunisia - Ministry of Environment and Sustainable Development, 2015), such as loss by submersion of agricultural land in low-lying coastal zones, loss of built-up areas, decline in the activities of seafront hotels owing to retreating beaches, and decline in port and shore infrastructure.

In Tunisia, results from the analysis of coastal morphodynamics and processes responsible for coastal modifications are also necessary to support stakeholders and policy-makers in the definition of adaptation measures and strategy planning to avoid or reduce risks related to climate change.

4.3.3 Algeria

The coast of Algeria is characterized by rocky littorals, cliffs, pocket beaches and sand/gravel beaches. It is exposed to several natural hazards (Bouhmadouche & Hemdane, 2016), such as erosion (Guerfi, 2007; Mezouar et al., 2014), sudden changes in sea level induced by atmospheric disturbances (Hemdane & Garcia, 2013) and tsunami waves (Meghraoui et al. 2004; Harbi et al. 2011; Amir et al., 2015). Erosion is the most frequent threat observed in several littorals along the Algerian coast, which has been studied by several authors (Boutiba et al., 2006; Guerfi, 2007; Boutiba et al., 2009; Boutiba & Bouakline, 2011; Bouakline, 2009; Mezouar et al., 2014) as it causes significant damages on the natural coastal patrimony. An example is represented by the Bejaia bay, one of the most beautiful and attractive littorals in Algeria owing to its landscape and ecological diversity. This site is currently experiencing a significant coastline retreat that is affecting touristic and industrial infrastructures (El Islam et al., 2017; Ayadi et al., 2016).

Over the last four decades, Algerian coast has witnessed a rapid growth of population and a great industrial development (Gabbianelli et al., 2007). At present, most of total population lives in the coastal zone and the majority of industries is located in the stretch of 50 km from the shoreline; this condition, accompanied by the lack of rational planning of land use, has resulted in severe degradation of Algerian coastal ecosystems (Gabbianelli et al., 2007; Ghodbani & Berrahi-Midoun, 2013). In the last years, the awareness that the coast is a dynamic environment requiring special planning and management has been increased. Consequently, middle- and long-term predictions of coastal morphodynamics and evolutionary trends are crucial issues for the correct management of the littorals. The availability of interactive maps and geospatial analysis tools and the direct access to outcomes of coastal planning projects and natural resource data sets represent the best way to inform decision-makers (Gabbianelli et al., 2007).

4.3.4 Morocco

Moroccan coast is characterized by various morphological and lithological types: rocky cliffs, sandy beaches, wetlands, estuaries and lagoons.

An extensive study on the interactions among coastal morphodynamics, geomorphological setting and human interventions along the Mediterranean beaches of north-western Morocco has been performed by El Mrini et al. (2012). Their purpose was to determine the geographic distribution of types of beaches according to their different degrees of exposure to natural and anthropogenic forcing. This research has allowed the identifications of the most vulnerable touristic coastal areas and represents an important approach for the implementation of appropriate coastal management strategies. Interesting studies on coastal morphodynamics and evolutionary trends of the littorals were also performed at a local scale by other authors, such as Anfuso et al. (2007), Salmon et al. (2010) and Mouzouri & Irzi (2011). Moreover, in-depth analyses on vulnerability and risk along the Moroccan littorals allowed identifying the main threats to the coastal environments, in particular the impacts of climate change (Snoussi et al., 2008; Snoussi et al., 2009; Snoussi et al., 2010; Satta et al., 2016). Due to diverse human pressures, many coastal areas have already experienced serious environmental problems such as coastal erosion, pollution, degradation of dunes and saline intrusion in coastal aquifers and rivers (Snoussi et al., 2009). Accelerated sea-level rise could intensify the stress on these territories, causing flooding of coastal lowlands, erosion of sandy beaches and destruction of coastal wetlands. These scenarios represent serious dangers for tourism, as beaches and coastal resorts constitute a large percentage of the Gross Domestic Product of Morocco (Snoussi et al., 2009).

4.4 Overview of morphodynamics and vulnerability in touristic transcontinental coasts

4.4.1 Turkey

Turkey is a transcontinental country (mainly in Asia, with a smaller portion in Europe) characterized by different coastal morphologies (i.e. rocky coasts with small beaches, cliffs, sandy littorals and wetlands). For examples, rocky coasts can develop in steep areas close to graben structures, whereas wide sandy gravel deltas can be present in zones characterized by transport of sediments to the graben through the streams (Gül et al., 2017). Furthermore, shallow-gravel beaches parallel to the shoreline may be present in front of rocky coastal areas by reworking and transport through longshore currents. Available data related to the evolutionary trends of the coast and local processes are mainly focused on specific sites, not on a regional scale.

The knowledge of the determining factors controlling these coastal types and their development are important in minimizing possible sea-level rise connected to global warming and tectonism (Gül et al., 2017). The impact of sea-level rise could be maximum especially on those areas having low heights, as they are seriously exposed to flood risk, and on narrow-gravel beach, which could be destroyed. Moreover, impacts could become more intense in graben type areas as in these zones sea-level variations are also significantly affected by tectonic activity.

At present, some coastal stretches are eroding (e.g., Kukeki, 2010); land loss is due to both natural modifications in the coastal system and human activities. Understanding the nature and dynamics of these changes, either natural or human, is a basic knowledge to facilitate suitable planning, management, and regulation of Turkish coastal zones (EUNETMAR, 2014). Focusing on the aim of this project, it should not be forgotten that Turkey also cumulates not only a long tradition of beach-based mass tourism but also the presence of coastal cities with huge cultural heritage, which must be preserved trough actions that make possible the coexistence of human activities and natural systems in a condition of equilibrium.

4.4.2 Egypt

Egypt is a transcontinental country (mainly in Africa, with a smaller portion in Asia), whose Mediterranean littorals are characterized by low sandy beaches. Nile Delta, consisting of flat, low-lying areas, is the most populated coastal zone. Large portions of the delta are used for agriculture, except marshy and waterlogged territories.

Owing to its economic importance, it also represents the most studied Egyptian coastal region. In fact, many investigations have been carried out to analyse its evolutionary trends (e.g., Ghoneim et al., 2015; El-Asmar et al., 2016, and references herein) as well as local hydrodynamics, climate conditions and anthropogenic impacts. The coastline of the Nile Delta has experienced accelerated erosion since the construction of the Aswan High Dam in 1964 and, consequently, the entrapment of a large amount of river sediments behind it (Ghoneim et al., 2015). In the deltaic area, the coastline of the Rosetta promontory has shown the highest erosion rates. In particular, the strip between Ras El-Bar and the Damietta Harbor may be subdivided into two segments: the first, to the east, protected against erosion by detached breakwaters, the second, to the west, between the eastern jetty of the Damietta Harbour and the tip of the detached breakwaters system (El-Asmar et al., 2016). These defence measures represent a must to protect private investments in real-estate of accommodations and hotels (estimated in tens if not hundreds of billions at Ras El-Bar) and in free industrial zones, shipping and logistics, as well as gas industries.

Attention has been also focused on the effects of climate change on the Nile Delta. In particular, sea-level rise, combined with geological and human factors, makes this region a highly vulnerable zone to flooding (e.g., Frihy, 2003; Frihy et al., 2010; Hassaan, 2013; Hassaan & Abdrabo, 2013; Frihy & El-Sayed, 2013). All these studies aim at analysing the risks, ranking the vulnerability and suggesting adaptation measures to mitigate the impact of the rising sea level along the Mediterranean coast of Egypt.

