Mapping and Modelling Coastal Protection at National Level: A Study on Greece's Coastal Zone

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July 2021

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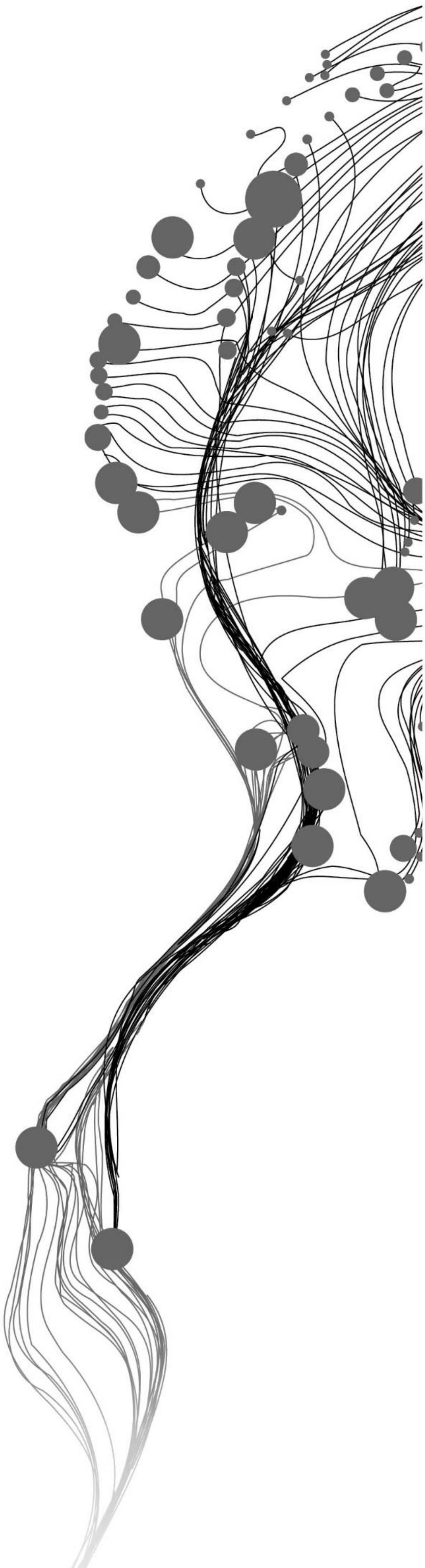

Mapping and Modelling Coastal Protection at National Level: A Study on Greece's Costal Zone

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ABSTRACT

Marine and coastal ecosystems are providing many kinds of ecosystem services for human-wellbeing including coastal protection. The number of research initiatives in the marine and coastal ecosystem service domain is increasing over time, but still, many marine and coastal ecosystem services such as coastal protection have not been yet assessed and mapped in various spatial scales despite having importance in policy decisions for ecosystem management and restoration. A regional level study has been conducted by providing a methodological and conceptual framework to assess and map coastal protection for the entire EU coastal zone which has opened the possibilities to incorporate coastal protection assessment in marine spatial planning at different spatial scales. This thesis adapted and downscaled the regional level model to the national scale in order to assess the model applicability at different spatial scales. The aim was dual: a) to map coastal protection at the national level and b) to assess the difference in the outcomes between the regional level and national level model. To downscale the model at the national level, the entire Greek coastal zone was chosen. The coastal zone has been delineated by considering the hydrodynamic, climatic, oceanographic, and socio-cultural conditions of the Greek coast. Coastal protection of the Greek coast has been assessed through three indicators namely, coastal protection capacity, exposure, and demand. To assess these indicators, 20 variables have been selected based on the literature search and the biophysical and socio-economic condition of the Greek coast. Expert opinion has been collected through an online survey in order to weigh the contribution of the selected variables. Within the results, no clear pattern of coastal protection capacity has been seen for the Greek coast. A continuous pattern has been seen for coastal protection exposure indicator and it has been identified that southern coastal areas of Greece are more exposed to natural hazard than the northern coastal areas. The higher the coastal protection demand of the Greek coast has been seen near the big cities such as Athens or Thessaloniki. To compare with the outcome of the regional level model, RMSE has been calculated of the variables and indicators that are similar in both models. From RMSE values of indicators, a relatively high discrepancy has been observed for coastal protection capacity indicator. A relatively higher similarity was seen for coastal protection exposure and demand indicators with some minor differences. These differences of both models might be the results of the differences in the demarcation process of coastal zone and development of calculation unit. The overall result suggests that the outcomes of the national level model can contribute more effectively to national-level policy decisions than the outcomes of the regional model.

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1. INTRODUCTION

1.1. Ecosystem services in the coastal zone

Ecosystem services are "the benefits that people derive from ecosystems" (MEA, 2005). These benefits include all the necessary elements for human beings such as food, clean water, medicine, and recreational facilities. The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) defined ecosystem services as "nature's contribution to people" and identified human-nature interaction as a key point for ecosystem services supply (S Díaz et al., 2019). Burkhard & Maes, (2017) also emphasized human dependency on a well-functioning ecosystem and natural capital and defined ecosystem services as the contribution of the ecosystem's biophysical structure and its associated function to human wellbeing. To maintain a constant flow of ecosystem services from the terrestrial and marine environment to society, human-environment relation is fundamental. This human-nature relation varies from terrestrial to marine environment due to the complexity of the ecological setting of marine and coastal environment (Walsh & Mena, 2016).

Coasts are considered as one of the most preferred places for human settlement where population density is three times higher than the global average density (Small & Nicholls, 2003). In Europe, more than 200 million people live in areas within 50 km of the sea (Eurostat, 2018). Some European countries for example Greece accommodates more than 55% of its total population in the coastal region (Polyzos & Tsiotas, 2012). The coastal areas are preferred for human living as they provide services (from marine and coastal ecosystems) essential for the sustenance of human life on the planet (Drakou et al., 2017a, Lopes & Videira, 2013, MEA, 2005). According to an estimation of 2014, around 40% of the total economic value of the biosphere are received from oceans and coastal zone (Costanza et al., 2014). Due to the overexploitation of marine and coastal resources by humans, many marine and coastal ecosystem components such as 50% of salt marshes, 35% of mangroves, 30% of coral reefs, and 29% of seagrasses are either lost or degraded worldwide over several decades (Valiela, Bowen, & York, 2001, MEA, 2005, Orth et al., 2006, UNEP, 2006, FAO, 2007, Waycott et al., 2009). Besides, due to changing climatic conditions, coastal areas are experiencing more erosion and disastrous events like floods which not only causing large social and economic damages but also responsible for loss of coastal biodiversity (Nicholls & Klein, 2005). For example, Greece alone lost more than 1 billion EUR since 2000 due to flood-related disasters (EIB, 2019).

Though marine and coastal environments provide many ecosystem services (Liquete et al., 2013a), there is no universal consensus about the demarcation of the coastal zone. In most cases, defining the coastal zone depends on the problem to be addressed or the objective of the study or scale of analysis (Liquete, Zulian, Delgado, Stips, & Maes, 2013b). For instance, Denmark in their Planning Act 1991, defined coastal zone as an area expanded up to 3 km inland from the coast whereas Spain in their Shores Act 1988 demarcated coastal zone up to 200m from the coast (Lavalle, Gomes, Baranzelli, & e Silva, 2000). On the other hand, according to the law 2971/2001, the Greek coastal area is extended up to 50m inland from the seashore (Doukakis, 2004, Giannakourou & Balla, 2015). European Commission Demonstration Programme on Integrated Coastal Zone Management (ICZM) defined the coastal zone as "a strip of land and sea of varying width depending on the nature of the environment and management needs. It seldom corresponds to existing administrative or planning units. The natural coastal systems and the areas in which human activities involve the use of coastal resources may therefore extend well beyond the limit of territorial waters, and many kilometers inland" (European Commission, 2020a).

Gordon & Barron, (2013) mentioned that most of the ecosystems that have been registered by the Millennium Ecosystem Assessment (2005) are directly or indirectly influenced by the geological/geomorphological, hydrological, or biological processes and factors of the coastal zone, that claim the potentiality of the coastal zone in terms of providing ecosystem services. Furthermore, marine and coastal areas are comprised of a wide variety of components such as mangroves, coral reefs, seagrass beds, deltas, estuaries, beaches, or bays which ensure the services in many forms. Ecosystem services that are received from marine and coastal ecosystems can be classified under three broad categories such as provisioning, regulatory and maintenance, and cultural services (Liquete et al., 2013a). A brief overview of the marine and coastal ecosystem services, their components, and descriptions are documented in Table 1.

To make the balance between the demand of marine and coastal ecosystem services and limit degradation of the ecosystem of coastal zone many policies such as 'UK Marine and Coastal Access Act 2009 (MCAA)', 'EU Marine Strategy Framework Directive 2008 (MSFD)', 'US National Ocean Policy 2013', 'EU Integrated Maritime Policy 2012', 'IMO Convention on Ballast Water Management 2004', 'UN Convention on Biodiversity 1992' are employed globally (Börger et al., 2014). As the policy decision is usually based on reliable estimation of current and expected trends of ecosystem services supply and their economic values, it needs proper quantification, assessment, and mapping of ecosystem services (Stępniewska, 2016, Maes et al., 2012). Moreover, quantification and mapping of supply and demand of marine and coastal ecosystem services can develop a baseline to assess the policy decision and can support the development of a financial instrument to invest in ecosystems (Maes et al., 2012). The inclusion of ecosystem services assessment and mapping in policy and decision-making process can help to decide where and how to restore the ecosystem or conserve the biodiversity, or how much investment is required to ensure multiple services from the ecosystem (Maes et al., 2012). Ecosystem services assessment and mapping have already been proven as an essential technique for the protection of the terrestrial environment and in recent times it is also getting more importance in coastal and marine spatial planning, coastal management, and protection (Garcia Rodrigues, Villasante, Drakou, Kermagoret, & Beaumont, 2017, Liquete et al., 2013a).

Though the number of research initiatives is increasing for mapping marine and coastal ecosystem services at different spatial and temporal scales, many marine and coastal ecosystem services are yet to be mapped and explored (Liquete et al., 2013a). Moreover, due to the multidimensionality of the marine and coastal environment (Drakou et al., 2017b), most of the services could not be directly quantified and needs proxy indicators (Liquete et al., 2013a). Besides lack of spatial data and difficulties in identification of service providing and benefiting areas also act as constraints in the research of this domain (Townsend et al., 2018). In marine and coastal ecosystem service research domain, most of the assessment and mapping initiative has been taken to assess and map provisioning services (Liquete et al., 2013a). Some researchers have also tried to assess and map regulatory ecosystem services (such as climate regulation) (Donato et al., 2011, Lal, 2008), but not many attempts have been seen to assess the ecosystem's potential to provide protection to the coast. Liquete et al., (2013b) tried to assess and map coastal protection as an ecosystem service for the entire European coast and suggested to reproduce their initiative at different spatial scales.

Table 1: List of main ecosystem services supplied from the coastal zone (Liquete et al., 2013a, Elliff & Kikuchi, 2015)

Types of ecosystem services	**Ecosystem service**	**Description**	**Marine/Coastal ecosystem components**
Regulatory and maintenance services	Water purification	Biochemical (such as nitrogen retention for treating human wastes, bioaugmentation after marine oil spills, oxygenation of "dead zones", decomposition) and physicochemical (such as sedimentation, trapping or sequestration, filtration and absorption; remineralization) processes involved in the removal of wastes and pollutants from the aquatic environment.	Estuaries, mangroves, coastal lagoons, wetlands, seagrass, coral reefs

	Air quality regulation	Due to the physical structure and microbiological composition of vegetation (e.g., in mangroves), soil (e.g., in wetlands), and water bodies (e.g., open ocean) they can absorb air pollutants like particulate matter, ozone, or sulfur dioxide which can regulate the concentration of air pollutants in the lower atmosphere.	Estuaries, mangroves, coastal lagoons, rocky shores, seagrass, coral reefs, continental shelf
	Coastal Protection	The natural defence system of the coastal zone against floods, hurricanes, erosion, wave actions, or sea-level rise. For example, coastal habitats formed from biogenic and geologic structures of the coast can control the water movement to stabilize sediments which can create protective buffering zones.	Beaches, estuaries, mangroves, coastal lagoons, Kelp forests, rocky shores, seagrass, coral reefs
	Climate regulation	Regulation of greenhouse and climate active gases through uptake, storage, and sequestration of carbon dioxide. The oceans act as a sink for greenhouse and climate-active gases and inorganic carbon can also be dissolved into the seawater.	Estuaries, mangroves, coastal lagoons, rocky shores, seagrass, coral reefs, continental shelf
	Weather regulation	Regulation of local weather conditions such as thermoregulation and relative humidity. For example, coastal vegetation and wetlands influence air moisture and that has an impact on the saturation point and cloud formation.	Estuaries, mangroves, coastal lagoons, rocky shores, seagrass, coral reefs, continental shelf
	Ocean nourishment	Regulation of soil quality and pedogenesis.	Estuaries, mangroves, coastal lagoons, Kelp forests, rocky shores, coral reefs, inner continental shelf
	Life cycle maintenance	Healthy and diverse reproduction of species (such as pollination, seed, and gamete dispersal) by organisms through biological and physical support such as the maintenance of key habitats that act as nurseries, spawning areas, or migratory routes.	seagrasses, coastal wetlands, coral reefs, mangroves
	Biological regulation	Biological control of pests (role of cleaner fishes in coral reefs), the spread of vector-borne human diseases, and potentially invasive species.	Estuaries, mangroves, coastal lagoons, rocky shores, coral reefs
Provisioning services	Food provision	The provision of biomass for human consumption and maintaining the conditions to grow it. It involves cropping, animal husbandry, and fisheries (both industrial and artisanal)	Estuaries, mangroves, coastal lagoons, Kelp forests, coral reefs, rocky shores, seagrass
	Water storage and provision	The provision of water for human consumption and other uses (such as industrial cooling processes or coastal aquaculture in ponds).	Rivers, lakes, aquifers
	Biotic material and biofuels	The provision of biomass or biotic elements for non-food purposes such as medicinal (e.g., drugs, cosmetics), ornamental (e.g., corals, shells), and	Beaches, estuaries, coral reefs, mangroves, inner continental shelf

		other commercial or industrial resources (e.g., fuels extracted from algal lipids or whale oil, biogas from decomposing material, fishmeal, seal leather, algal or plant fertilizers, wood).	
Cultural services	Symbolic and aesthetic values	The happiness of observing and enjoying landscapes, habitats, or species. For instance, the existence and beauty of charismatic habitats and species such as coral reefs or marine mammals have a great value to both coastal and inland societies.	Beaches, estuaries, mangroves, coastal lagoons, Kelp forests, rocky shores, coral reefs
	Recreation and tourism	Capabilities of the natural environment to provide relaxation and amusement that may be linked to the wilderness, sports, or iconic landscapes and species.	Beaches, estuaries, mangroves, coastal lagoons, Kelp forests, rocky shores, coral reefs
	Cognitive effects	Inspiration for arts and applications (e.g. architecture designs) by knowing, developing, perceiving, or being aware of natural landscapes or living organisms	Beaches, estuaries, mangroves, coastal lagoons, rocky shores, seagrass, coral reefs, inner continental shelf

1.2. Coastal protection as an ecosystem service

Coastal protection is the actual benefit derived from the ecosystem's regulatory capacity to protect coastal zone against inundation, erosion from waves, storms and sea-level rise or other natural hazards and disasters (MEA, 2005, TEEB, 2010, Guisado-Pintado, Navas, & Malvárez, 2016). The potential of the natural landscape for mitigating the effect of coastal disaster has been neglected for long (Liquete et al., 2013b). Globally, the common practice for protecting coastal areas is relying on "hard" measures such as building seawalls or bulkheads (Rosenzweig et al., 2011, Sterr, 2008). Those measures are highly effective in many cases but require a huge amount of money for construction as well as for maintenance (Anthony & Gratiot, 2012, Bosello, Nicholls, Richards, Roson, & Tol, 2012). Moreover, those "hard" structures are not damage-proof, they can fail and in many cases, they trigger coastal erosion (Saengsupavanich, Chonwattana, & Naimsampao, 2009) and hinder biodiversity protection and provision of ecosystem services (e.g. loss of habitat due to building dykes and dams) (Elosegi, Díez, & Mutz, 2010). On the contrary, many coastal zones provide natural protection capacity against erosion, flood, and other natural disasters as ecosystem services (Spalding et al., 2014). For instance, if any coastal zone is flourished with salt marshes or mangroves or dense vegetation cover, it generates resistance capacity against wave energy, flow velocities, turbulent flows, and erosion in the bank and increases sediment deposition which may promote accretion and formation of new lands (Gedan, Kirwan, Wolanski, Barbier, & Silliman, 2011, Shepard, Crain, & Beck, 2011). Mangrove forests can slow down the storm surges and it has been estimated that 4 to 40 cm of surge height can be reduced per km of the passage of mangrove (Mcivor, Spencer, Möller, & Spalding, 2012, Zhang et al., 2012). Furthermore, seagrass beds weaken both ocean waves and current and help in capturing and storing sediment that leads to vertical accretion of the sea bed and regulates erosion (Spalding et al., 2014). In addition to this, coral reefs are also considered as a front line of coastal defense in many coastal zones as those have a strong influence on the reduction of coastal erosion due to the surface roughness and abilities to form habitat for other species (Sheppard, Dixon, Gourlay, Sheppard, & Payet, 2005). Apart from this, beaches, dunes, barrier islands, and shallow nearshore habitats reduce the wave energy and promote sediment deposition which ultimately helps in the formation and maintenance of coastline by increasing the adaptation capacity to sea level change (Defeo et al., 2009). In some cases, human beings use nature to increase nature's capability to protect the coast from disasters (Rijkswaterstaat, 2020). In most cases, the coastal ecosystem not only protects the coastal area from disaster but also ensures sustenance of life by providing food, fresh water, and recreational facilities. Therefore, to get the maximum benefit from the marine and coastal environment proper assessment and mapping of ecosystem services is essential. But due to the complexity of the coastal and marine system as well as lack of data, it is difficult to assess and map the ecosystem service flow of the coastal environment, which is one of the reasons behind the limited inclusion of ecosystem service information in decision making and planning process for coastal protection (Liquete et al., 2013a).