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ANNEX 1

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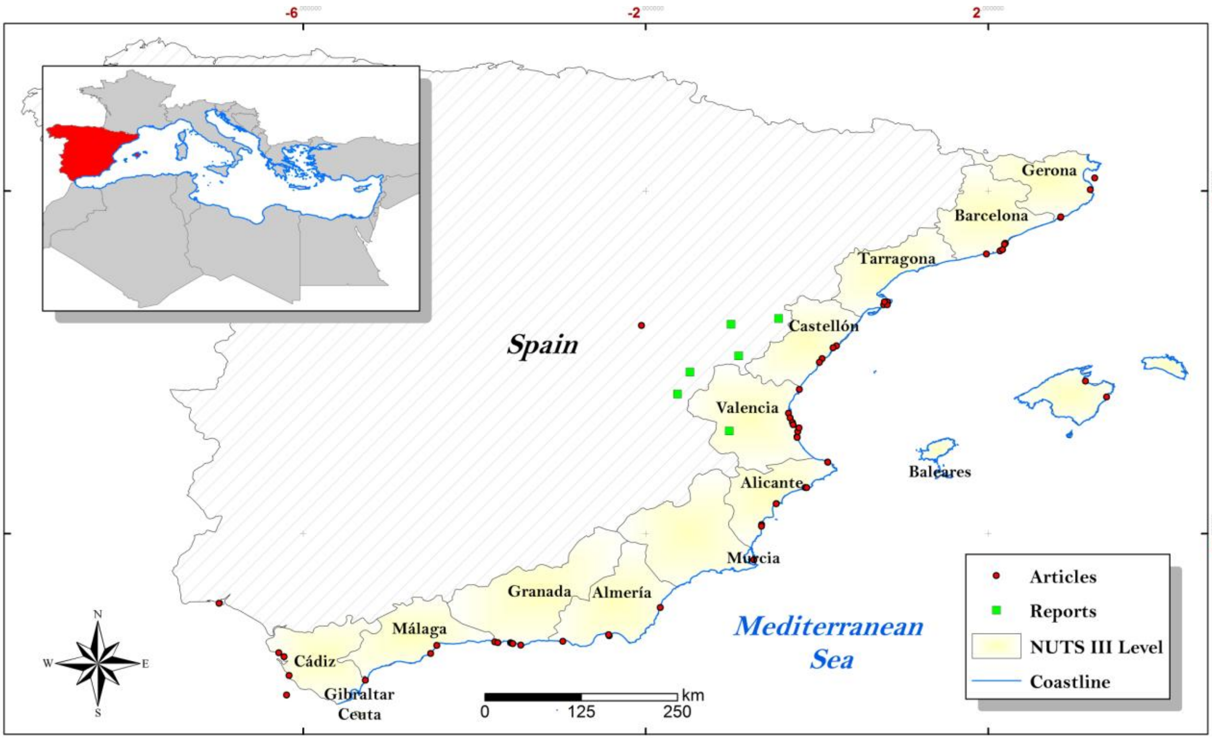

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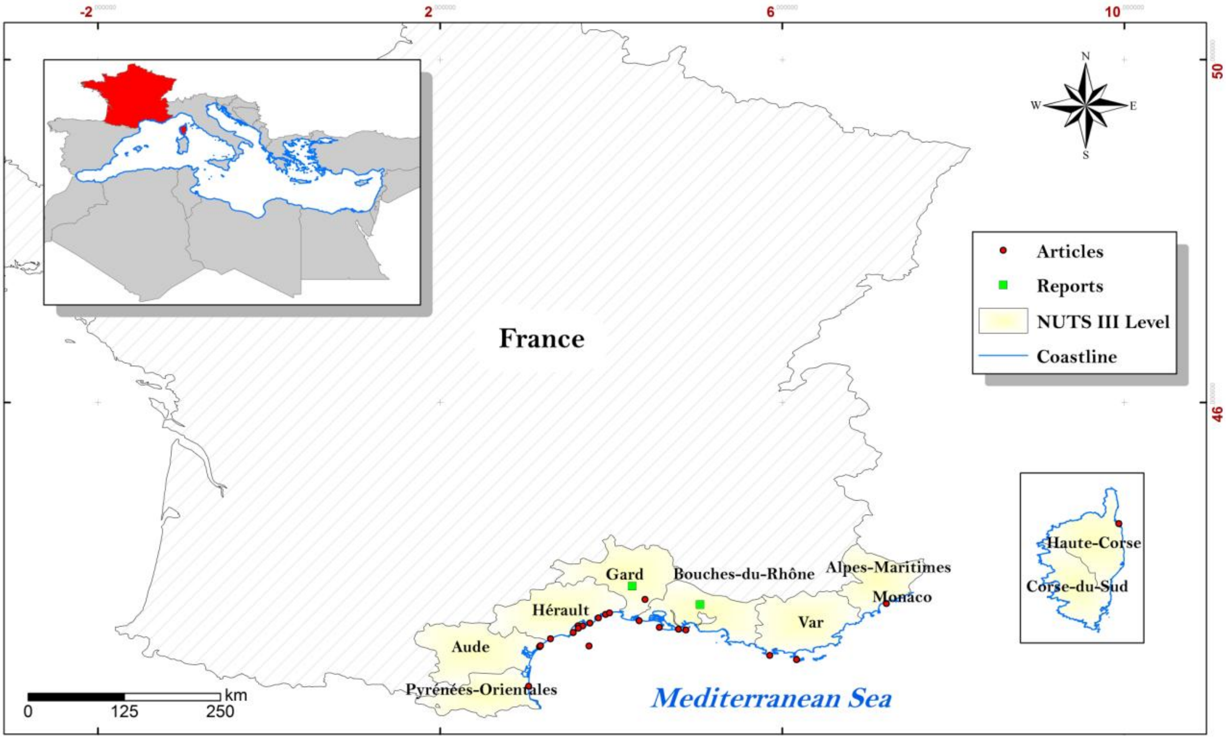

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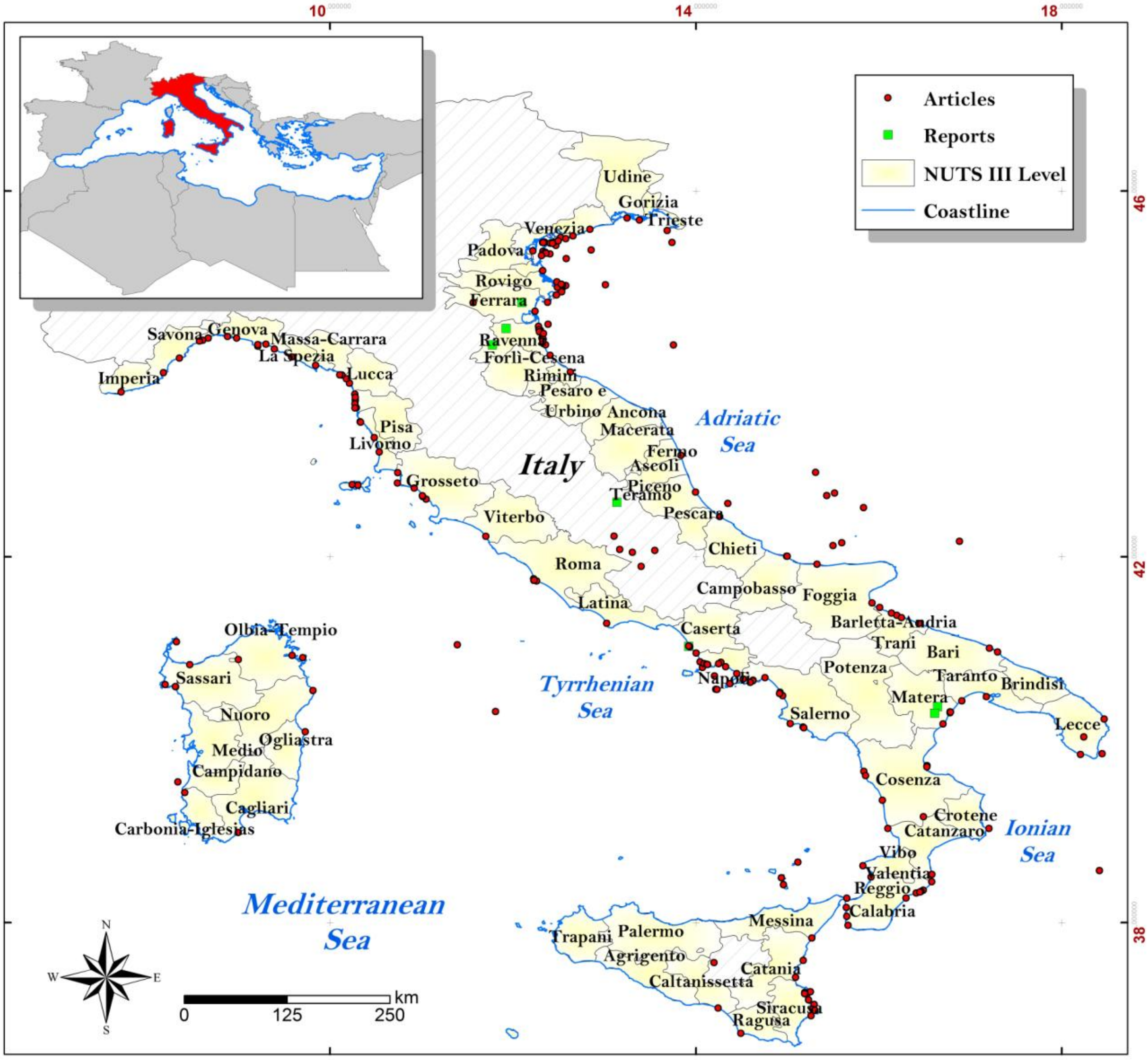

Distribution of articles and reports along the Italian coast. The points located offshore, but not close to the littoral, represent studies performed at NUTS I scale, whereas those placed inland refer to researches carried out at NUTS 0 scale.

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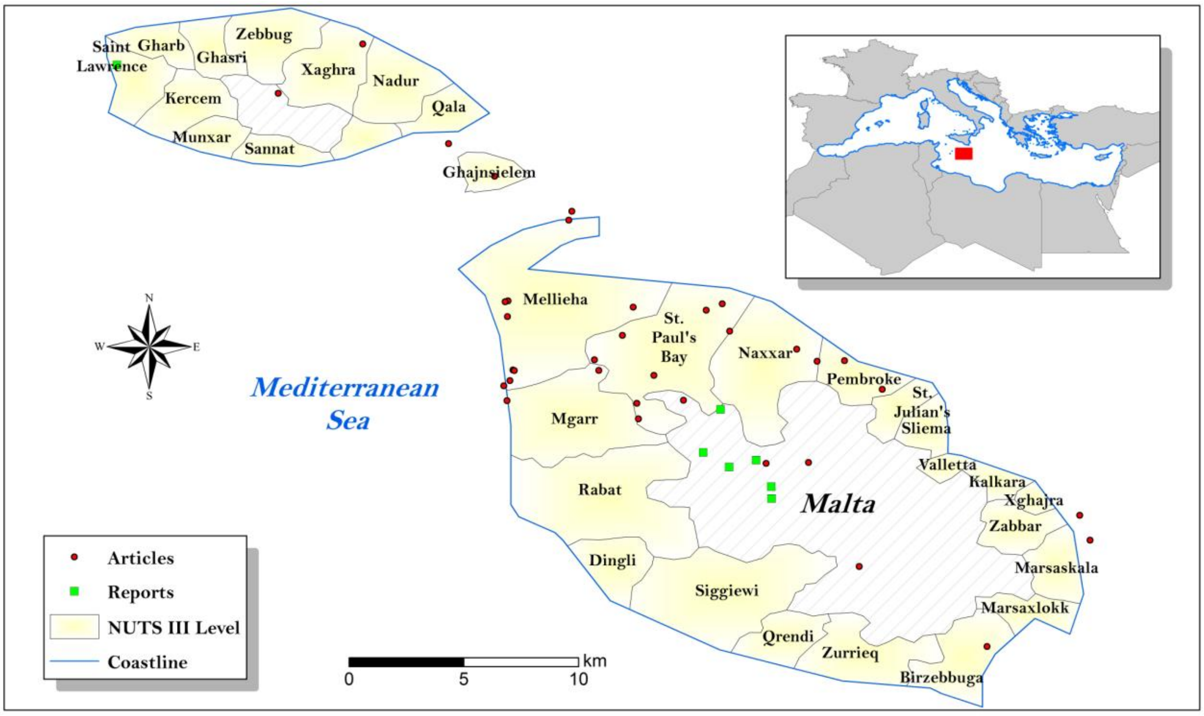

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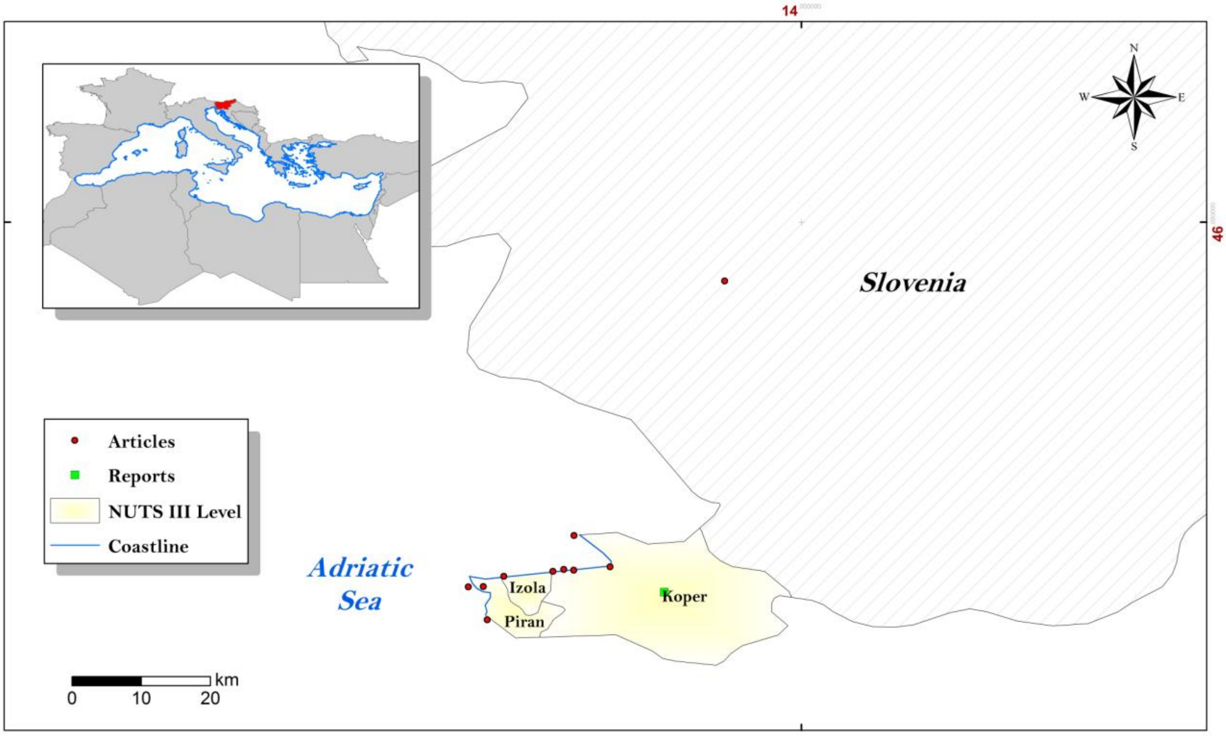

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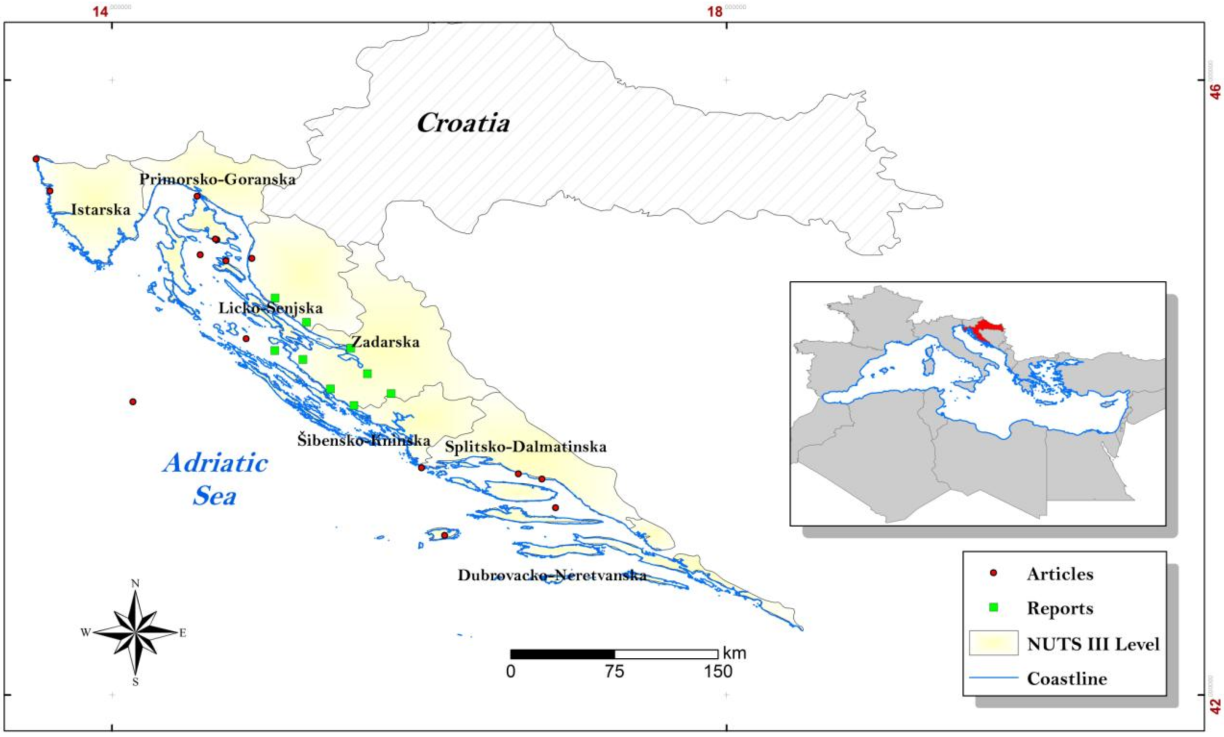