1.3. Quantifying and modelling coastal protection

The coastal zone in Europe is experiencing an increasing rate of erosion due to the rise of sea level, increasing frequency of storm surge, reduction of sediment supply in the coast as well as by human intervention (EEA, 2006). In Greece, over 20% of the total coastline is under severe erosion threat (Eurosion, 2004), which makes Greece the 4th vulnerable country among 22 coastal European member states in terms of physical impacts (Kontogianni, Tourkolias, Damigos, & Skourtos, 2014). Along with strong winds and storm surges in the Aegean Sea, anthropogenic intervention has been identified as the main cause of coastal erosion in Greece (Kontogianni et al., 2014). Apart from erosion, the Greek coast is also vulnerable due to sea-level rise. It has been estimated that around 6% of the Greek coast is highly vulnerable and 21% of the coast is medium to highly vulnerable due to sea-level rise (Kontogianni et al., 2014). The increasing coastal vulnerability has been experienced by most of the coastal countries and considering this issue attempts have been taken to explore the nature-based solution for coastal vulnerability problems (e.g., erosion, flooding) by addressing the ecosystem's potential in various spatial scale (EEA, 2006). Most of the assessment of coastal protection were focusing on specific ecosystem types such as mangrove forests (Granek & Ruttenberg, 2007, Barbier et al., 2008), seagrass meadows (Bos, Bouma, de Kort, & van Katwijk, 2007), coastal wetlands (Costanza et al., 2008), sand dunes (Everard, Jones, & Watts, 2010) and coastal wildlife habitats (Koch et al., 2009) and its role in coastal protection. Some researchers took initiative to see coastal protection only from the demand perspective and its associated economic valuation (Pascal et al., 2016, Alves et al., 2009). In some cases, the researcher tried to explore the non-linearity and spatial and temporal variability in coastal protection service (Koch et al., 2009) and also tried to incorporate coastal protection directly into management practice (Barbier et al., 2008). Besides research initiative has also been taken to develop tools such as Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST), Artificial Intelligence for Ecosystem Services (ARIES) and Multiscale Integrated Models of Ecosystem Services (MIMES), etc. to assess risks from flooding and erosion, and to estimate coastal protection benefits from natural habitats (Kroeker, Reguero, Rittelmeyer, & Beckd, 2016). In continuation to this, Liquete et al., (2013b) assessed and mapped the ecosystem's coastal protection capacity for the entire European coast. They tried to include all the relevant and available ecosystem components of the European coast and its provided protection capacity. Moreover, they also incorporated many oceanographic and hydro-meteorological factors that poses threat to coastal areas of Europe. In their study, they followed the ecosystem services cascade framework (Haines-Young & Potschin, 2010) to assess the overall protection capacity, exposure, and protection demand of the European coast. Similar work has been carried out by Guisado-Pintado et al., (2016) for a local scale in a highly urbanized area of southern Spain where coastal exposure to hazards is increasing due to the urban and tourism activities. They also adapted indicators developed by Liquete et al., (2013b) for the European scale for coastal protection services (capacity, flow, and benefit). These kinds of modelling and mapping approaches have direct application in many policies and planning processes. For instance, the EU Biodiversity Strategy to 2030 can directly be addressed in the protection and restoration of marine and coastal ecosystem by these kinds of approach (European Commission, 2020b). These approaches can also increase the chance for success in the restoration of the coastal ecosystem which is one of the prime aspects of "UN Decade on Ecosystem Restoration 2021–2030"

(Waltham et al., 2020). Besides, assessment and mapping of the coastal ecosystem can also support the implementation of the EU Floods Directive (Directive, 2007/60/EC) (Tsakiris, Nalbantis, & Pistrika, 2009). Apart from these, being concerned about the increasing coastal hazard and its associated impact on people living near the coast, the European Union Directives and Horizon 2020 strategies initiative has been taken to develop a common framework to manage disastrous events. For this, quantification and evaluation of ecosystem services provided by coastal systems have been given high importance to preserve both ecosystems and the benefits received from the system (Guisado-Pintado et al., 2016). In Greece, the policy-level initiative has also been taken in National Biodiversity and Action Plan (NBSAP) where producing maps of ecosystem services including marine and coastal ecosystem services has given utmost priority (Dimopoulos et al., 2017).

1.4. Research problem

Marine and coastal ecosystem services have been assessed in various spatial and temporal scales ranging from global to local and among which very few attempts have been seen to map and model coastal protection ecosystem service (Liquete et al., 2013a). Quantifying and mapping coastal protection poses severe challenges, because of the variation in the types of variables that contribute to it, the variety in indicators, the plural ways of measuring them, the heterogeneity across countries etc. Attempts of mapping coastal protection and vulnerability have been seen at broad spatial scales (Liquete et al., 2013b), which have a high degree of uncertainty and oversimplification or at very detailed local case studies (Guisado-Pintado et al., 2016, Tragaki, Gallousi, & Karymbalis, 2018, Gad, Chatzinaki, Vandarakis, Kyriakidou, & Kapsimalis, 2020), no attempt has been seen to map coastal protection at the national level. Besides, the extent to which the outcomes of a regional level model can be used to fully explain the national level scenario in terms of coastal protection has not been directly explored to our knowledge. Moreover, in a regional level study, many important coastal ecosystem components (such as local sediment budget) cannot be incorporated due to the lack of data in the appropriate scale of research. Besides, it is yet to be identified how much the national level model's outcome differs from the outcome of regional level models after including national scale ecosystem components. It is also not known, to what extent the outcome of a regional level study can be informative in a national-level policy for coastal protection. Other limitations refer to the fact that the coastal zone is demarcated for a regional level study in a way that may not appropriately include the characteristics of the coastal zone at the national scale for some countries. Besides, despite significant development in the marine and coastal research domain, there is still lacking of developing appropriate indicators to evaluate and map the coastal protection ecosystem service at different spatial scales (Guisado-Pintado et al., 2016). Considering these issues, this research work aims to adapt the regional level coastal protection model and downscale it at a national scale, while at the same time critically reflecting on the use of such a model for national level assessments. Downscaling the regional level model to a national scale requires harmonization of the different appropriate datasets which needs specific knowledge of data manipulation. Besides, the national-level study requires high-resolution data comparing with regional study, and in many cases finding a suitable dataset with required detailed information for the national-level study is challenging. At the national level, variation within data in spatial scale may not always be visible due to lack of systematic data collection and coarse resolution of data which may pose an extra challenge in modelling and assessing actual coastal protection capacity, flow, and demand. Besides, it is yet to be identified which ecosystem component is more influential and how they interact to generate function and ensure service flow for coastal protection at the national level. Considering these aspects, this research will examine the difference between regional level and national level coastal protection model outcomes and for this, the coastal zone of Greece has been chosen as an example.

1.5. Justification of the research

This research work aims at downscaling a regional level model of coastal protection to the national level. Most of the marine ecosystem assessments focused on food production such as fisheries (Alcamo et al., 2005) with less attention to other services like coastal protection (Liquete et al., 2013a). And most of the coastal protection works were conducted focusing on specific habitat types such as mangroves or seagrasses (Trégarot et al., 2021) rather than the entire coastal zone. This research work will contribute to scientific knowledge by downscaling a regional model to map coastal protection capacity, exposure, and demand at a national scale (Greece) by considering all the necessary and available data with the final intention to assess the discrepancies between the regional versus a national-level approach.

The societal contribution of this research work is to give the first national-level assessment of inland environmental protection provided to society at the national level (Greece).

1.6. Research objectives and questions

1.6.1. Main objectives

The main objective of this research work is to model and map ecosystem service for coastal protection by adapting and downscaling a European-wide model at the national level of Greece.

1.6.2. Research objectives and questions

A set of specific objectives and research questions have been developed to achieve the main research objective:

Objective 1: To identify the biophysical and socio-economic variables and indicators describing the ecosystem service of coastal protection supplied from the coastal areas of Greece.

i. Which are the biophysical variables and indicators that contribute to the coastal protection of Greece?
ii. Which are the socio-economic variables and indicators of the coastal areas that contribute to the coastal protection demand of Greece?
iii. What is the relative contribution of each biophysical and socio-economic variable in the country's coastal protection?

Objective 2: To downscale an existing regional level coastal protection model to the national level.

i. What are the processes to harmonize and normalize different types (such as biophysical and socio-economic) of data that come from different sources?
ii. What are the modelling approaches to downscale the regional level model to the national level?

Objective 3: To compare the downscaled national-level model with the regional one (European), in terms of model outputs.

i. What are the similarities and differences between the models in terms of data and indicators?
ii. What are the similarities and differences between the output of the models?
iii. For which areas in Greece, the downscaled model showed differences in the model outputs compared to the regional model?

1.7. Thesis outline

Chapter 1 provides the general introduction of the context and motivation of the research by explaining the concept of ecosystem services in the coastal areas, sketch out the problem statement by stating the state-of-the-art research condition in the coastal areas of Greece, outline the research objectives and research question to address the problem.

Chapter 2 is about the literature review of ecosystem service concepts, ecosystem services classification systems, and assessment and mapping techniques. This chapter tries to incorporate different tools, techniques, and methods used in the assessment and mapping of ecosystem services. It gives a brief overview of the indicators used in ecosystem service assessment especially in the marine ecosystem service domain. Moreover, it discusses the spatial context of mapping ecosystem services.

Chapter 3 outlines the methodology used in every step of this research work. This chapter includes the description of the study area in the context of coastal protection, delineation procedure of coastal zone and calculation unit, steps taken in data acquisition, pre-processing and data management, expert opinion collection procedure to weight variables used to assess indicators, modelling techniques applied for assessing coastal protection through indicators by adapting regional level model at national scale and finally simple statistical procedure followed in comparison of the models.

Chapter 4 presents the overall outcome of this research work. It includes a brief description of the coastal zone, expert profile and outcome of the questionnaire survey. The condition of the coastal zone through selected variables has also been discussed in this chapter. This chapter also includes the description of the national level model by discussing and mapping the coastal protection capacity, exposure, and demand indicators. This chapter also includes the maps and description of ecosystem service flow and benefits. Finally, it also includes the comparison of the outcome of the regional and national models.

Chapter 5 is about the discussion of the outcomes of selected indicators and the influence of associated variables. Why some areas of coastal Greece have higher protection capacity or exposure or demand than others and which variable has influenced more or what biophysical and socioeconomic condition is responsible for this have been included in this chapter.

Chapter 6 provides the conclusion and recommendations for this research work. The conclusion links the overall objectives of this research work, the methodology followed for this, and the outcome of the analysis by answering the research questions. It also includes the limitation that has been encountered during the research time and provides recommendations for future work.

2. LITERATURE REVIEW

2.1. Concepts of ecosystem services

2.1.1. Terminology

The idea of ecosystem services originates from the concept of valuing nature for contributing to human wellbeing (MEA, 2005). Over-exploitation of nature by humans has imposed tremendous pressure on ecosystem services (Rüdisser, Leitinger, & Schirpke, 2020). In such cases, mapping ecosystem services can be helpful to identify the ecosystem's health, volatility in service supply, the discrepancy in the spatial flow of ecosystem services, and disparity in ecosystem services supply and demand (Maes et al., 2012). Ecosystem services mapping includes mapping and assessing ecosystem properties and conditions, ecosystem services potential, supply, flow, and demand, all of which can be mapped either using qualitative and quantitative indicators or both (Burkhard & Maes, 2017) (Figure 1).

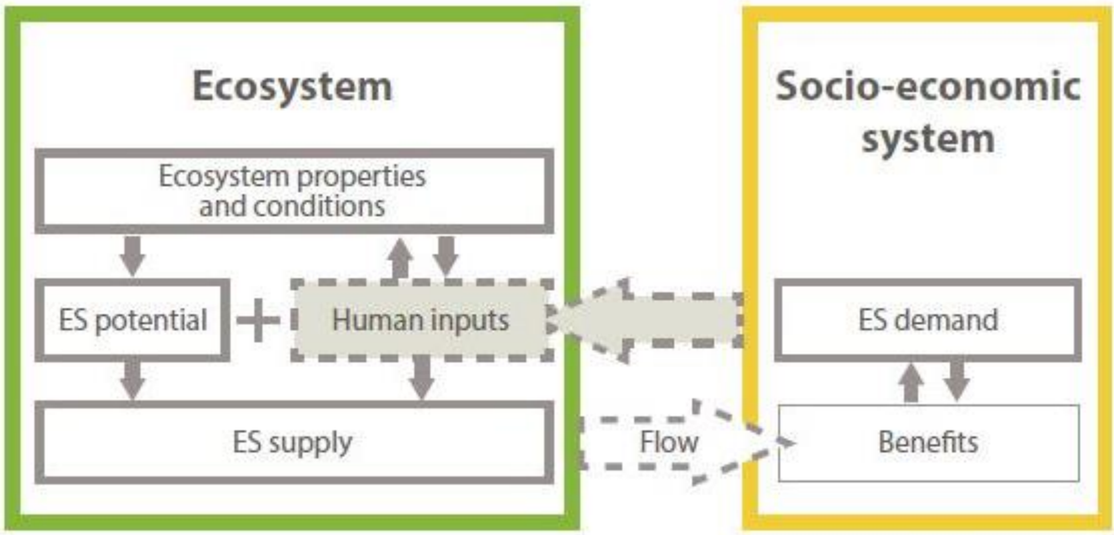


Figure 1: Mapping aspects of ecosystem services (Bold grey: subject relevant for mapping, dashed: may be mapped, thin: additional aspects for which mapping could be developed) by (Burkhard & Maes, 2017).

The natural state of the ecosystem is reflected through both properties and conditions of the ecosystem. The character, structure, and process of the ecosystem are identified through the properties of the ecosystem whereas the ecosystem condition refers to the integrity, health status of the ecosystem, and ability to generate ecosystem services (Bastian, Haase, & Grunewald, 2012). For instance, relief or geomorphology of an area can articulate the properties of the ecosystem of that area, and a healthy ecosystem condition of that area can be reflected through having healthy vegetation cover and high species composition. Ecosystem properties and conditions are directly linked with the biodiversity of an area which indicates the potentiality of supplying multiple ecosystem services (Egoh, Reyers, Rouget, Bode, & Richardson, 2009, Bai, Zhuang, Ouyang, Zheng, & Jiang, 2011).

Ecosystem service potential is the amount of ecosystem services that can be provided or used sustainably in a certain region considering the ecosystem properties and conditions (Bastian et al., 2012). In another word, ecosystem potential is nature's capacity to generate ecosystem services (Burkhard, Kroll, Nedkov, &

Müller, 2012). Potential groundwater recharge can be considered as an example of ecosystem service potential as this water can be supplied for human use. For assessing ecosystem potential to provide services, ecological carrying capacity and resilience should be considered. Ecosystem potential is highly applicable in planning, management as it distinguishes between a realized ecosystem services and the opportunities and limits of use. Ecosystem potential should be assessed for long-term periods and it should be oriented on natural regeneration rates without considering human interventions (Burkhard, Kandziora, Hou, & Müller, 2014).

Ecosystem services supply is the provision of a service by a particular ecosystem irrespective of its actual use which can be determined for a specific period in the present, past, or future (Burkhard et al., 2012). For instance, the actual groundwater recharge in a specific year of an area can be considered as an indicator of ecosystem service supply. Ecosystem services supply depends on both natural conditions and human input such as land management, knowledge, or technology (Willemen, Veldkamp, Verburg, Hein, & Leemans, 2012). Ecosystem services supply indicates the stocks of natural assets which triggers the flow of materials, energy, information, and organisms (Bastian et al., 2012).

Ecosystem service flow is the transmission of ecosystem services to people in a specific area and time (Bagstad, Johnson, Voigt, & Villa, 2013). Ecosystem services supply can turn into ecosystem services flow depending on the demand of service (Burkhard et al., 2014). The amount of groundwater pumped in a year can be considered as the flow of ecosystem services. Inadequacy of ecosystem services supply can constrain ecosystem services flow which may outstrip the ecosystem services potential, which can lead to the degradation of natural capital (Syrbe & Grunewald, 2017).

Ecosystem services demand is the need for consumption or use of specific ecosystem goods or services by society, particular stakeholders, groups, or individuals (Burkhard et al., 2012). Demand is not always static, it depends on current desires and needs and the availability of alternatives (Villamagna, Angermeier, & Bennett, 2013). Without the demand for a service, there will be no service flow (Burkhard et al., 2014).

2.1.2. Classification systems of ecosystem services

Classification of ecosystem services is the basis of assessing, mapping and valuing ecosystem services. There are several classification systems available ranging from global to local scales and each follows a specific conceptual framework. Major global classification systems are Millennium Ecosystem Assessment (MEA) (MEA, 2005), The Economics of Ecosystems and Biodiversity (TEEB) (TEEB, 2010), and The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Sandra Díaz et al., 2018). Moreover, The Common International Classification System for Ecosystem Service (CICES) which is currently the most popular one was originally developed for the European Union also used in various spatial scales (Armoškaitė et al., 2020). To fulfil the aims and objectives of the assessments, global ecosystem frameworks may need to be adapted for specific ecosystem types (e.g., marine systems, wetlands) as the global classification system may not be suitable for these specific types of ecosystems. In such cases tailored classification system is developed which can be ecosystem-specific (e.g., marine system or urban system) (Liquete et al., 2013a) or country-specific (e.g., for EU overseas territories, UK, Germany, and Spain) (UK NEA, 2011).

Ecosystem service research has progressed a lot over time at different levels, but still, some inconsistency can be detected in developing conceptual and empirical frameworks within the research and policy assessments (La Notte et al., 2017). Having numerous ecosystem service conceptualization and classification systems leads to the plurality in the interpretation of the definition of the ecosystem services and related terminology in terms of its application (Boerema, Rebelo, Bodi, Esler, & Meire, 2017). The major discrepancy can be detected in the interpretation of the biophysical structure, ecological functions, intermediate service, and the final service (Mononen et al., 2016, Spangenberg, von Haaren, & Settele, 2014, Landers & Nahlik, 2013, UK NEA, 2011, TEEB, 2010). These differences make it difficult to distinguish between the intermediate and the final services and also responsible for poor correspondences between service and benefit (La Notte et al., 2017). To overcome this problem and reduce the double-counting of ecosystem services, the Common International Classification System for Ecosystem Service (CICES) was proposed in 2009 by the European Environmental Agency (EEA) which has become an indispensable frame of reference for ecosystem service research (Maes et al., 2014). CICES has a four-tier nested hierarchical system to categorize the ecosystem services into three categories namely provisioning, regulating and maintenance, and cultural (Armoškaitė et al., 2020) (Figure 2). CICES is based on the cascade framework which was proposed in 2010 (Haines-Young & Potschin, 2010). Cascade framework is similar to a production chain and is effective in communicating societal dependence on ecosystems (Spangenberg et al., 2014). But challenges arise to apply this framework when the simultaneous presence of bio-centred and human-centred spheres is seen. This challenge is evident in measuring individually categorized and accounted ecosystem services (La Notte et al., 2017). Considering the challenges of the CICES classification system a more modified and updated classification system was developed by the IPBES which also categorizes ecosystem services into three categories namely material, non-material, and regulating (Sandra Díaz et al., 2015).

To summarize, the MEA classification system emphasized ecosystem change and its impact on human well-being whereas the main focus of TEEB's classification was in valuing nature (MEA, 2005, TEEB, 2010). CICES classification system is based on environmental accounting and it also included abiotic services in its classification system (Turkelboom et al., 2013). IPBES classification system prioritizes biodiversity and ecosystem services, nature's contribution, and material and non-material services of the ecosystem (Sandra Díaz et al., 2015).

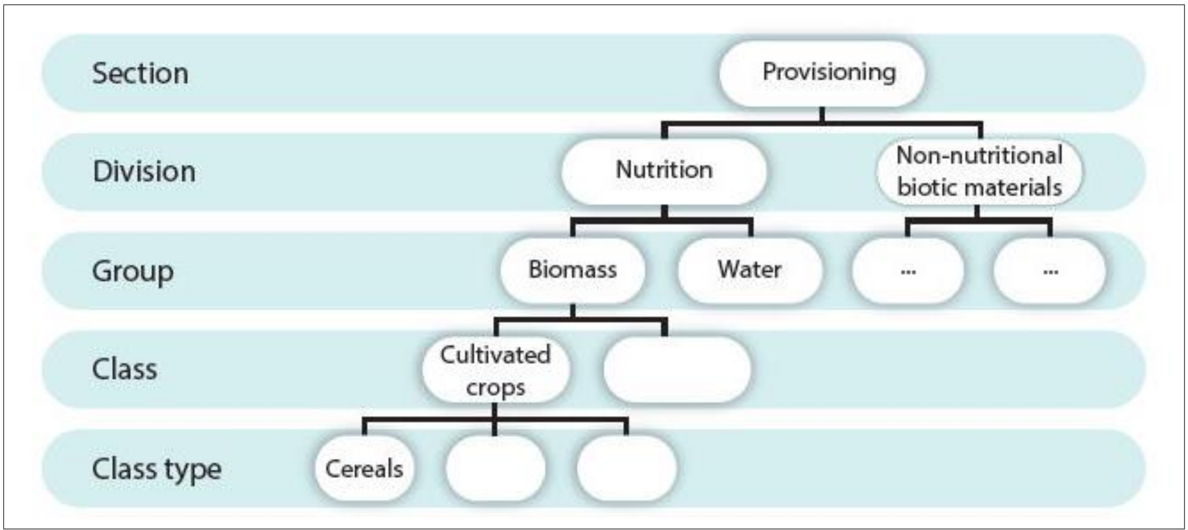


Figure 2: The hierarchical structure of CICES is illustrated by giving an example of provisioning service by (Burkhard & Maes, 2017).

2.2. Quantification and mapping of ecosystem services

2.2.1. Biophysical quantification of ecosystem services

Biophysical quantification of an ecosystem focuses on ecosystem structure, processes, functions, and service flow (Vihervaara et al., 2017). It is seen in the supply side of the ecosystem service cascade model (Figure 28). It quantifies the ecosystem's capacity in providing services and the amount of harvested yield of such capacity for human benefit through indicators (Vihervaara, Mononen, Nedkov, & Viinikka, 2018).

Ecosystem service indicators help to understand the characteristics and trends of ecosystem services by facilitating the simplification of the highly complex human-environmental system (Müller & Burkhard, 2012). Indicators are ecosystem service-specific, and it depends on the purpose, the beneficiary, position in the ecosystem service cascade model, considered spatial and temporal scale, and data availability (Layke, 2009). Considering these issues biophysical quantification of ecosystem services is done in three different ways, such as direct measurement, indirect measurement, and model-based measurement (Vihervaara et al., 2019) (Figure 3).

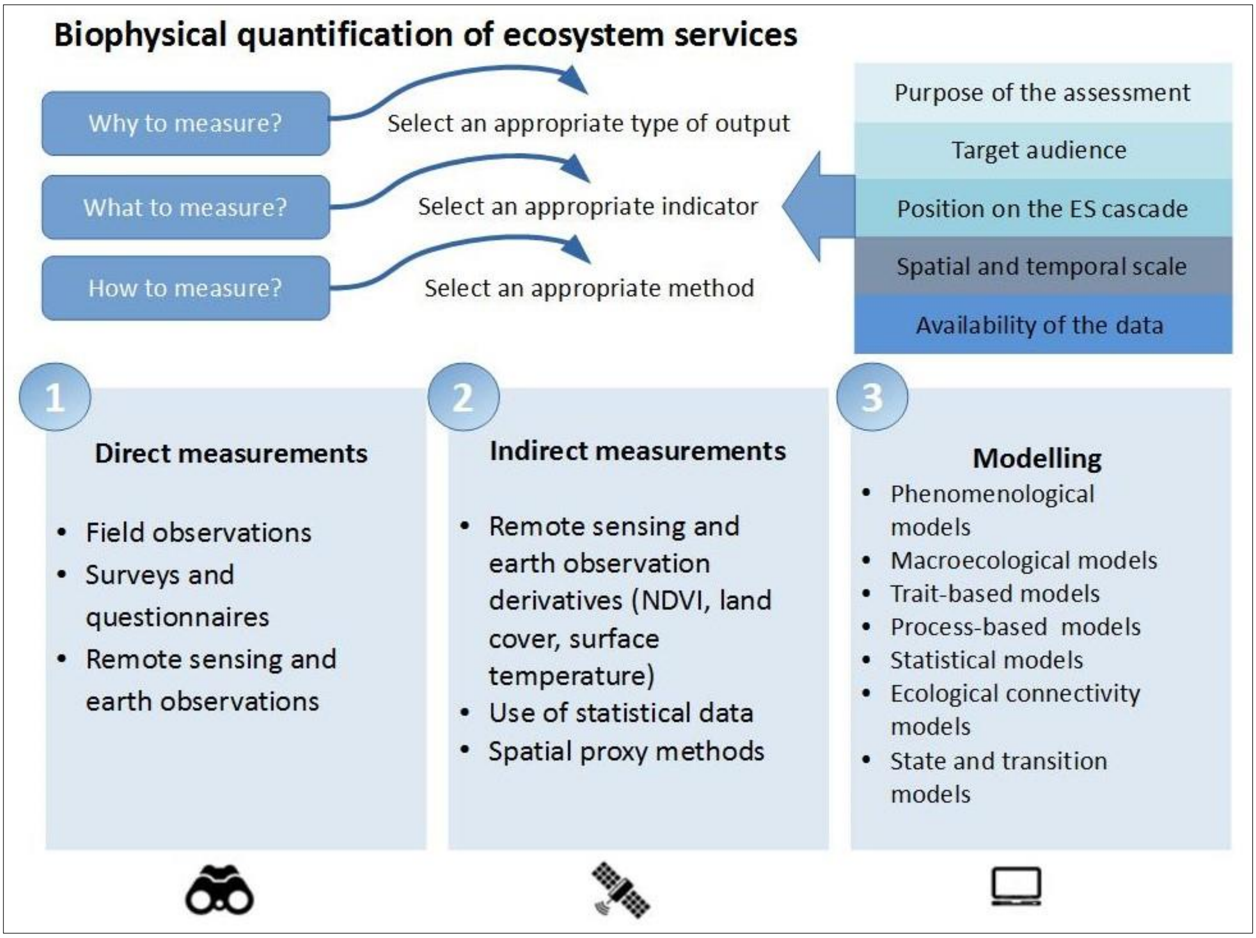


Figure 3: Biophysical quantification techniques of ecosystem services by (Vihervaara et al., 2019)

Measuring the state, amount, process of ecosystem services, or flow of ecosystem services of an area in a representative way using primary data which comes from observations, monitoring, surveys, and questionnaire techniques is known as direct measurement of ecosystem services (Vihervaara et al., 2019). To assess the food provision ecosystem services of the marine environment, especially ecosystem services received from fish resources many researchers used direct measurement techniques (Sato, Nakamura, & Hori, 2021, Wei et al., 2017, Miller et al., 2016, Bergstrom, Dorfman, & Loomis, 2004).
Indirect biophysical quantification of ecosystem services provides value in physical units which further needs to interpret, process, or combine with other information for getting a final assessment about ecosystem services (Vihervaara et al., 2019). Indirect measurements are effective for global-scale assessment, which is quite easy to updates and suitable for environmental accounting and monitoring. Remote sensing is a widely used technique for indirect measurement of ecosystem services which is quite effective in cross-scale ecological research in different spatial, temporal, and spectral scales (Andrew, Wulder, & Nelson, 2014). Flourishment of remote sensing techniques made landcover data more available which has been used in

different spatial scale from global to local level for ecosystem service assessment (Konarska et al., 2002, Zhao et al., 2004, Wang et al., 2006, Hu, Liu, & Cao, 2008). Many components of the coastal ecosystem such as (habitat, mangroves, seagrass, salt marsh) have been studied widely using remote sensing especially using land use and land cover data (Maurya, Das, & Kumari, 2021, Sheppard et al., 2005, Mumby et al., 2008, Lee, 2008).

In most cases, it is not possible to assess or quantify ecosystem services directly or indirectly. In such cases, the ecosystem services modelling approach can be used to have a reliable assessment of ecosystem services in complex, multiscale biophysical, and socio-economic conditions (Vihervaara et al., 2019). Ecosystem modelling can be a simple expert-based scoring system or complex ecological or hydrological model-based (Burkhard & Maes, 2017). For instance, Liquete et al., (2013b) and Guisado-Pintado et al., (2016) used an expert-based modelling approach to assess ecosystem services for coastal protection. Termansen, McClean, & Jensen, (2013) used GIS-based modelling techniques to assess the spatial heterogeneity of cultural ecosystem services from the forest. On the other hand, Guerry et al., (2012) applied InVEST tool to model, map and valuation of multiple ecosystem services from marine ecosystem. The modelling approach is mainly used to understand the supply and flow of provisioning and regulating ecosystem services. It has still some lacking in incorporating cultural ecosystem services and the demand side of ecosystems services.

2.2.2. Socio-economic quantification of ecosystem services

Socio-economic quantification or valuation of ecosystem services extracts the cognitive, emotional, and ethical preferences of people towards nature (Pascual et al., 2017). This assessment helps to understand the importance of nature to people (Iniesta-Arandia, García-Llorente, Aguilera, Montes, & Martín-López, 2014) and their perception in conserving and restoration of the ecosystem (Scholte, Todorova, van Teeffelen, & Verburg, 2016).

Both qualitative and quantitative assessment techniques exist for socio-economic quantification of ecosystem services among which seven methods have been used frequently (Santos-Martín et al., 2017):

1) **Preference assessment**, which is based on identifying the importance of the ecosystem by knowing the individuals' motivations, perceptions, knowledge, and values. Bagstad, Reed, Semmens, Sherrouse, & Troy, (2016) in their study tried to combine public preference with biophysical assessment techniques to assess the ecosystem services of southern Rocky mountain.
2) **Time-use**, which is assessed by knowing people's willingness to dedicate the amount of time to an ecosystem service. García-Llorente et al., (2016) used this method to analyze the social support in biodiversity conservation and ecosystem service supply in a semi-arid environment of Spain.
3) **Photo-elicitation survey** is used for socio-cultural valuation of ecosystem services by assessing visual experiences, perceptions, and preferences of people to a landscape. Sherren & Verstraten, (2013) used this technique to see farmers' perception of the valuation of wetlands. Sherren, Fischer, & Fazey, (2012) used this technique in their study to identify the best practice of managing grazing landscape for agricultural adaptation.
4) **Narrative methods** are interviews, focus group discussion, participant observation, content analysis, voice and video recording of events, artistic expression, etc. which is mainly used for collecting qualitative data of participant's plural and heterogeneous values of ecosystem services. Ramirez-Gomez et al., (2015) used a narrative technique for identifying the change of stock and area of ecosystem service provision in the lower Caquetá River basin in Colombia. For this, they conducted 22 focus group discussions and eight participatory mapping activities.
5) **Participatory mapping or participatory geographical information systems or PGIS methods** are used to assess the spatial distribution of ecosystem services based on stakeholder's perception and knowledge which is collected through workshops and/or surveys. This approach is also used to construct a decision support system for land management through ecosystem service (Schmidt et al., 2019).
6) **Scenario planning** is usually conducted through interviews or brainstorming in workshops for identifying the futuristic conditions of ecosystem services and uncertainties (Peterson, Cumming,

& Carpenter, 2003, Bohensky, Reyers, & Van Jaarsveld, 2006, Malinga, Gordon, Lindborg, & Jewitt, 2013).

7) **Deliberative methods** are composed of different tools and techniques to assess the preference of stakeholders and citizens for ecosystem services by addressing ethical beliefs, moral commitments, and social norms. Palomo, Martín-López, Zorrilla-Miras, García Del Amo, & Montes, (2014) in their study within and around the Doñana National Park (SW Spain) used this technique to see the changes of ecosystem service and its relationship with land uses.

2.2.3. Mapping methods of ecosystem services

Ecosystem services mapping has been used for different purposes including ecosystem assessment, accounting, research, advocacy, and policy implementation which can show spatially heterogeneous aspects of ecosystem services. Ecosystem services maps can help in revealing the condition of the ecosystem, uncertainty of ecosystem service provision, inconsistency in ecosystem service flow, and mismatch between ecosystem service supply and demand (Maes et al., 2012). Ecosystem services emerge from the ecological process of a particular area which can be labelled as a spatial unit for assessing and mapping ecosystem services. This spatial unit can be designated as a service providing area (SPA), service benefiting area (SBA), and service connecting area (SCA) (Figure 4). SPA is the spatial unit from which ecosystem services are provided, SBA is the spatial unit from where the beneficiary gets the ecosystem services and SCA is the connecting area of non-adjacent SPA and SBA (Burkhard & Maes, 2017).