Distribution of articles and reports along the Croatian coast. The points located offshore, but not close to the littoral, represent studies performed at NUTS I scale, whereas those placed inland refer to researches carried out at NUTS 0 scale.

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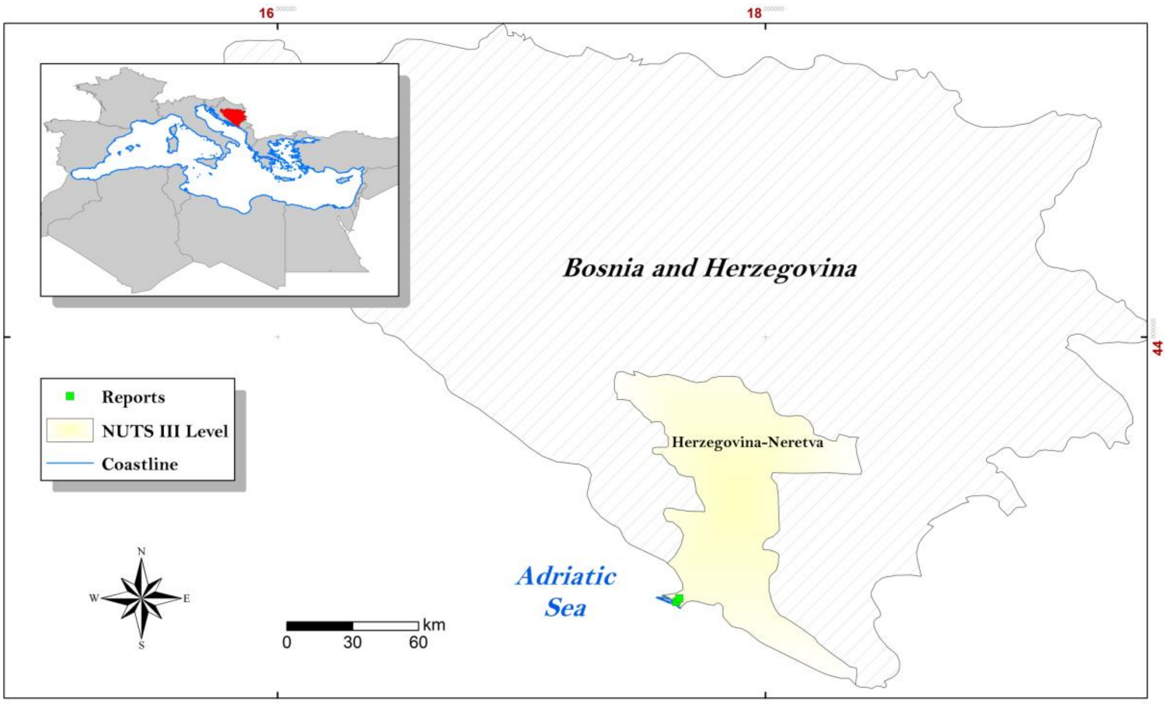

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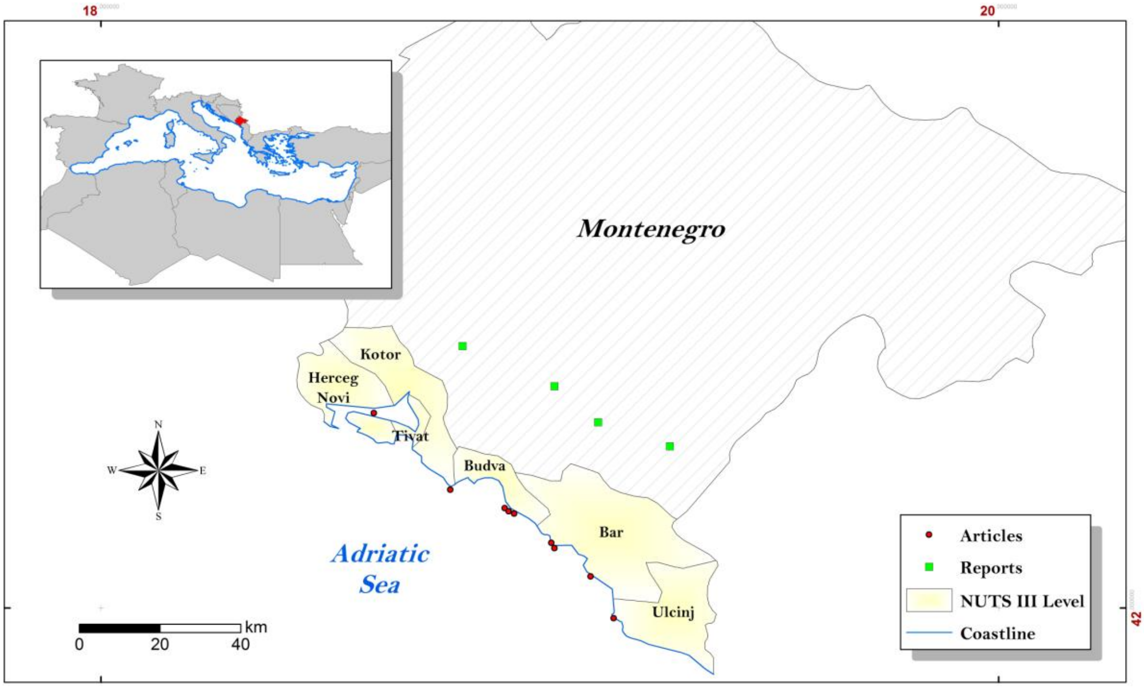

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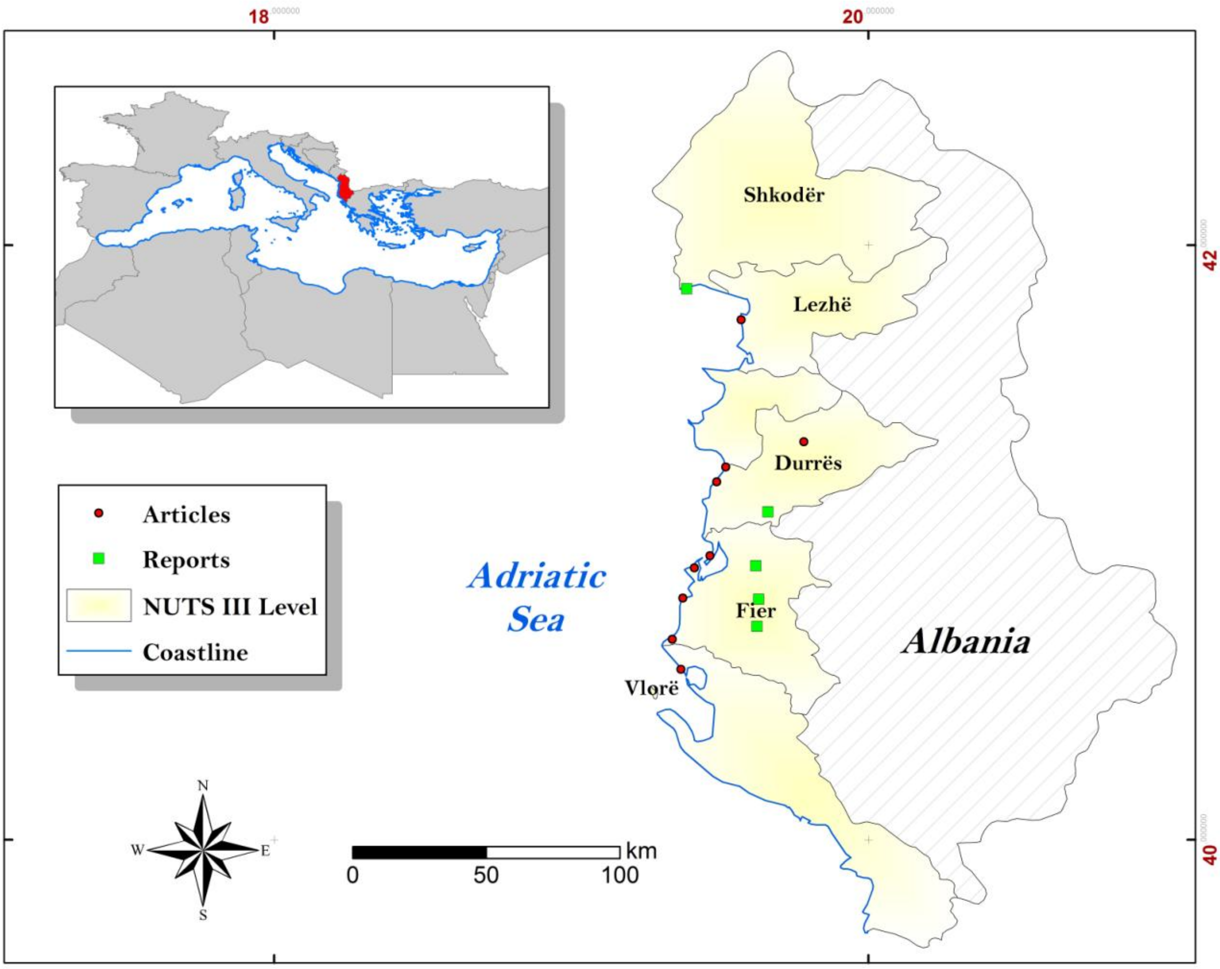

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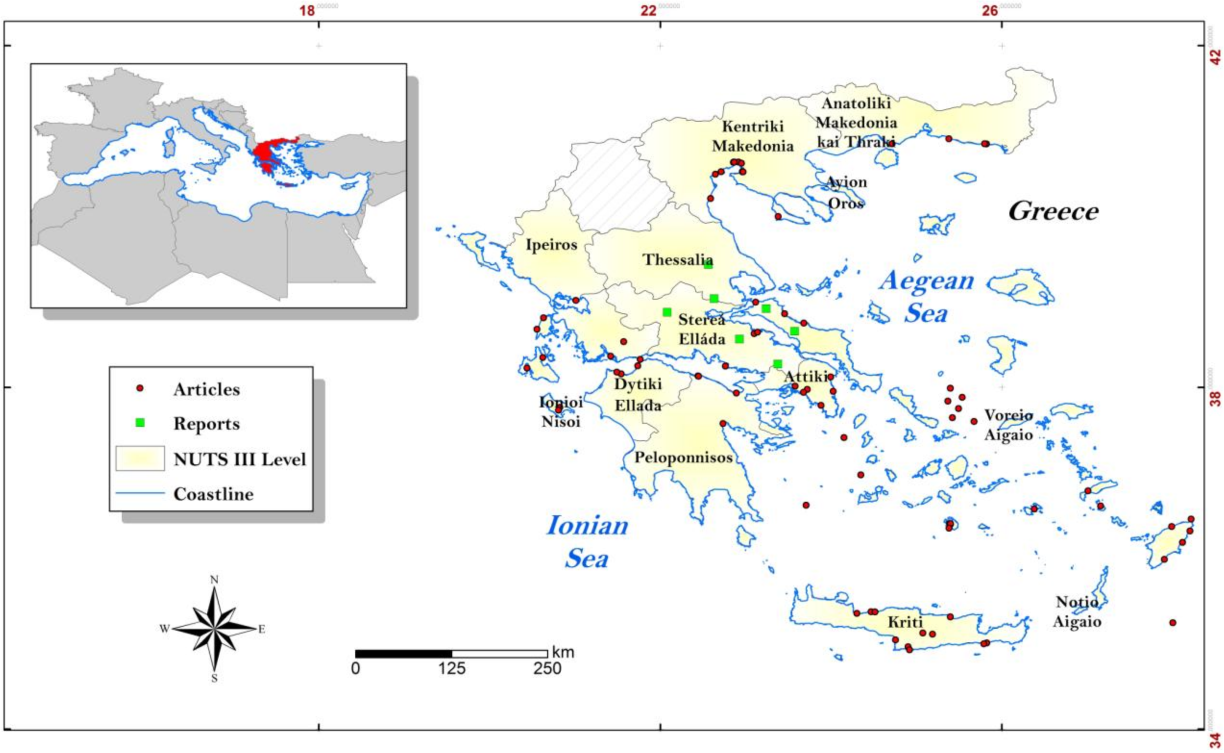

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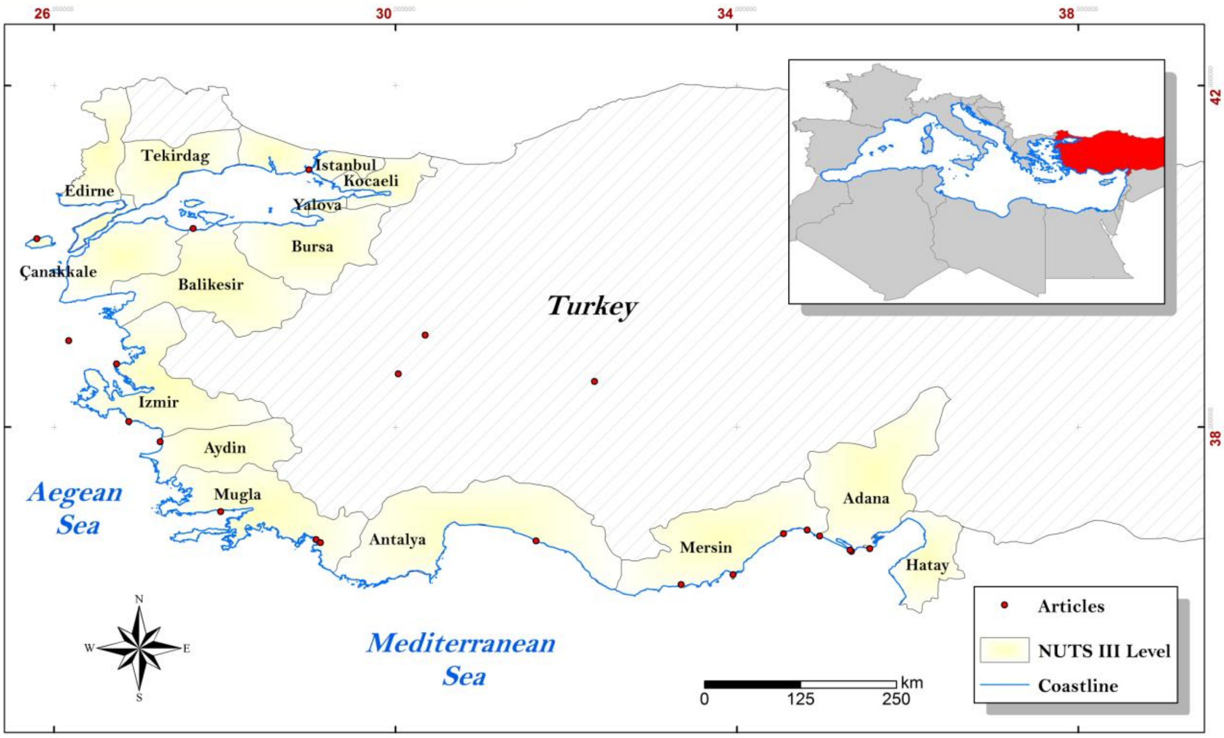