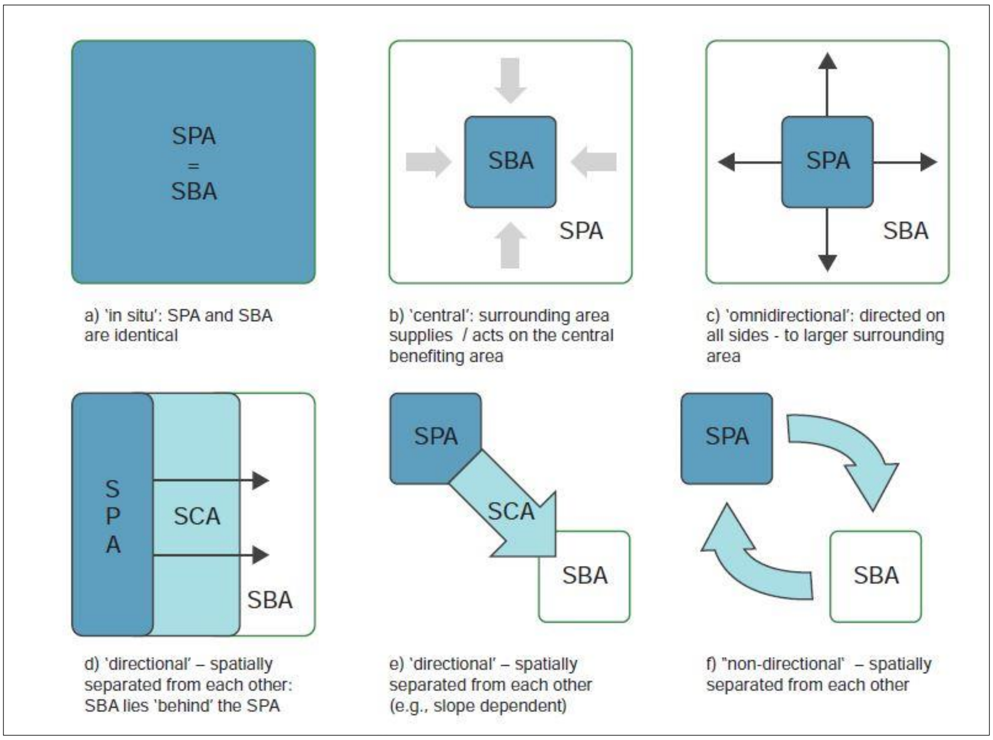


Figure 4: Spatial relation between Service Providing Area (SPA), Service Benefiting Area (SBA), and Service Connecting Area (SCA) by (Burkhard & Maes, 2017).

It is important to know which methods to use for what type of ecosystem services in which condition to prepare reliable, accurate, and high-precision ecosystem service maps and to derive correct information from the map. Choosing appropriate methods for mapping ecosystem services is not straightforward. Spatial scale, heterogeneity, and accessibility of the study area, budget, time, and proper knowledge and experiences should be given priority while choosing appropriate methods (Schröter, Remme, Sumarga, Barton, & Hein, 2015). Ecosystem services maps should be robust, transparent, and stakeholder relevant for maximum usability and impact on decision support (Burkhard, Drakou, Palomo, Willemen, & Crossman, 2015). To choose proper methods for mapping ecosystem services and to ensure comparability in ecosystem service assessments Grêt-Regamey, Weibel, Kienast, Rabe, & Zulian, (2015) proposed three-tiered methods (Figure 5). According to this method, tier 1 approaches should be selected if the purpose of the map is to provide information about the abundance, presence, and absence of ecosystem services and their values. If an ecosystem service map needs to express information about a certain ecosystem at a certain level of detail but it is not linked explicitly for management of the ecosystem then tier 2 approaches will be suitable and if a deeper understanding of the ecosystem service components and processes is required which is explicitly related to management measure than tier 3 approaches should be selected. After choosing the appropriate tier, available data needs to be checked to fulfil the demand of this tier. If there is a limitation of data, then a lower tier can also be selected.

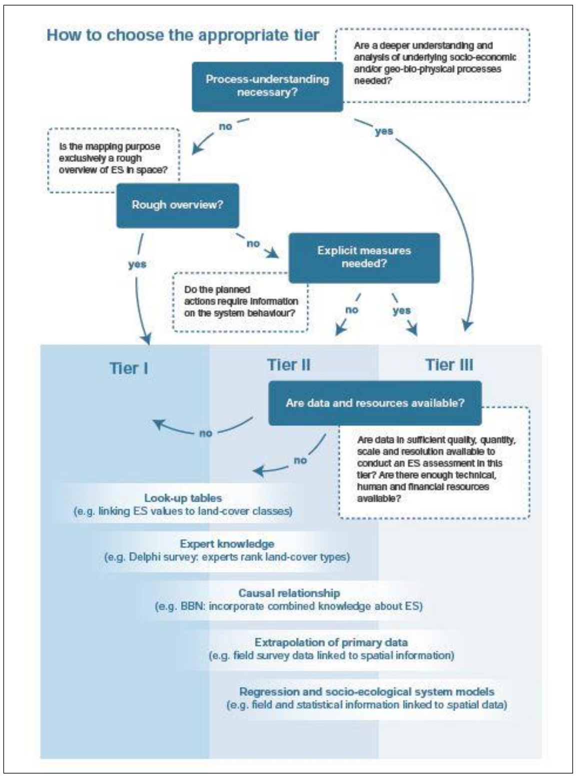


Figure 5: Choosing the appropriate tier for mapping ecosystem services by (Burkhard & Maes, 2017).

During the last decades, continuous development has occurred in the ecosystem service domain where different techniques have been adopted to map ecosystem services among which participatory approaches, land-cover-based approaches, remote sensing, mixed or model-based approaches have been mentioned frequently in the literature (Burkhard & Maes, 2017). The participatory mapping technique is usually applied for local case studies by incorporating individuals, groups, or social values through interviews, focus groups, or online surveys to examine the spatial distribution pattern of the social benefit of ecosystem services and also to predict the spatial distribution of future benefit (Reilly, Adamowski, & John, 2018).

Landcover-based approaches often incorporate an expert-based method where experts or stakeholder knowledge helps to valuate ecosystem services from different landcover types. This approach is quite useful to generate information for environmental management, landscape planning, and ensuring sustainable use of nature (Burkhard, Kroll, Müller, & Windhorst, 2009).

Remote sensing technique is quite often used to map properties and function of ecosystem processes and services of large areas where complex interactions occur between natural and social systems (Ustin et al., 2004, Chambers et al., 2007, Muraoka & Koizumi, 2009, Chopra, Verma, & Sharma, 2001). Remote sensing provides synoptic, spatially continuous, and frequent observation at the terrestrial system to map ecosystem services at varying spatial and temporal resolutions (Atzberger & Rembold, 2013, Lewis, Phinn, & Arroyo, 2013).

To map complex, multi-scale, biophysical, and socio-economic dynamics of different ecosystem services by integrating different knowledge groups, modelling approaches are highly effective (E. J. Nelson & Daily, 2010). Various tools are developed to model various ecosystem service among which Integrated Valuation of Ecosystem Services and Trade-offs (InVEST), and Artificial Intelligence for Ecosystem Services (ARIES) are widely applied (Tallis et al., 2010, Kareiva, Daily, Ricketts, Tallis, & Polasky, 2009, Villa, Ceroni, Bagstad, Johnson, & Krivov, 2009).

Ecosystem services have been mapped at various spatial and temporal scales using different techniques. Crossman et al., (2013) indicate that regulating services have been mapped most often followed by provisioning and cultural ecosystem services. Among regulatory ecosystem services, climate regulation has been assessed and mapped most frequently. Most of the time climate regulation has been mapped and modelled using proxies in various complicated levels (Egoh et al., 2008, E. Nelson et al., 2009, Crossman, Bryan, & Summers, 2011, Lal, 2004, Liu, Chan, & Conyers, 2009). Apart from climate regulation, in flood moderation and regulation ecosystem services, proxies are also used by incorporating information of runoff, topography, geology, soil, vegetation, and management practices to predict the magnitude of flood or examine the water retention capacity of the soil. (Chan, Shaw, Cameron, Underwood, & Daily, 2006, Ming, Xian-guo, Lin-shu, Li-juan, & Shouzheng, 2007, Schulp, Alkemade, Klein Goldewijk, & Petz, 2012, Posthumus, Rouquette, Morris, Gowing, & Hess, 2010, Ennaanay et al., 2011, Nedkov & Burkhard, 2012). Moreover, the use of hydrological models to map water flow regulation ecosystem services is also very common (Guo, Xiao, Gan, & Zheng, 2001, Crossman, Connor, Bryan, Summers, & Ginnivan, 2010, Laterra, Orúe, & Booman, 2012).

2.3. Modelling and mapping marine and coastal ecosystem services (MCES)

2.3.1. Indicators for modelling marine ecosystem services

Indicators are quite useful to understand the complex phenomena which aim to model and value ecosystem services and also provide support to management activities (Burkhard & Maes, 2017). The selection of indicators is not straightforward and a proper guideline for selecting indicators especially for marine ecosystem services is still limited (Hattam et al., 2015). Indicators for provisioning ecosystem services of the marine environment are most available followed by regulatory and cultural ecosystem services (Hattam et al., 2015). In regulating ecosystem services, indicators provide useful insight to identify negative change or degradation of ecosystem services, but its usefulness in prediction for future degradation of ecosystem services is still limited and challenging (Hattam et al., 2015, Layke, 2009). On the other hand, indicators for cultural ecosystem services of the marine environment is very minimal, and in most cases, its definition, purpose, and measuring process is not clear (Hernández-Morcillo, Plieninger, & Bieling, 2013, Milcu, Hanspach, Abson, & Fischer, 2013).

The appropriate spatial and temporal scale for indicators are problem-specific (Hattam et al., 2015), but in most cases, it is measured at local and regional scales (Feld et al., 2009). In the marine ecosystem service domain, many services are not location dependent (Costanza, 2008) and many marine species are mobile and spend their different stage of life at different parts of the sea, which makes a more complex spatial and temporal condition for choosing appropriate indicators than terrestrial environment (Hattam et al., 2015). Besides, the distance between beneficiaries and the marine ecosystem acts as a barrier to assign specific benefits to a specific location which ultimately creates challenges for selecting proper ecosystem services (Hattam et al., 2015).

Ideally, indicators should robust enough to describe the dynamic nature of ecosystem services. To have a better understanding of ecosystem change, indicators need to be developed in such a way that, they will be able to describe not only ecosystem services but also ecological functions that provide the services (Nicholson et al., 2009, de Groot, Alkemade, Braat, Hein, & Willemen, 2010) and for this, multiple dimensions and composite indicators will be needed for each ecosystem services (Hattam et al., 2015). To ensure these credibilities and usability of indicators Link et al., (2010) and Dale & Beyeler, (2001) developed some criteria's such as measurability, sensitivity, specificity, anticipatory, unifying capacity, ability to predict change, less variability in response, and ability to respond in stress against which indicators needs to be assessed. Liquete et al., (2013a) identified that the number of indicators for benefit analysis of marine provisioning and cultural ecosystem services is higher than the capacity and flow analysis whereas the scenario is opposite for marine regulating ecosystems services. A list of the most frequently used indicators in coastal protection ecosystem service is displayed in Table 2.

Table 2: Example of indicators used in coastal protection ecosystem service (Liquete et al., 2013a).

Ecosystem service	**Indicators for ecosystem service supply analysis**	**Indicators for ecosystem service flow analysis**	**Indicators for ecosystem service benefit analysis**
Coastal protection	Mangrove extent (Martinez-Alier, 2001), temporal change of mangrove extent (López-Medellín et al., 2011), coral size and substrate cover (Harris, Manahira, Sheppard, Gough, & Sheppard, 2010), plant cover (Imbert & Houle, 2000), presence of seagrass meadow (Cognetti & Maltagliati, 2010), kelp occurrence (H. Tallis et al., 2012), sediment accumulation (Bos et al., 2007).	Surge reduction (Engle, 2011), wave attenuation (Iftekhar, 2008), sediment deposition (McGlathery et al., 2012), loss rates of experimental equipment on the coast (Granek & Ruttenberg, 2007).	Value of the disturbance regulation service based on benefit transfer (Lozoya, Sardá, & Jiménez, 2011), Loss in property values from declining reef protection (Barbier et al., 2011), Replacement cost for coastal protection (Hicks, 2011), Economic value of protection against natural disasters (Walters et al., 2008), etc.

2.3.2. Mapping of coastal ecosystem services

Similar to terrestrial ecosystem services, mapping marine, and coastal ecosystem services needs the understanding of marine and coastal ecosystem components, associated functions and processes, but additionally, marine ecosystem services mapping require an understanding of a third dimension as many ecosystem functions occur within the ocean's water column (Drakou et al., 2017b). Marine and coastal ecosystem services have been mapped for various purposes including marine spatial planning, resources management, and valuation (Veidemane et al., 2017, Sinclair, Sagar, Knudsen, Sabu, & Ghermandi, 2021, Afonso et al., 2021). While mapping, it has been recognized as a strong intersect of multiple values in many studies (Klain & Chan, 2012, Drakou et al., 2017b). Mapping of MCES has been carried out in local to national and even supernational scale considering the specific policy and management needs (Arkema et al., 2015, Liquete, Piroddi, Macías, Druon, & Zulian, 2016, Mononen et al., 2016, Oinonen et al., 2016). Besides, choosing appropriate classification while mapping MCES is also important and Sousa et al., (2016) suggested that the CICES classification system is suitable for mapping and analyzing complex coastal ecosystems with minor adjustments. They also pointed out that, lack of supporting information about water conditions, insufficient knowledge about species, and ambiguity and subjectivity of cultural aspects are the major challenges of assessing and mapping complex marine ecosystem services. Mapping of MCES can help to ensure payments for ecosystem services, identify vulnerability and associated risks, assessing environmental impacts, managing marine protected areas as well as their natural resources (Blake, Augé, & Sherren, 2017). Many studies have already tried to find a way to incorporate the outcome of ecosystem services research in coastal protection policy considering those issues (Fox, Graham, Eigenbrod, Bullock, & Parks, 2020, Geneletti et al., 2020). Though MCES has multidimensional benefits, scarcity of data limits the possibilities of mapping marine and coastal ecosystem services (Drakou et al., 2017b). The data scarcity issue has already been discussed in many studies and the way to overcome it has been discussed by Townsend et al., (2014). On the other hand, visualization of ecosystem services of marine and coastal environment through maps is very challenging as it needs to be less complicated with maximum information for the highest usability. Drakou et al., (2017b) mentioned several challenges in mapping marine and coastal ecosystem services including the dynamic three-dimensional nature of the marine environment, scarcity of marine habitat distribution information, difficulty in quantifying the function and process involved in the marine ecosystem, scarcity and high uncertainty in data, and difficulties of linking of human aspiration with specific habitat types.

2.3.3. Mapping and assessment of coastal protection

According to the review work of Liquete et al., (2013a), the most frequently analyzed and mapped marine ecosystem services are food provision ecosystem services and in regulatory ecosystem services mapping, climate regulation has been given the most attention. Some attempts are also seen in mapping coastal protection. Coastal protection is most often mean protection of assets from coastal erosion and flooding (Schernewski, Löser, Schernewski, & Löser, 2004). For long coastal protection has been studied from an engineering or hard measure perspective which can provide an immediate solution but have an adverse impact on coastal biodiversity and ecosystem services in the long run (Stamski, 2005, Cooper, O'Connor, & McIvor, 2020). Coastal infrastructure not only damages coastal biodiversity in long run but also hinders the ecosystem services supply from minor flooding and coastal erosion events (Cooper et al., 2020). In many cases, artificial coastal defence system impedes sediment accumulation on the coast, prevents energy attenuation, alters habitat type, or even eliminates coastal habitats (Greene, 2002, L. Jones et al., 2011). Moreover, due to losses of coastal and nearshore marine habitats caused by artificial protection measure, negative impact on many important ecosystem services including recreation, storm attenuation, and food production is seen in many parts of Europe (Gibson, Atkinson, & Gordon, 2007, UK NEA, 2011). Considering these, the European Parliament and Council urged governments to take strategic approaches to manage coastal zone by prioritizing ecosystem service-based approaches and ensuring ecology responsive coastal protection measures recognizing the threat to coastal zone posed by climate change (CEC, 2002).

Coastal protection as an ecosystem service has been assessed and mapped on various scales and in various dimensions against different disasters. But very few works can be seen where all the available coastal components have been considered for assessing and mapping the protection capacity of the coast. In most cases, coastal protection as an ecosystem service has been assessed based on the services provided by single ecosystem components (Trégarot et al., 2021, Costanza et al., 2008). Ecosystem services such as wave attenuation, storm surge reduction, and seabed elevation provided from mangroves, seagrass beds, coral reefs, and salt marshes to reduce the disaster risk in the low-lying coastal zone have been studied quite frequently (Shepard et al., 2011, Duarte, Losada, Hendriks, Mazarrasa, & Marbà, 2013, Ondiviela et al., 2014, Zhang et al., 2012, Spalding et al., 2014). In some studies, researchers incorporated multiple ecosystem components to assess and map coastal protection. For instance, Trégarot et al., (2021) tried to incorporate all the major biophysical components of the Mauritanian coast, West Africa to assess and map the protection capacity against coastal hazard risk linked with wave height. Guisado-Pintado et al., (2016) assessed and map coastal protection at the local level on a highly urbanized area considering the same biophysical and socioeconomic variables used in the European studies of Liquete et al., (2013b). Stürck et al., (2014) mapped the supply and demand of flood regulatory ecosystem service for the entire European land including the coastal areas. Nedkov & Burkhard, (2012) and Shen et al., (2019) assessed and mapped the supply and demand of the same ecosystem service on a local scale. On the other hand, human activity on the flow of benefits received from coral reefs and mangroves against storms and sea-level rise has been discussed by Arkema et al., (2015). Trégarot et al., (2021) argued that to effectively reduce disaster risk, coastal protection as an ecosystem service should be considered as an integral part of the policy of coastal zone management plan ensuring proper acknowledgement of social, economical and ecological dimension of the coastal system and interaction between them. For successful policy implementation, it is also essential to overcome the knowledge gap that exists in the coastal process to remove the impediment of understanding and quantification of the service (Bouma et al., 2014).

2.3.4. Mapping and assessment of MCES in Greece

In the late 1990s, researchers started to consider doing research on the ecosystem services of Greece focusing on the socio-ecological aspect (Dimopoulos et al., 2017). After that several studies have been conducted focusing on the economic assessment of the environment or evaluating environmental benefits (Dimopoulos, Bergmeier, & Fischer, 2006). Ecosystem services have also been assessed for their capacity in improving water quality or provisioning biodiversity considering social preferences (Genitsariotis, Chlioumis, Tsarouhas, Tsatsarelis, & Sfakiotakis, 2000). Attempt has also been seen to develop a national set of indicators that will act as a basis to assess and map the terrestrial ecosystem services of Greece (Kokkoris et al., 2020). Most ecosystem services related works in Greece were conducted on provisioning services such as agriculture and also a significant amount of work had been done on regulating services and their associated functions (Zalidis, Tsiafouli, Takavakoglou, Bilas, & Misopolinos, 2004, Garantonakis et al., 2016). Several research works highlighted the cultural importance of ecosystem services (Neves, Petanidou, Rufino, & Pinto, 2005), and some of them incorporated GIS-based technologies to quantify and mapping cultural elements (Vlami et al., 2017). One of the most important ecosystem services of Greece that has been identified in several studies is recreation and most of the studies applied different methods to assess tourist pattern and their linkage with different landscapes (Makrodimos, Blionis, Krigas, & Vokou, 2008). It has been identified that less attention has been given to the mapping and assessing of marine and coastal ecosystems especially in coastal protection. In most of the cases, marine ecosystems were assessed in terms of the food supply through commercial and recreational fishing which is also identified as one of the high potential ecosystem services in Greece (Skourtos et al., 2015). In the case of coastal protection, most of the works emphasized on risk and vulnerability assessment of the Greek coast. Kontogianni et al., (2014) tried to see the impact of sea-level rise and associated vulnerability on the entire Greek coast. Tragaki, Gallousi, & Karymbalis, (2018) incorporated geographic, oceanographic, and demographic parameters to assess the vulnerability of Peloponnese in terms of coastal hazard. Anastasiou & Sylaios, (2016) assessed the shoreline change of Northern Greece through remote sensing techniques and evaluated various existing protection methods for mitigation of erosion. On the other hand, some research initiative has been seen to map coastal ecosystem components which can be indirectly linked with coastal protection. For instance, Issaris et al., (2012) mapped several marine and coastal ecosystem components including the seabed habitat of the Ionian Sea and adjacent Gulf area, and tried to link it with marine spatial planning. Research has also been undertaken to assess ecosystem functions on islands of Greece (Lesvos) by using multi-criteria evaluation techniques (Oikonomou, Dimitrakopoulos, & Troumbis, 2011). Some researchers tried to assess people's perception and willingness to protect various marine and coastal ecosystem components of Greece (Jones, Panagiotidou, Spilanis, Evangelinos, & Dimitrakopoulos, 2011, Togridou, Hovardas, & Pantis, 2006).

3. METHODOLOGY

3.1. Study area

3.1.1. Morphological, ecological, and hydrodynamic condition of the study area

Greece has the longest coastline among all the Mediterranean countries, stretching over 18,000 km in length, located at the eastern part of the Mediterranean Sea. It has more than 9800 islands and islets stretching over the Ionian and Aegean seas (Simboura et al., 2018). Greece is one of the most mountainous countries of the Mediterranean and the Balkans having three-fifths of its surface covered by mountainous area (Dimopoulos et al., 2017), with a maximum slope around 84 degrees (Figure 6). The country has 13 administrative regions, of which 12 are coastal, 70% of the coasts are rocky, and the rest of the parts are comprised of sandy beaches, dunes, coastal wetlands, and lagoons (Mourmouris, Kasidi, Vourvahis, Grigoriou, & Kanellopoulou, 2006).

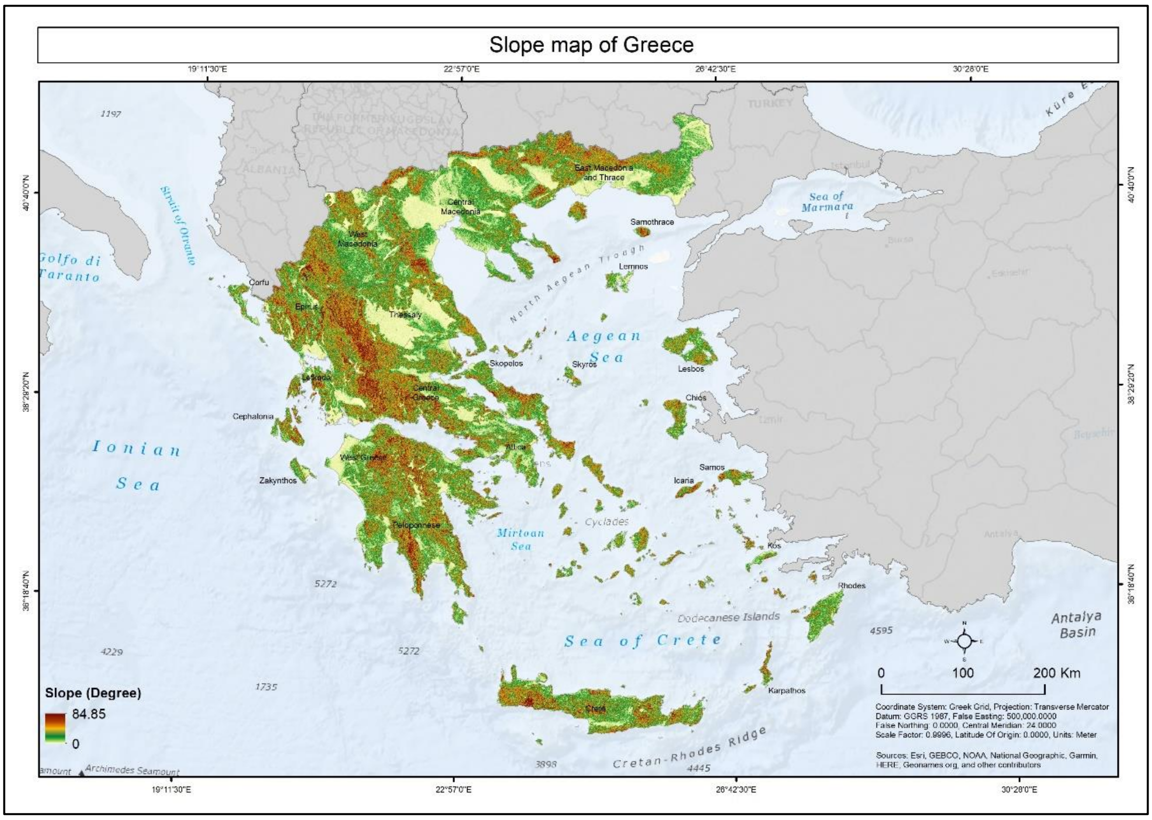


Figure 6: Slope map of Greece. (Data source: EEA, 2016)

Over the last several million years, geological processes have guided the development of Greece's current geomorphologically complex coastal areas (Simboura et al., 2018). According to the classification of Directorate-General for Environment (DG ENV, 2016), there are broadly 13 geomorphology types (Figure 7) visible in the Greek coast of which "Rocks and/or cliffs with small beaches" and "Small beaches separated by rocky capes" are most prominent, covering more than 8500 km (58%) of the coastline of Greece (Table 3).

Table 3: Types of geomorphology in the Greek coast by (DG ENV, 2016)

Geomorphology types	Percentages (%)
Rocks and/or cliffs made of hard rocks (subject to little erosion)	11.02
Rocks and/or cliffs with small beaches	29.01
Conglomerates and/or cliffs made of material subject to erosion: presence of rock waste and sediments (sand pebbles on the strand)	10.82
Small beaches separated by rocky capes	29.79
Developed beaches (length of the beach > 1 km) with strands made of coarse sediments: gravels or pebbles	1.42
Developed beaches with sandy strands: fine to coarse sand	8.41
Coastlines made of soft non-cohesive sediments	0.19
Strands made of muddy sediments: "waddens" and intertidal marshes with "slikkes and schorres"	0.36
Harbour areas	4.10
Coastal embankments for construction purposes (e.g., by emplacement of rocks earth etc.)	0.08
Soft strands with "beach rock" on intertidal strands	0.06
Soft strands of heterogeneous category grain size	3.89
Soft strands of unknown category grain size	0.86

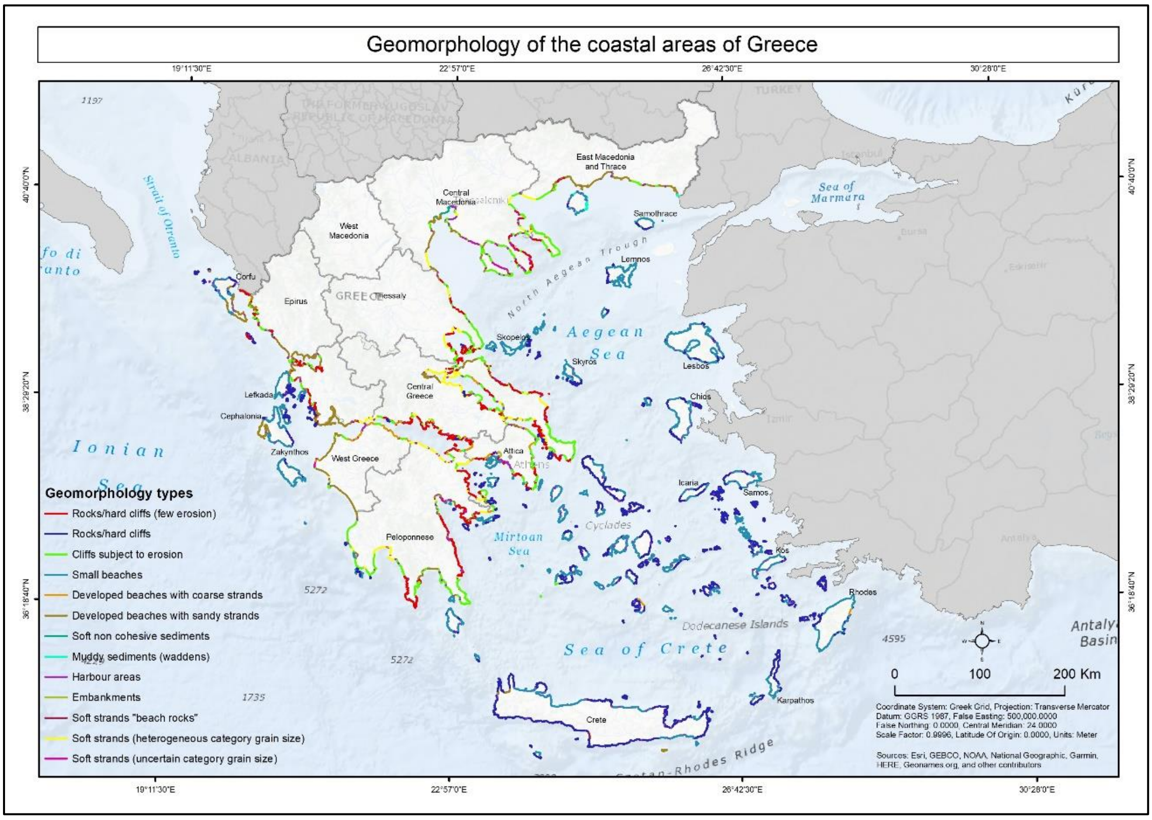


Figure 7: Types of the geomorphology of the Greek coast. (Data source: DG ENV, 2016)

Greece is also rich in biogeographical heterogeneity with at least 30 marine habitat types according to the EUNIS European habitat classification system, ranging from pelagic to benthic, which can be further subdivided into rocky substrates, soft substrate habitats, and seagrass meadows (Davies, Moss, & Hill, 2004). The soft substrate is composed of shallow muds and shallow sands, which are the two most prominent coastal habitat types in the Hellenic seas (Figure 8). It has been identified that more than 600 marine macrophyte species hotspots are present in the Hellenic seas, which also host around 96 green seaweeds, 107 brown seaweeds, and 400 red seaweeds (Simboura et al., 2018). Besides, the softer part of the Greek coasts, such as sand dunes or wetlands, are considered highly productive that accommodate numerous species of marine mammals (Simboura et al., 2018). Moreover, Forest land, including forests and other wooded lands (branchy dwarf trees and scrubs), covers 49.4% of the total area of the country (Giannakopoulos, Kostopoulou, Varotsos, Tziotziou, & Plitharas, 2011) and 60% of the total country's forest area is located within the coastal zone (Mourmouris et al., 2006). The vegetated area that cannot be classified as forest such as grassland, rangeland, and pasture cover 13% of the total area of the country, and 29.2% of the total area are agricultural land, including fallow land (Giannakopoulos et al., 2011) (Figure 9).

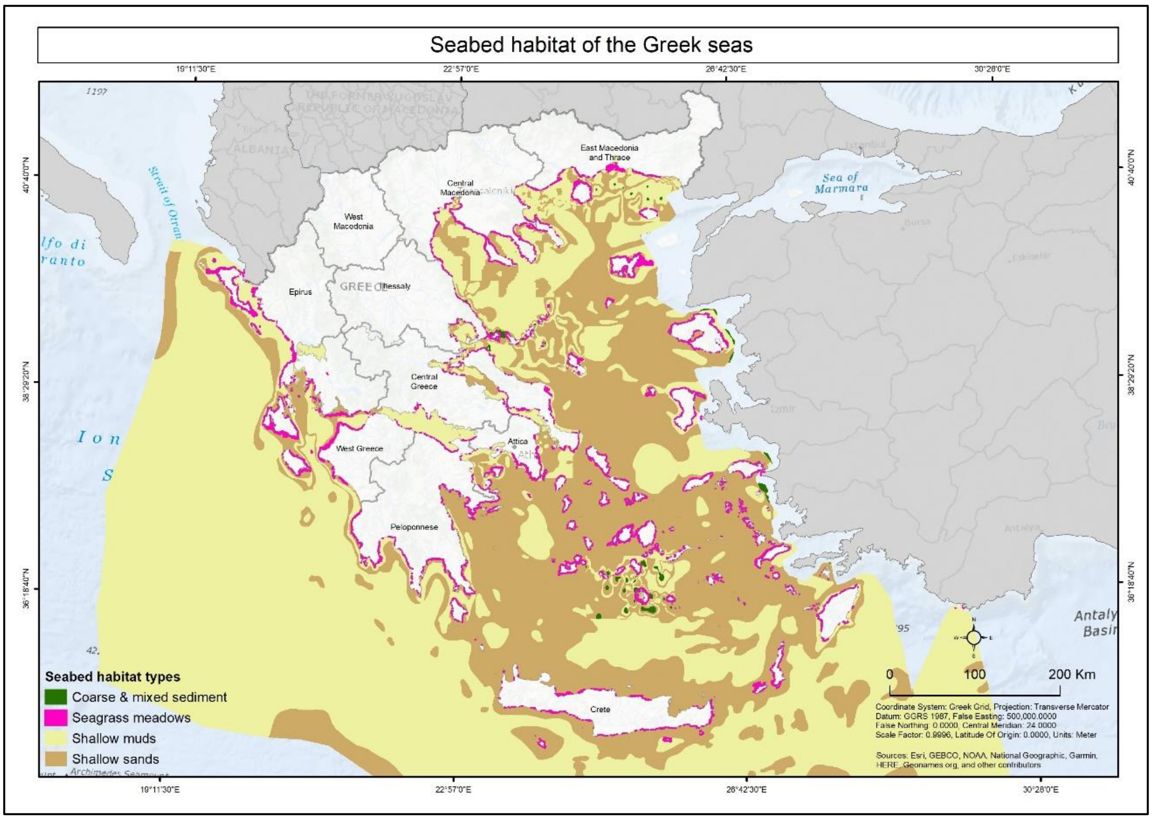


Figure 8: Seabed habitat map of Greek seas. (Data source: EMODnet Seabed Habitats Consortium, 2014)

Greece has a typical Mediterranean climate with mean maximum temperatures ranging between 29 and 35 ˚C and mean minimum temperature ranging between 5 and 10 ˚C near the coast and 0-5 ˚C over the mainland (Giannakopoulos et al., 2011). The mean seawater temperature lies between 18 to 20˚C (Velaoras et al., 2013) (Figure 12). Greece is one of the 18 most vulnerable areas of the planet due to climate change (Demertzis & Iliadis, 2018). With the changing climatic condition and increasing human pressure, many marine ecosystem types are being lost in Greece. Hoegh-Guldberg et al., (2014) pointed out that the effects of climate change and global warming in the coastal areas of Greece are being visible in terms of sea-level rise (Figure 10), increase in the storm surge height (Figure 11), sea temperature rises, and acidification of seawater. Different climatic models forecasted that between 2015 to 2039 Greece will experience a 2 to 3 ˚C rise in temperature and a 5-10% decrease in rainfall (Demertzis & Iliadis, 2018). According to the IPCC A2 scenario report, the temperature of the Aegean Sea might increase up to 3 ˚C by 2100, and sea level might rise by 0.5 m causing flooding to 15% of the coastal wetlands (Pachauri & Reisinger, 2008). These may increase spreading diseases, the toxic bloom of seaweed, and proliferating of thermophilic species.