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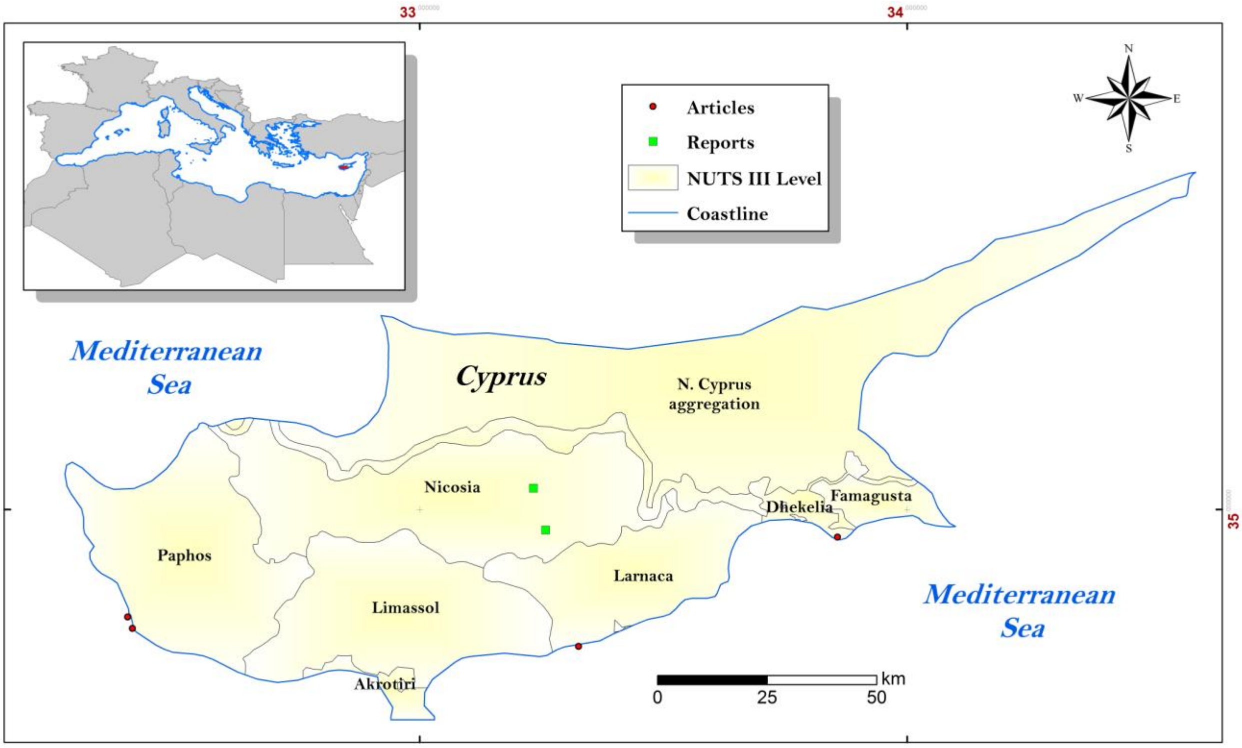

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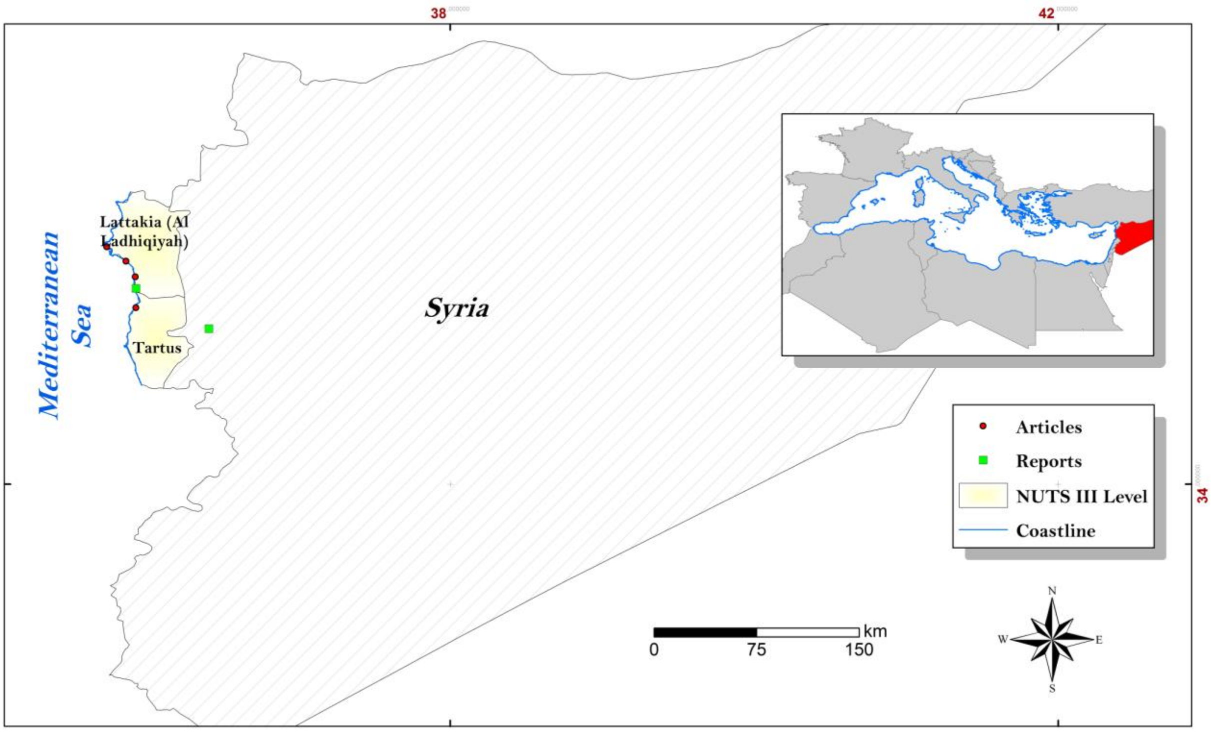

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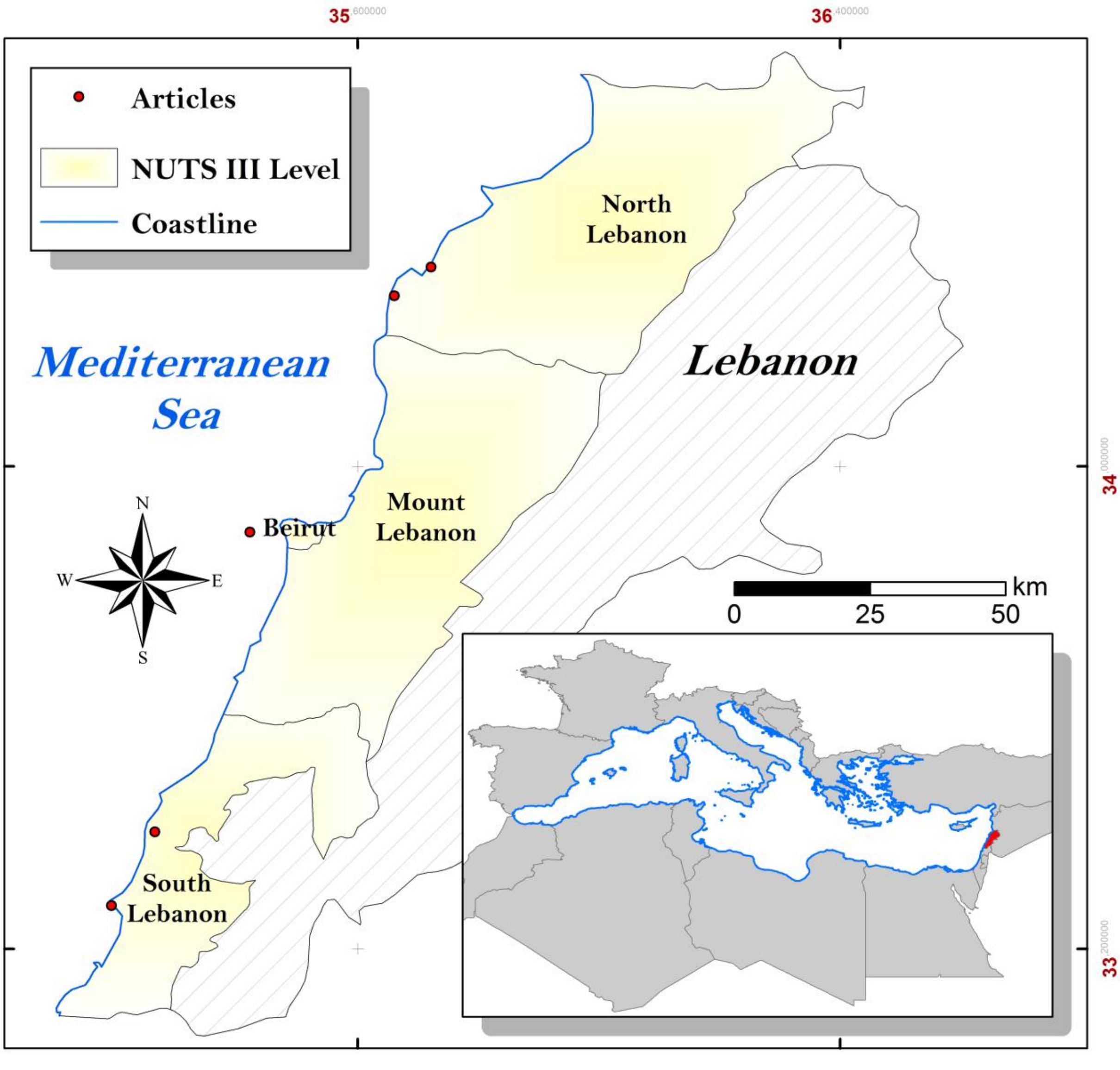

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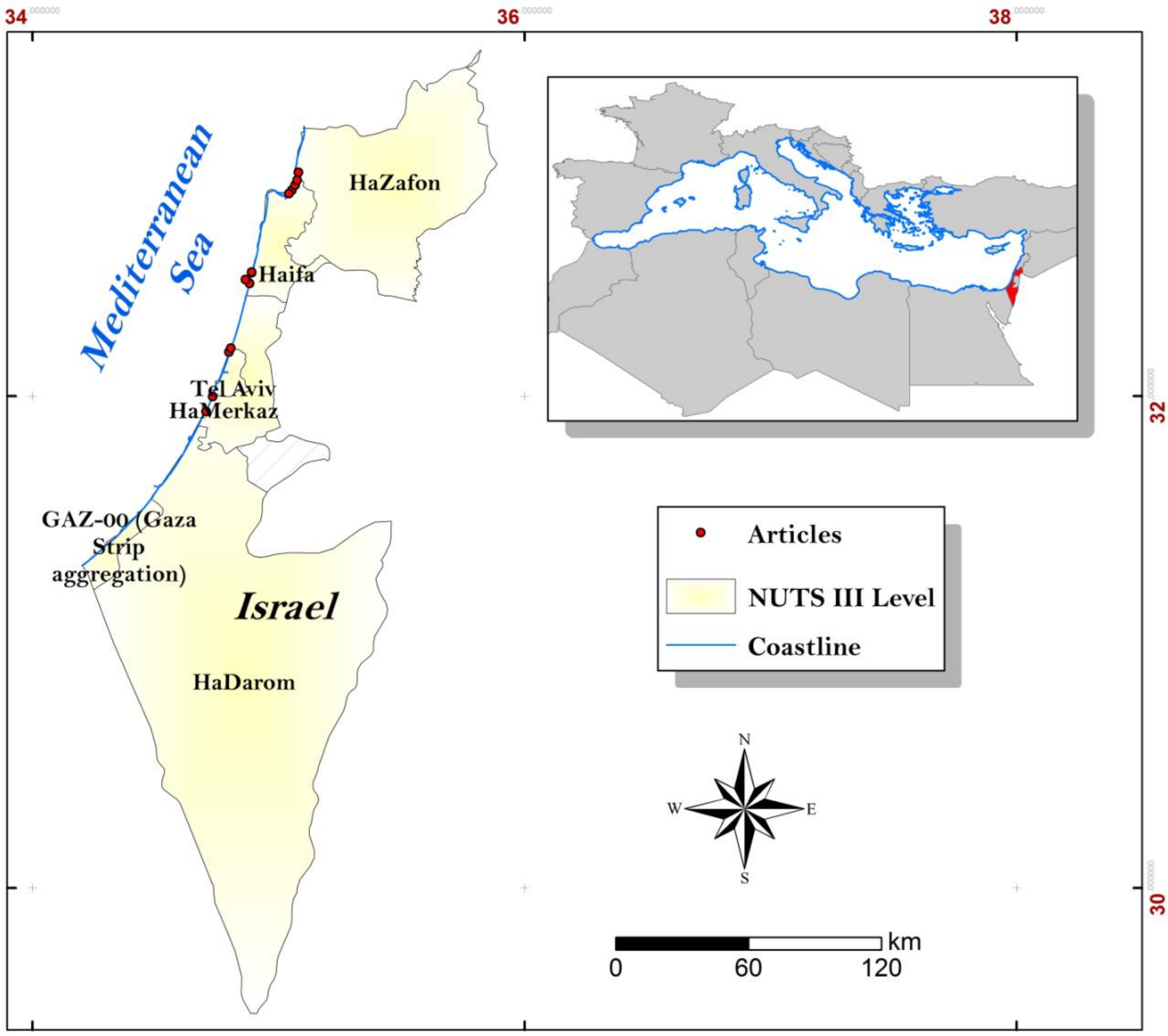

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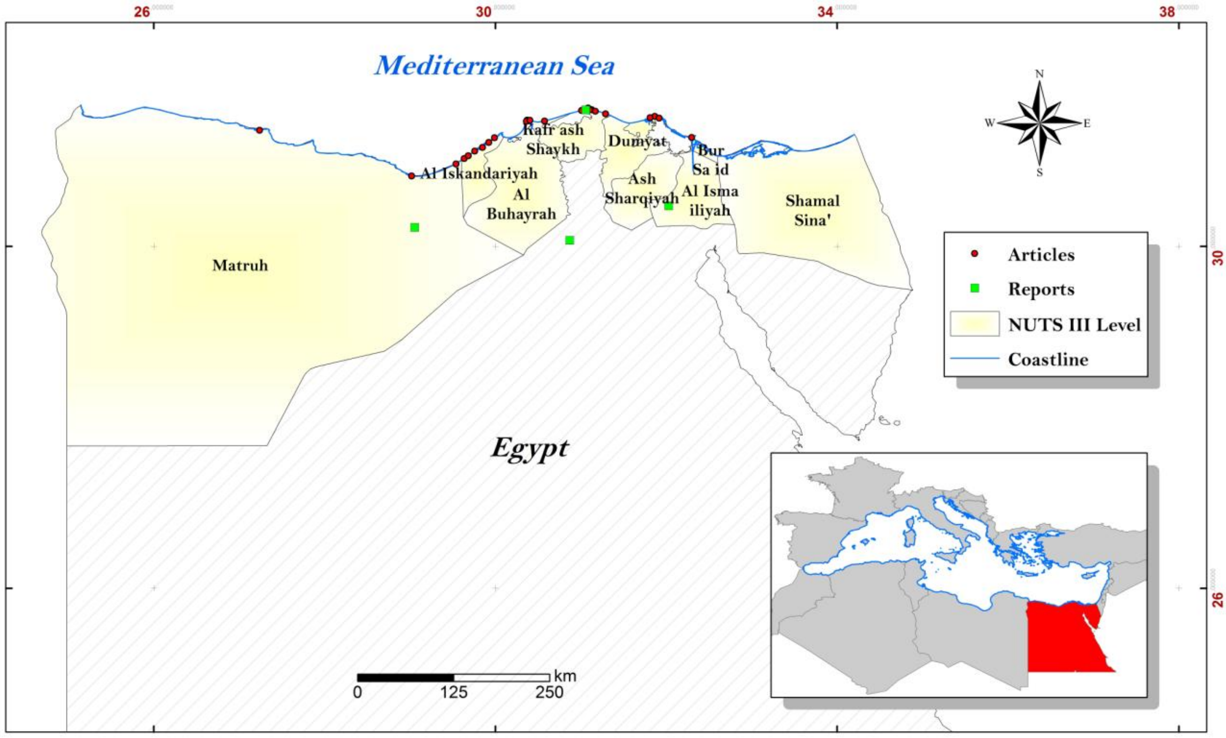