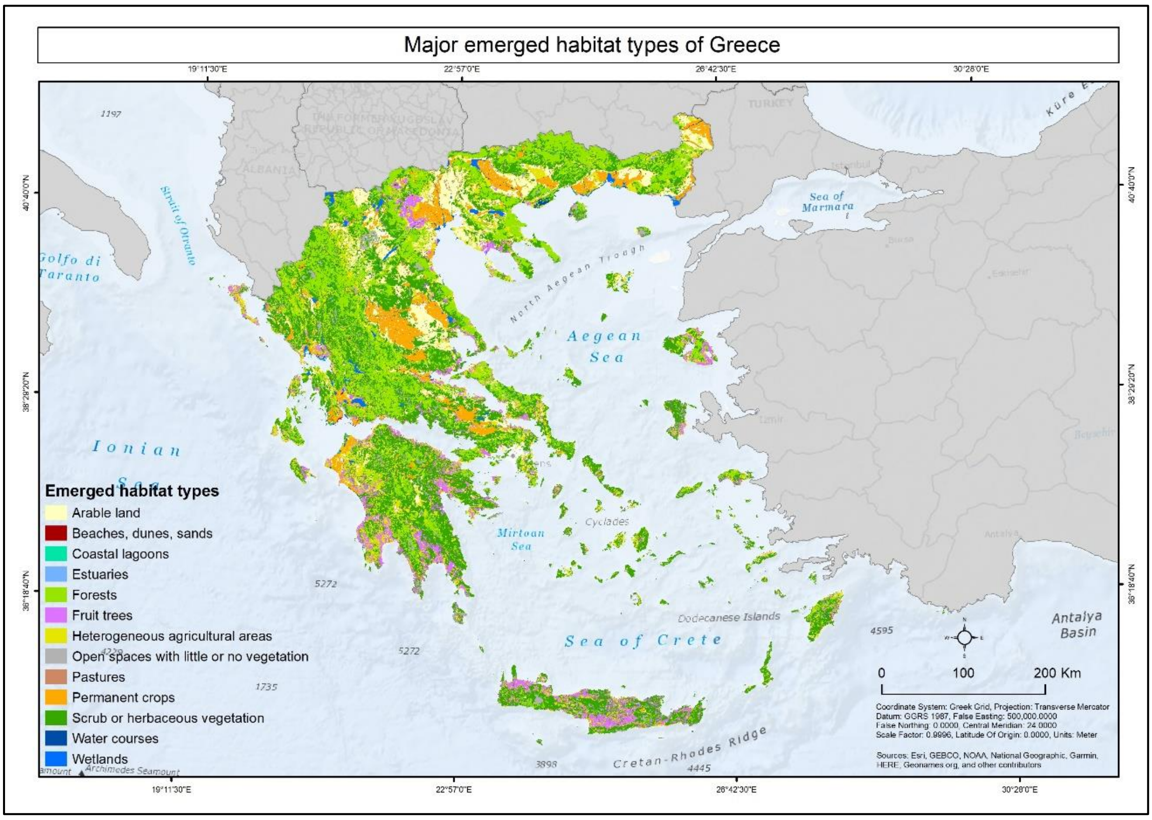


Figure 9: Map of emerged habitat types of Greece. (Data source: EEA, 2018)

Moreover, the softer part of the Greek coasts is experiencing more and more erosion, and it is estimated that 28.6% of the Greek coastline is prone to high erosion (Mourmouris et al., 2006). Apart from sea level rise or human interventions, some local factors such as coastal geology, coastal morphology, wave height and tidal regime, storm surge, wind speed, frequency and intensity of extreme weather events, and supply of sediments (Figure 13) are also playing a major role in the coastal erosion of Greece (Papadopoulou, Papanikolaou, & Vasilakis, 2010, Xeidakis & Delimani, 2002).

The wind speed in the northern Aegean Sea is relatively high and can reach 17-20 m/sec or even higher to create a 7 m high wave in the open sea (Xeidakis & Delimani, 2002). The prevailing winds in this sea are blown in the north or northward direction in the winter and summer and the south or southeast direction in the autumn and spring (Xeidakis & Delimani, 2002). The winds in the eastern part are generally stronger than in the western part of the sea (Figure 14). This wind directly influences the wave height. Therefore, the south-eastern part has a stronger wave than the western part. In the central part, such as in the Corinth Gulf, the average offshore wave significant height is less than 0.3 m (Karymbalis et al., 2012) (Figure 15). The tide in the Mediterranean Sea is generally small (Xeidakis & Delimani, 2002) and may range between 0.006 m to 0.2 m which can be increased at the time of powerful winds (Figure 16). Ocean current is also an important factor that influences sediment transportation and gets influenced by the wind (Xeidakis & Delimani, 2002). Two types of ocean currents (northward and eastward) are active in the Mediterranean Sea, and it flows with an average speed from 0.07 to 0.15 m/sec (Figure 17 and Figure 18).

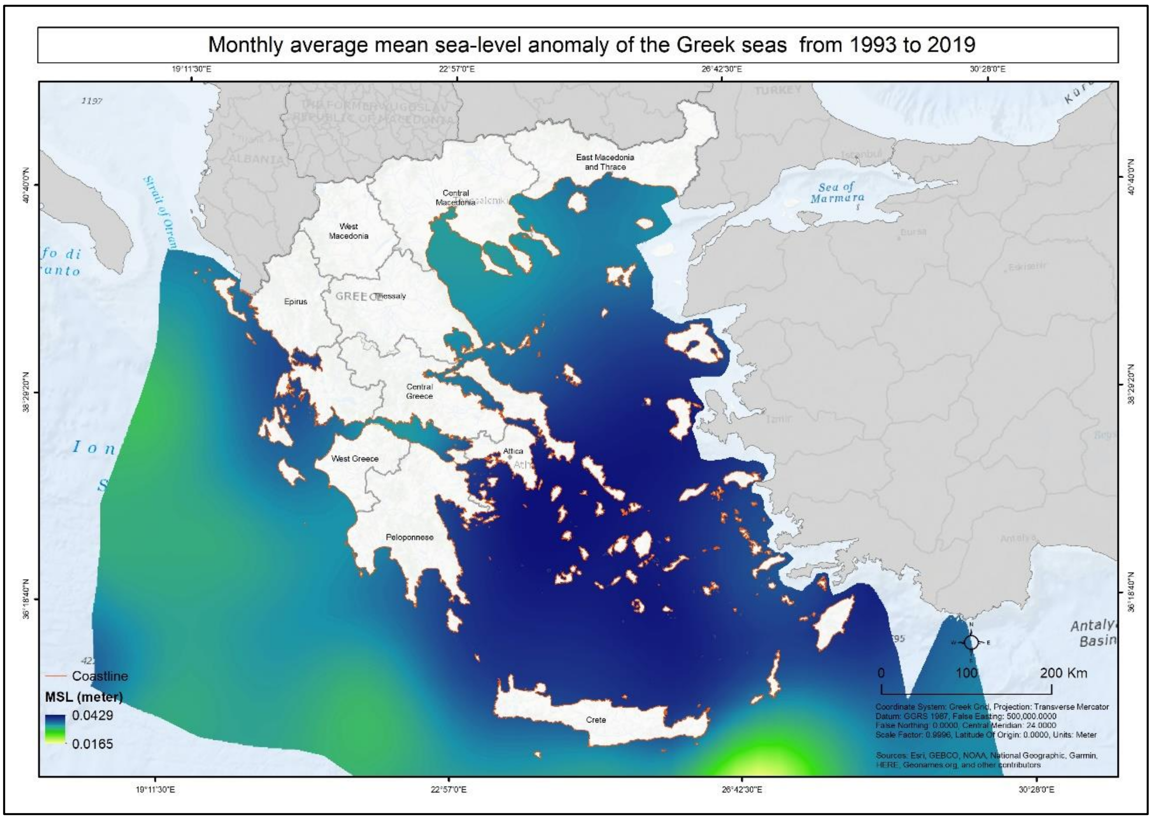


Figure 10: Mean sea level anomaly in the Greek seas. (Data source: AVISO+, 2019)

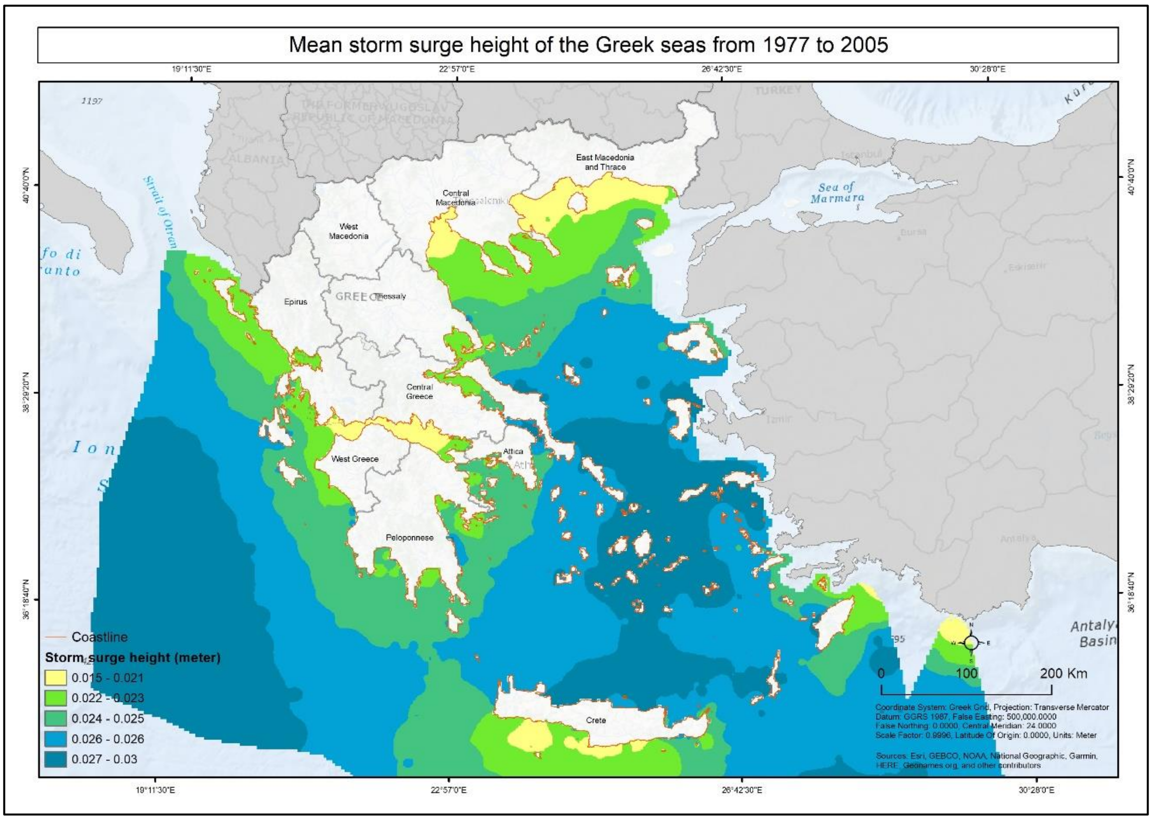


Figure 11: Storm surge height in the Greek seas. (Data source: ECMWF, 2021)

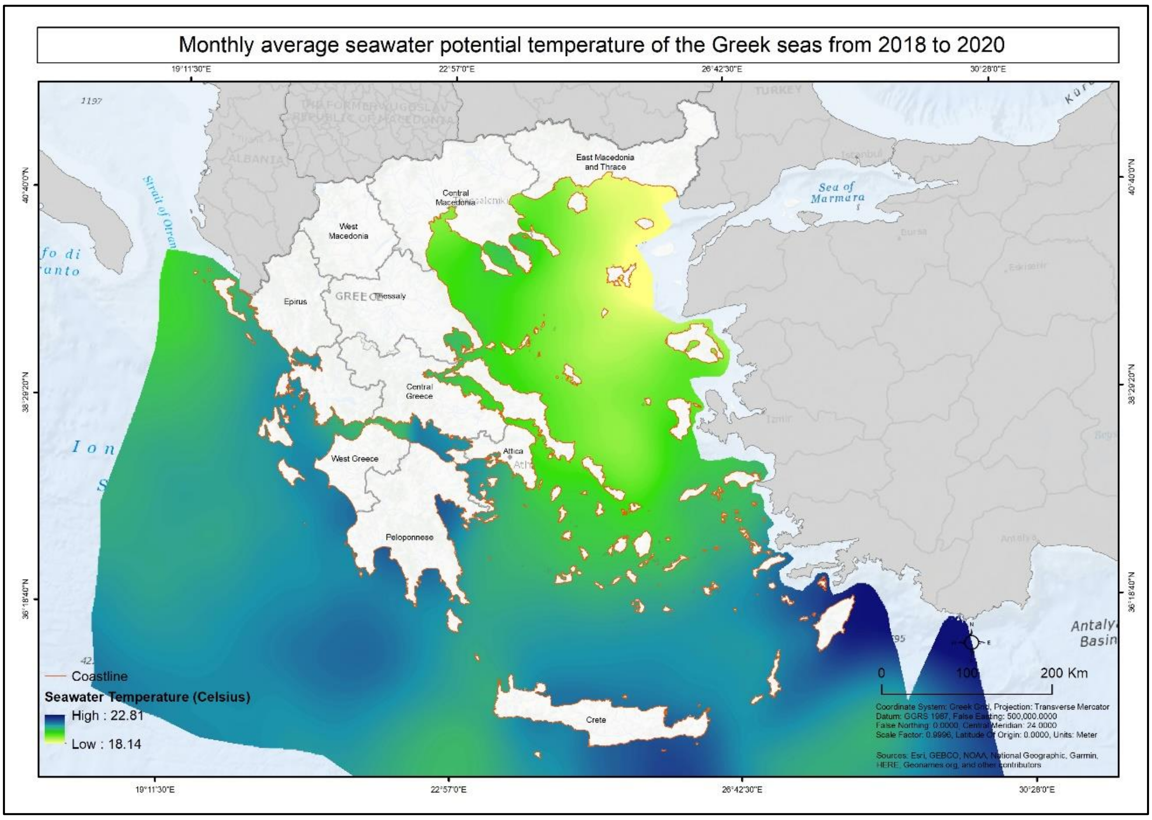


Figure 12: Seawater potential temperature in the Greek seas. (Data source: Clementi et al., 2019)

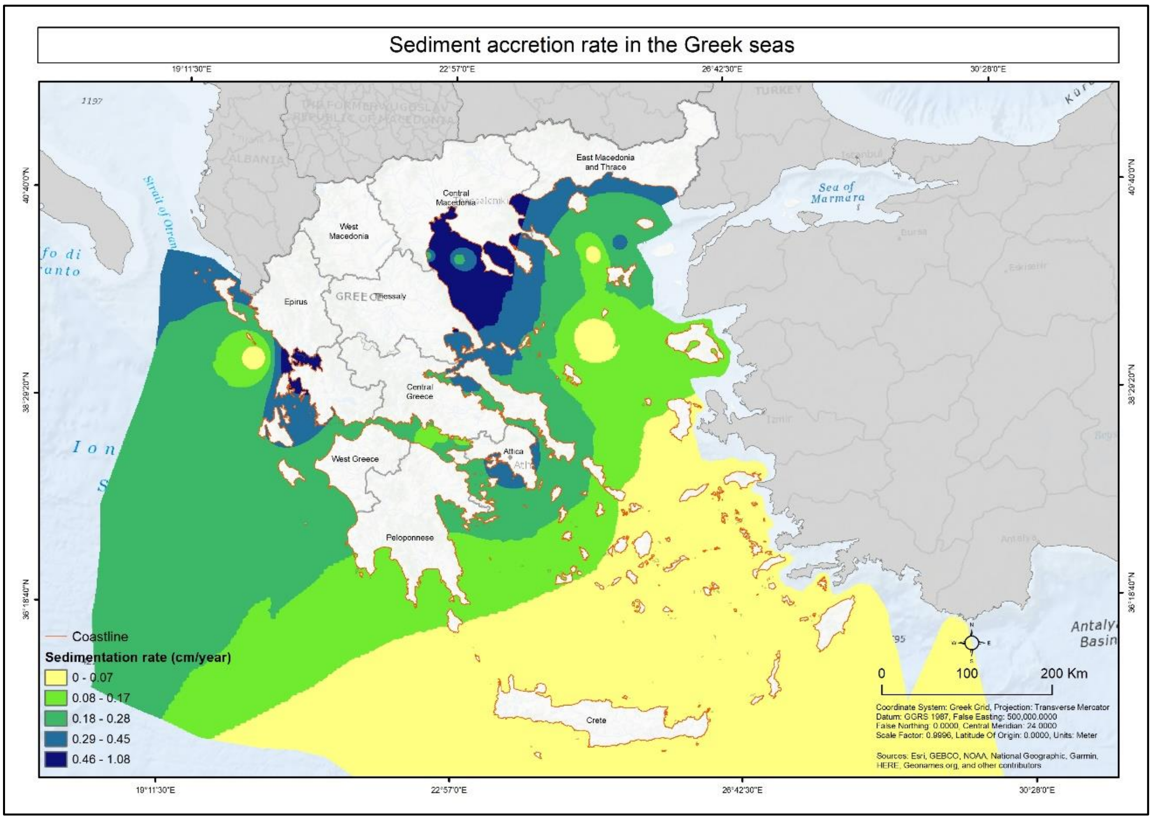


Figure 13: Sediment accretion rate (cm/year) in the Greek seas. (Data source: EMODnet-Geology, 2019)