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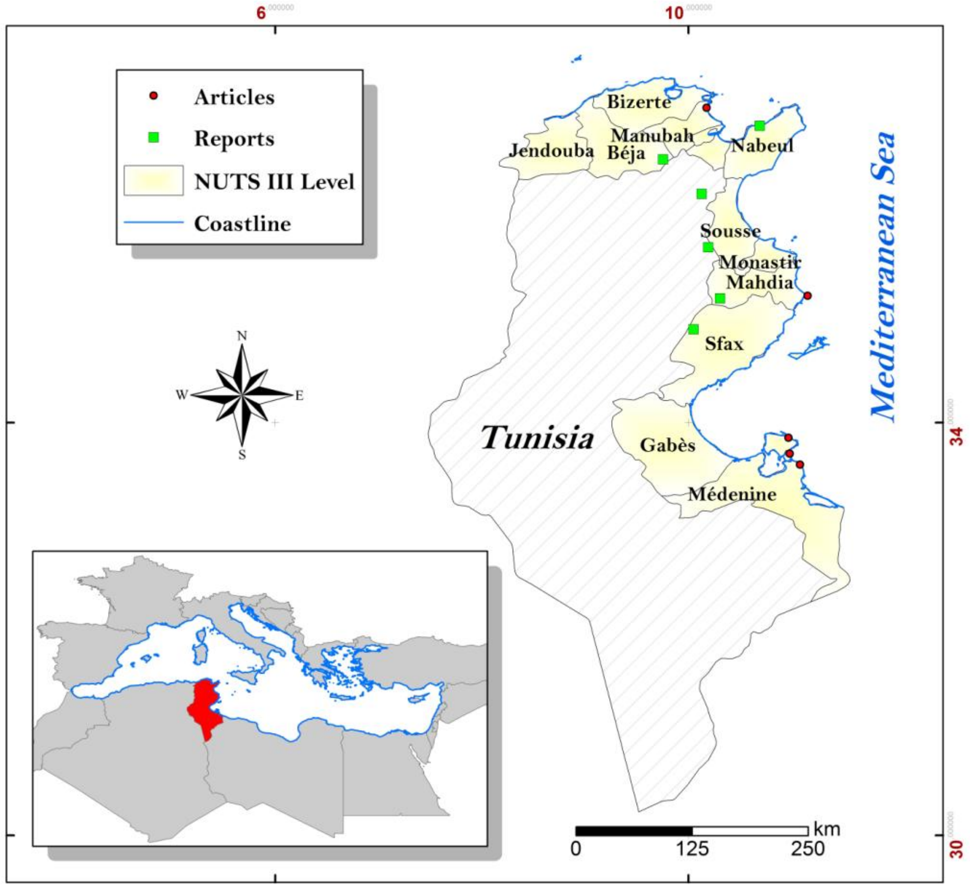

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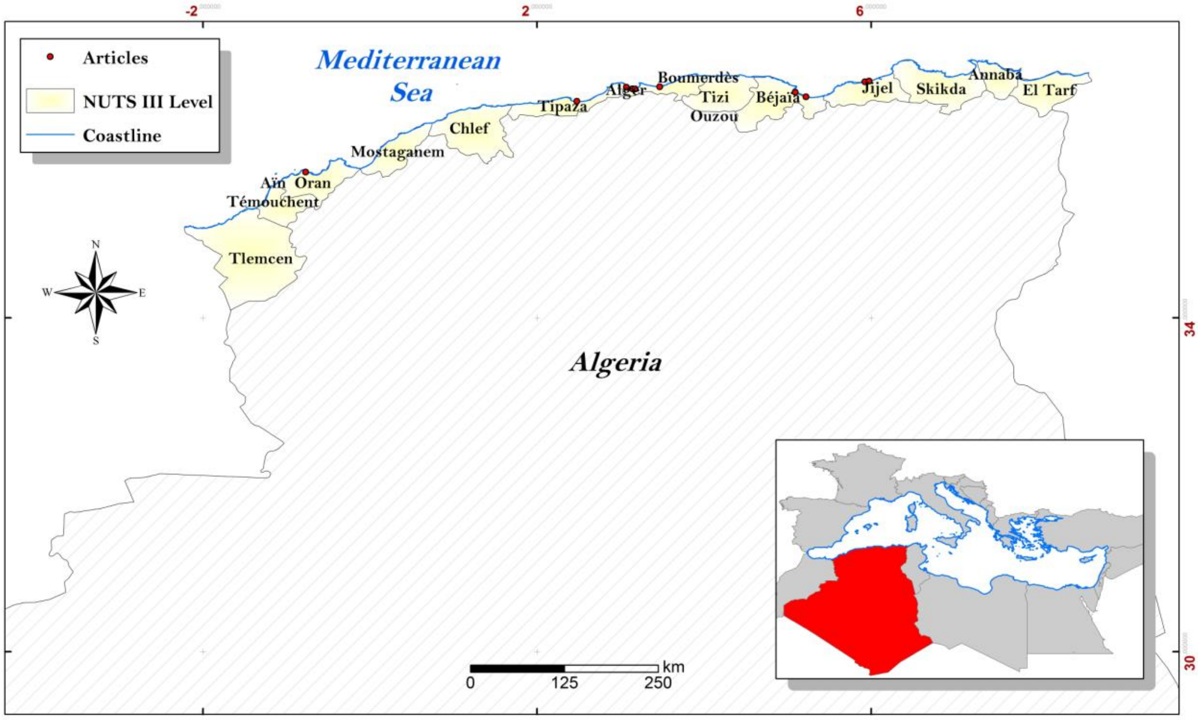

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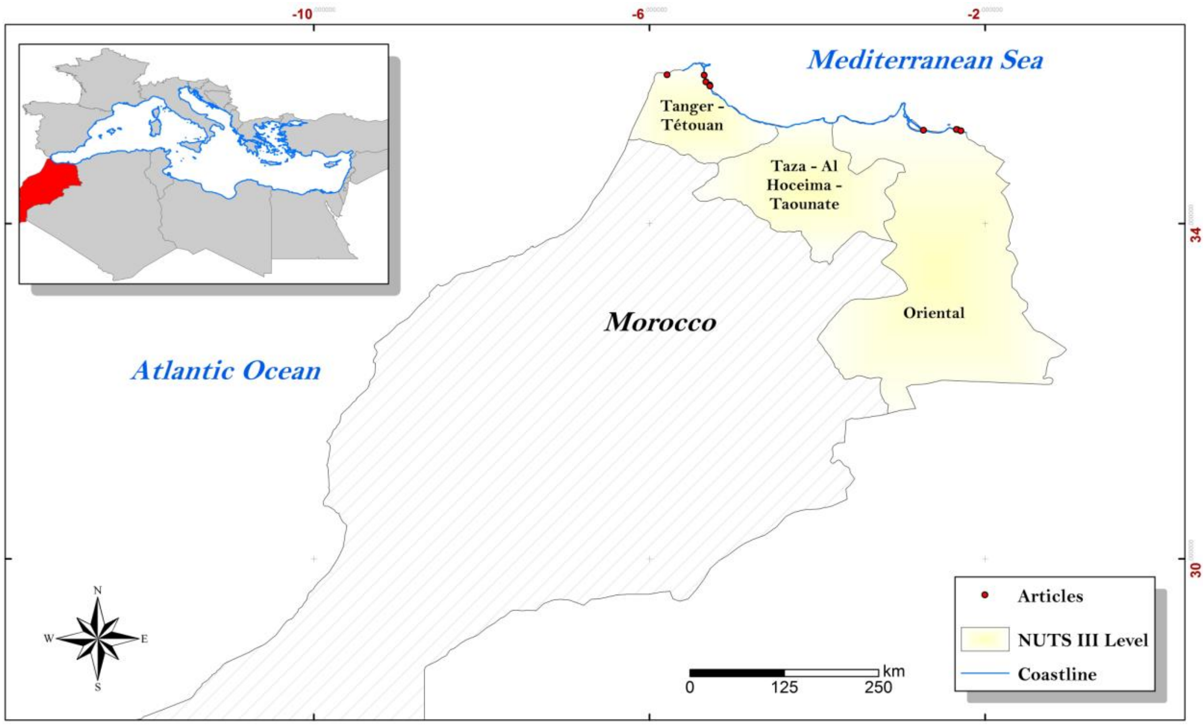

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