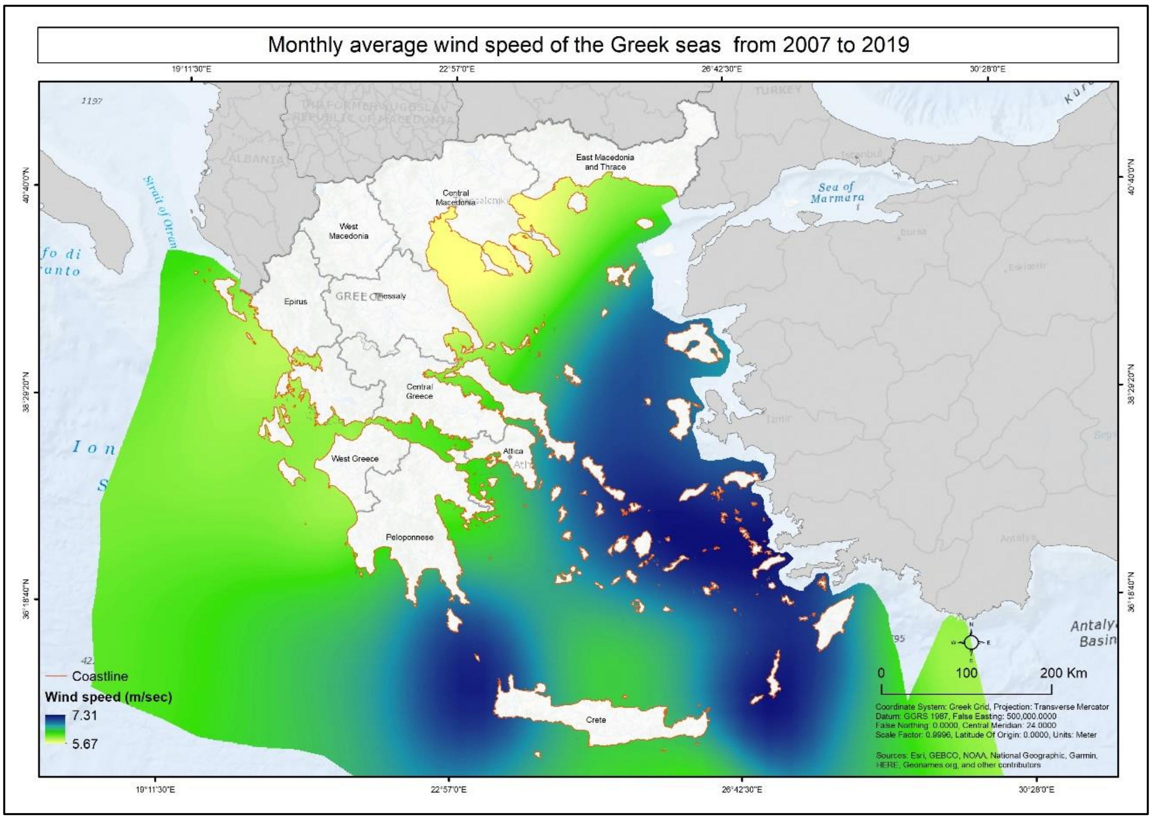


Figure 14: Wind speed in the Greek seas. (Data source: Global Monitoring and Forecasting Center, 2019)

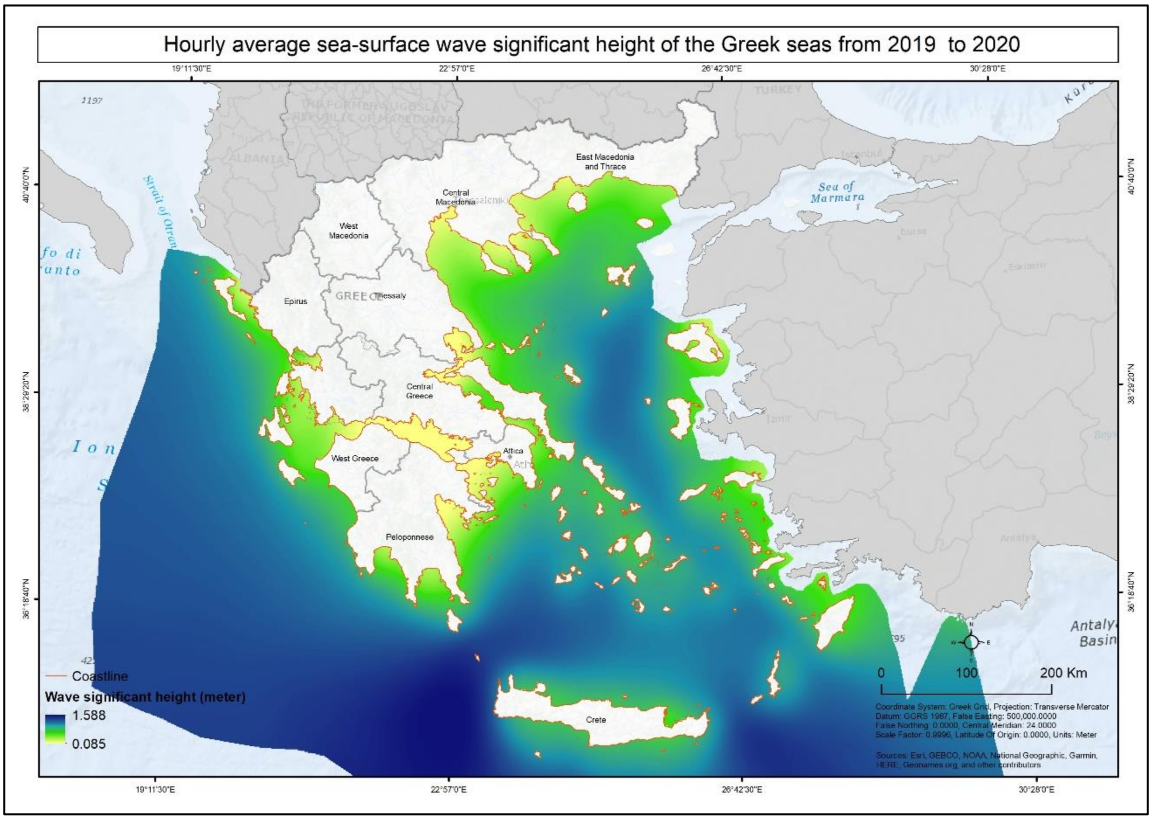


Figure 15: Wave significant height in the Greek seas. (Data source: Korres, Ravdas, & Zacharioudaki, 2019)

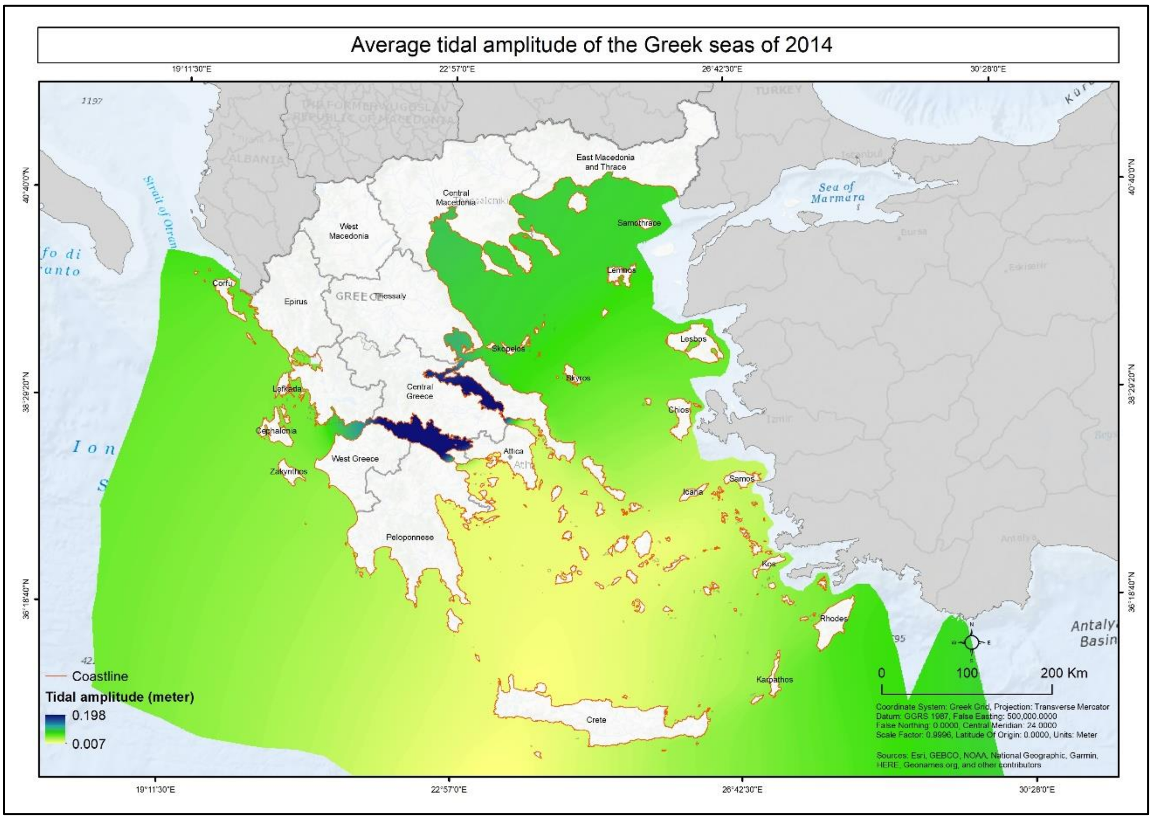


Figure 16: Tidal range in the Greek seas. (Data source: AVISO+, 2016)

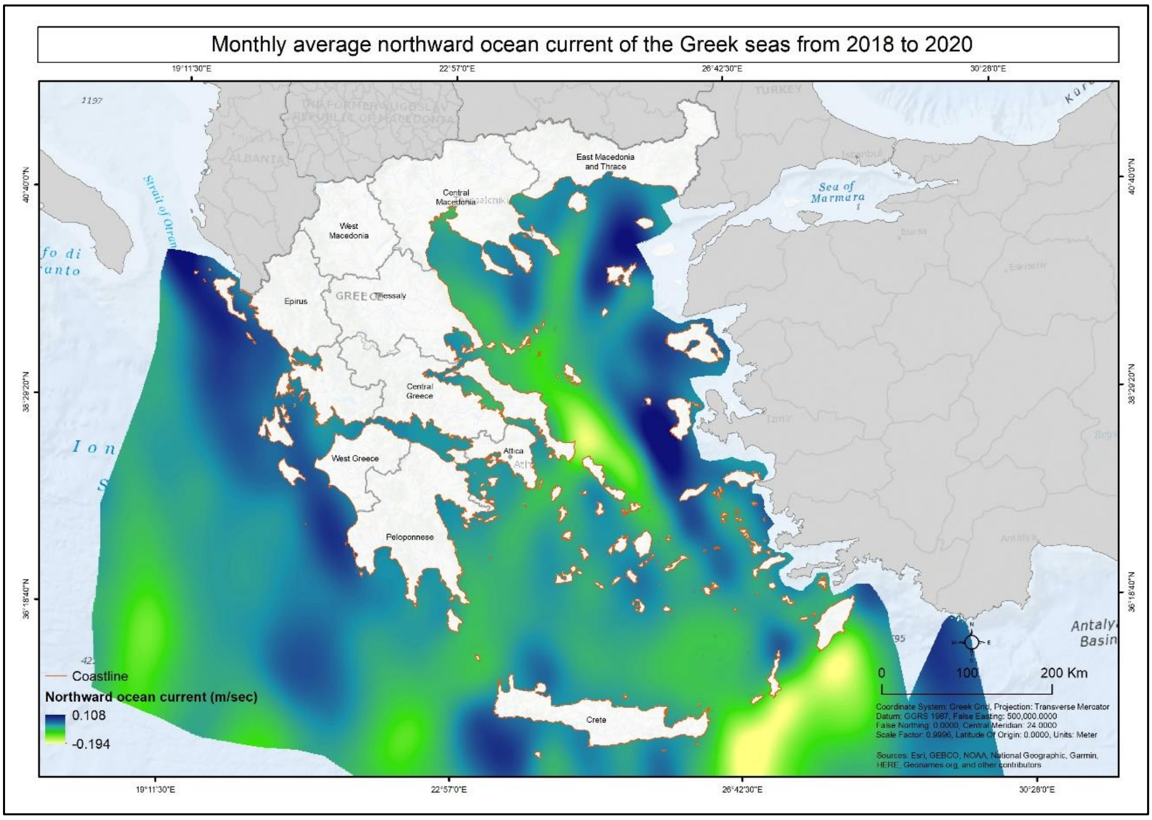


Figure 17: Northward ocean current in the Greek seas. (Data source: Clementi et al., 2019)

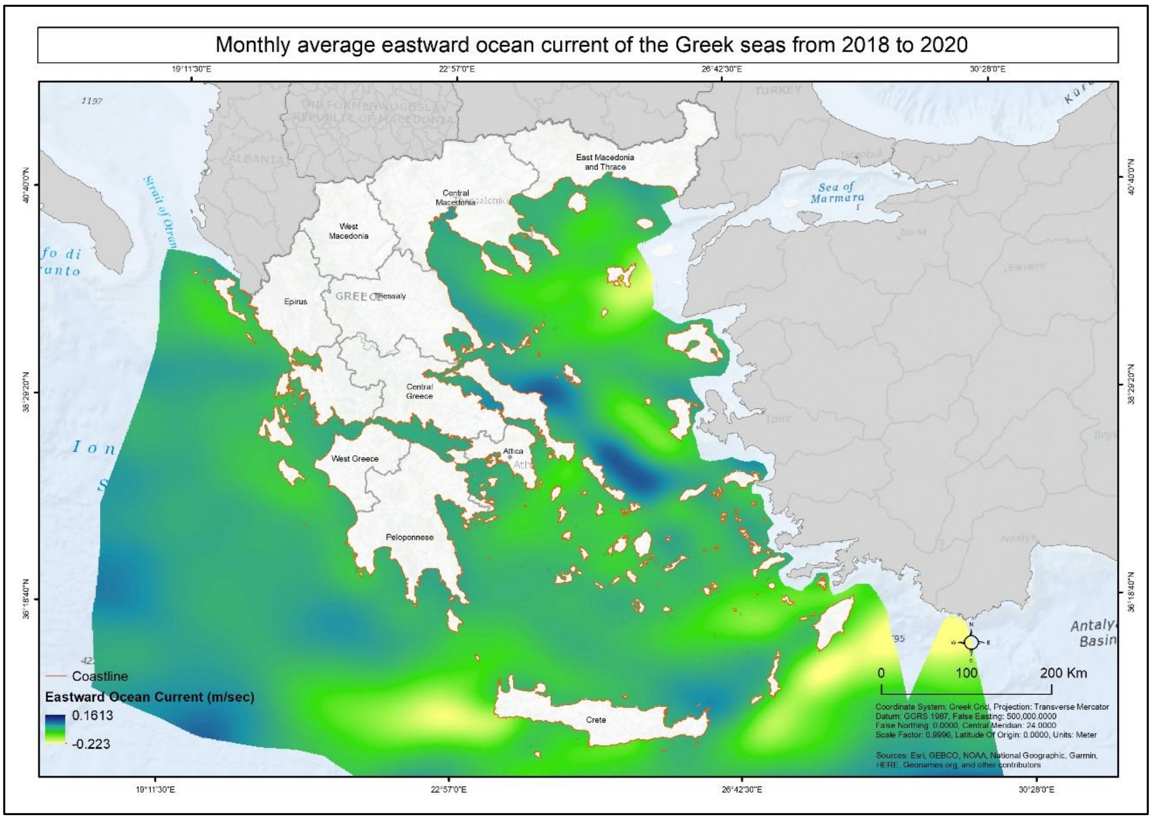


Figure 18: Eastward ocean current in the Greek seas. (Data source: Clementi et al., 2019)

3.1.2. Socio-economic condition of the study area

The Greek coast is a very popular destination for living as well as for local, national, and international tourism. Around 33% population lives within 1-2 km from the coast, and the population density of the Greek coast is 87 people per square km (Simboura et al., 2018). If the population living within the 45 minutes or 50 km driving distance is considered, then the coastal population will be 85% of the total population of Greece (Mourmouris et al., 2006). But the major concentration of population is seen in the major cities of the coastal areas such as Athens or Thessaloniki (Polyzos & Tsiotas, 2012) (Figure 19). Besides, 90 % of the tourism and recreational (Figure 21) activities, 80% of the industrial activities, 35% of agricultural activities, and most of the fishing and aquacultural activities can be seen in those coastal zones (Mourmouris et al., 2006). Apart from this, a large number of settlements (Figure 20) and other infrastructure such as harbors, airports (Figure 20), roads (Figure 22), electricity network, telecommunications, etc., are also visible near the coastal zone. Moreover, Greece is one of the prominent countries in supplying different ore among European countries. Most of its mineral extraction sites are in Central Greece and Western Macedonia (Melfos & Voudouris, 2012) and very few mineral extraction sites can be seen near the coast (Figure 21). The physical setting and changing climatic conditions make this densely populated and highly attractive touristic coastal zone vulnerable in terms of erosion, floods, or other natural disasters. This vulnerability in coastal protection is posing threats not only to human wellbeing but also to nature and biodiversity.

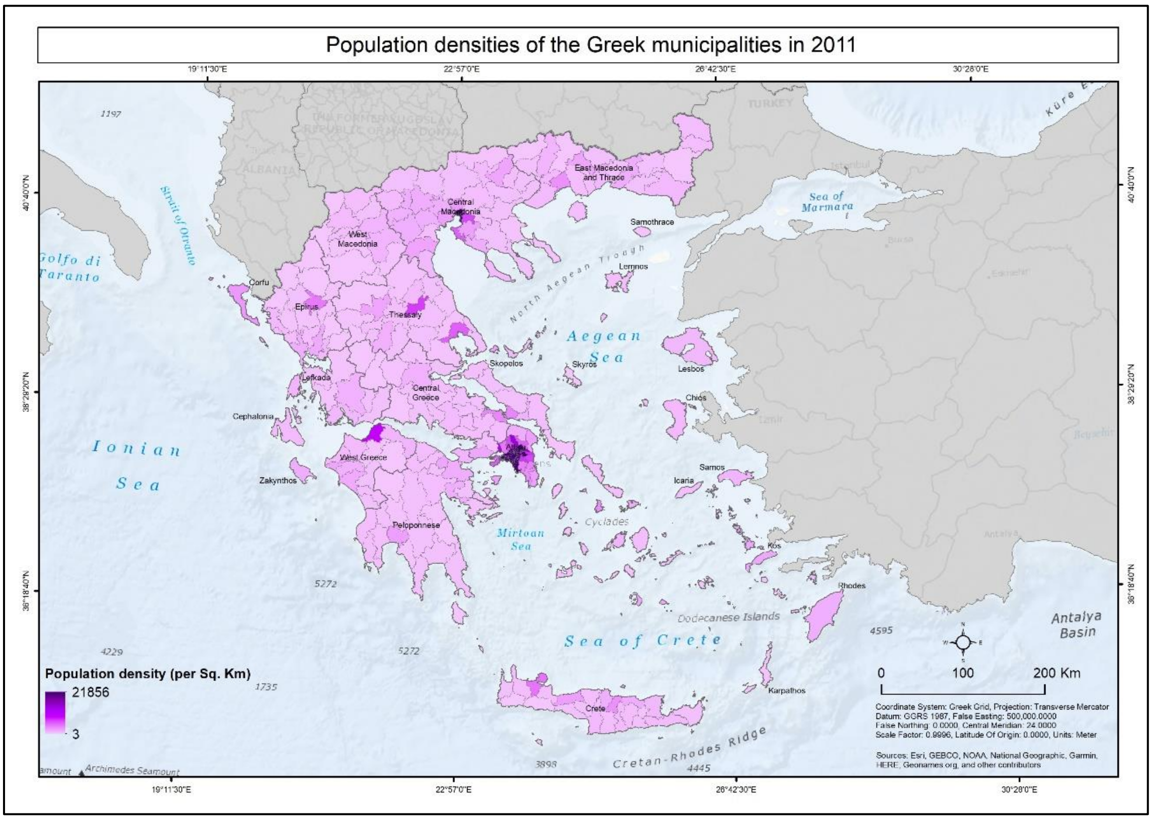


Figure 19: Population density of the Greek municipalities in persons per square kilometre (Data source: Hellenic Statistical Authority, 2011)

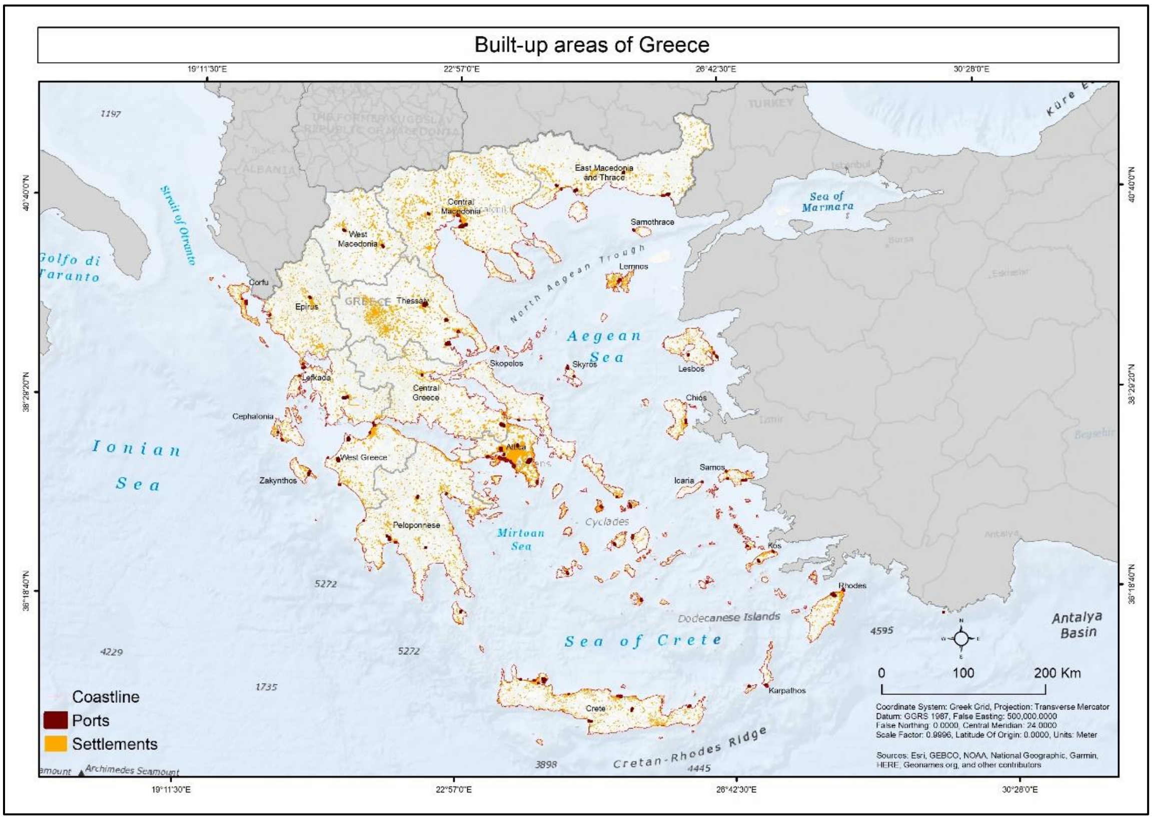


Figure 20: Built-up area of Greece. (Data source: EEA, 2018, OpenStreetMap contributors, 2017)

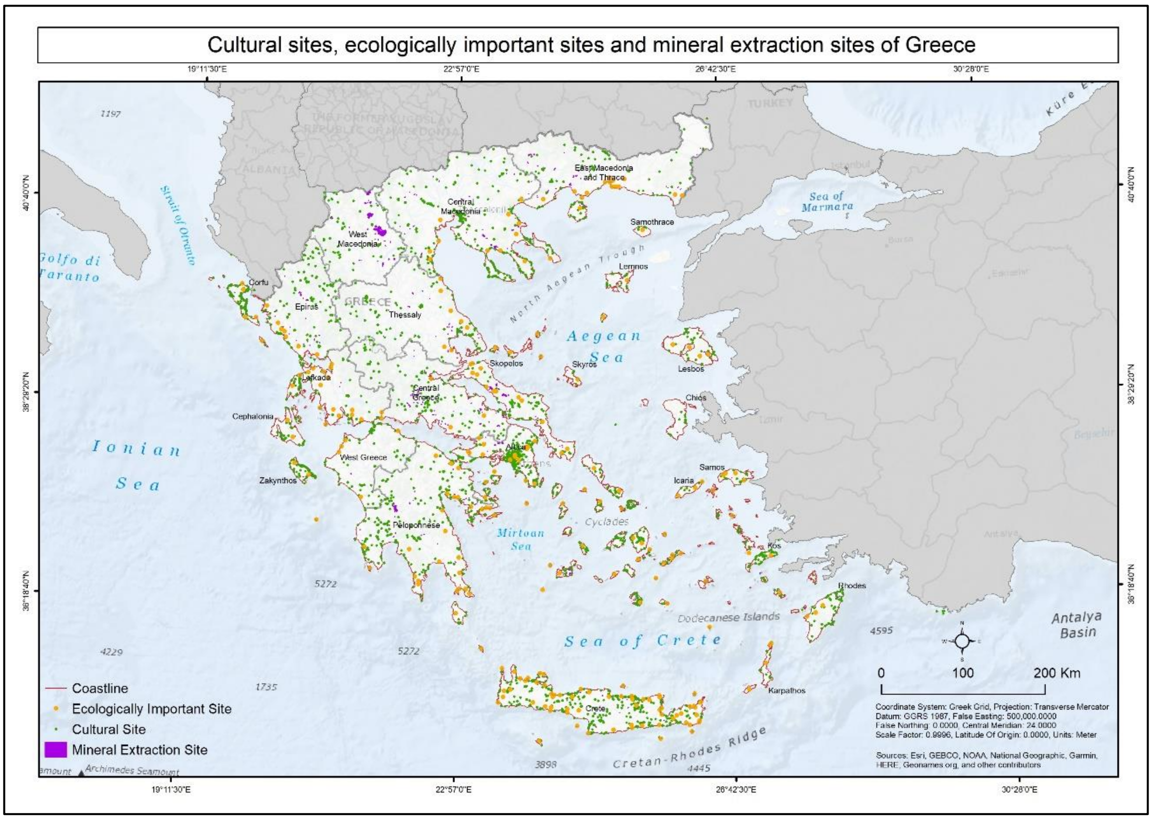


Figure 21: Cultural sites, ecologically sites, and mineral extraction sites of Greece. (Data source: EEA, 2018, OpenStreetMap contributors, 2017)

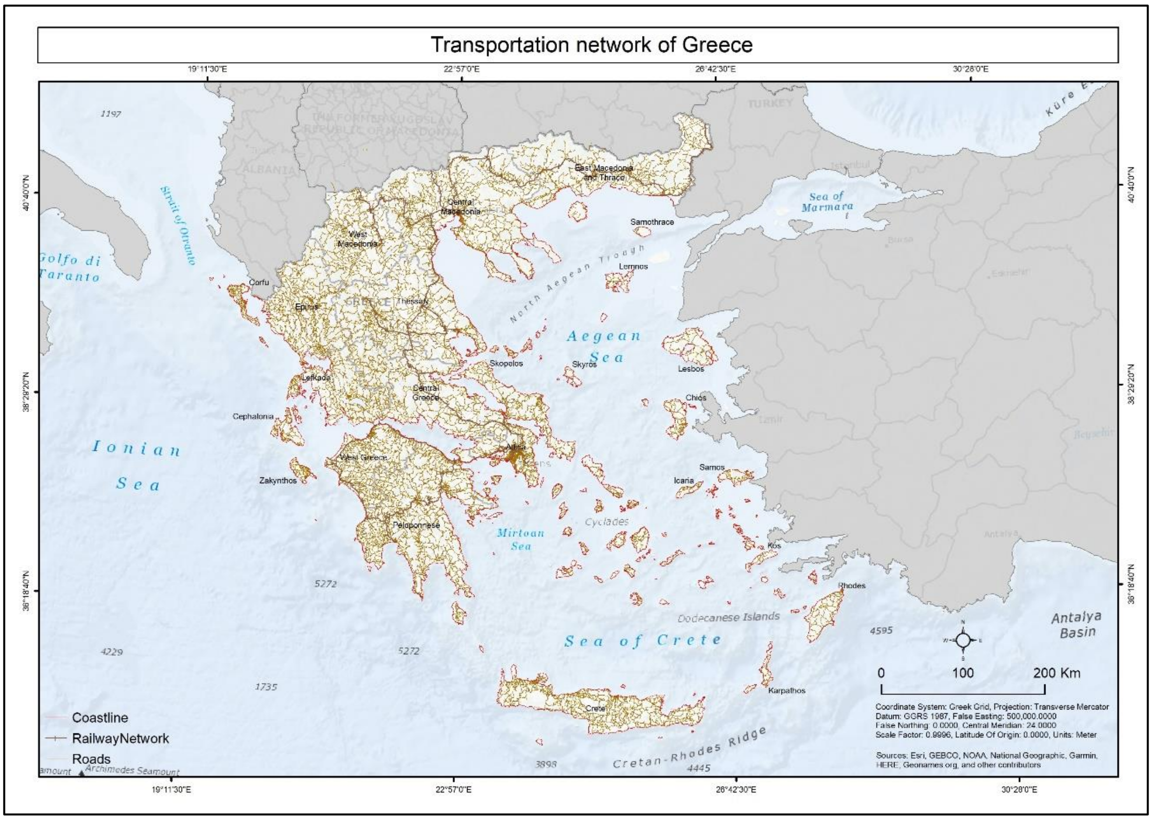


Figure 22: Transportation network of Greece. (Data source: EEA, 2018, OpenStreetMap contributors, 2017)

3.1.3. Delimitation of the coastal zone and calculation unit

The ocean and coast have always been considered essential for the national economy of Greece. The geophysical condition of coastal Greece has facilitated the development of urban areas near the sea (Camhis & Coccossis, 1982). Considering the importance of the coast, the government of Greece has depicted its vision for the protection and development of coastal zone through law 2971/2001 (Doukakis, 2004). According to this law, the coastal zone of Greece is consists of "seashore" and "beach zone" where private construction is prohibited (Giannakourou & Balla, 2015). In this law, the seashore is defined as the land zone where the maximum winter waves run up, and the beach is the land zone that is adjacent to the seashore and extends up to 50 m from the seashore to the inland area (Doukakis, 2004, Giannakourou & Balla, 2015). The beach acts as a communication area between the mainland and the sea. But it has been argued that hydrodynamic condition and coastal protection have not been appropriately considered in this demarcation of the coastal zone (Doukakis, 2004).

Generally, the coastal zone is shaped by both the hydrodynamic condition of the ocean and the socio-economic structure of the adjacent area (Le Hir et al., 2000, Dronkers & Stojanovic, 2016). Hydrodynamic condition is usually influenced by the geomorphological and biological condition of the ocean (Jouon, Douillet, Ouillon, & Fraunié, 2006). Considering the importance of hydrodynamic factors on the coastal zone, Liquete et al., (2013b), in their regional level study, have delineated coastal zone based on the extreme hydrodynamic effects of oceans. They considered the coastal zone as the area which falls under 50m depth isobath with minimum one nautical mile offshore distance and 50m height contour with minimum 1 km inland distance from the coastline. On the other hand, Guisado-Pintado et al., (2016), in their local level study, also considered the hydrodynamic condition of the sea to demarcate coastal zone. They delimited the coastal zone by 100m depth isobath with a minimum distance of one nautical mile from territorial water baseline and 100m height topographic contour, considering the study area's steepness.

The coastline is the most clearly delineated feature of any coastal zone (Dronkers & Stojanovic, 2016). The coastal areas of Greece are composed of numerous small islands and other geomorphic features that made the coastline very complicated and overlapped. Following the works of Liquete et al., (2013b), and Guisado-Pintado et al., (2016) and considering the socio-economic and hydrodynamic condition of coastal areas of Greece, the coastal zone for this research work has been considered as the areas which fall under 100m depth isobath and 100m height contour line. A minimum of one nautical mile and a maximum of two nautical miles offshore distance is also considered for delimiting the seaward boundary. To delineate the coastal zone's landward boundary, a minimum of one km inland distance from the coastline has been considered (Figure 23). The biophysical and socio-economic characteristics of the mainland of Greece differ from its coastland. To include only those areas in this study that resemble coastal biophysical and socio-economic characteristics and also those areas which face the extreme hydrodynamic condition of the coast, a maximum five km inland distance from the coastline has been considered for those landmasses which have an area of more than or equal to 20,000 km^2 and a maximum of three km inland distance from the coastline has been considered for those landmasses which have an area of more than or equal to 3,000 km^2 but less than 20,000 km^2 (Figure 23). For the rest of the areas of Greece, a minimum of one km inland distance or 100m height contour line and one nautical mile or 100m depth isobath rule have been followed (Figure 23). This delineation will avoid the mixture of inland characteristics to the delineated coastal zone and will also maintain the uniqueness of coastal characteristics throughout the coastal zone.

Finally, the entire coastal zone has been divided into calculation units. The coastal protection capacity or coastal exposure or protection demand of the Greek coast depends on several hydrodynamic, oceanographic, and socio-economic variables such as geomorphology, slope, sea-level rise, storm surge height, population, and settlement density, etc. As throughout the coastal zone there is a variation of hydrodynamic, oceanographic, and socio-economic conditions, the entire coastal zone needs to be divided into several calculation units to encompass the variation in the analyses process. These calculation units will help to capture those variations to assess the protection capacity or exposure, or protection demand of a particular area based on the hydrodynamic, oceanographic, and socio-economic condition of that area. After implying several spatial and statistical processes the mean or weighted values of those biophysical and socio-economic variables within the delineated coastal zone has been assigned to these calculation units maintaining the variation of values of different variables. This value for each calculation unit expresses the hydrodynamic, oceanographic, and socio-economic condition of that calculation unit. The division of coastal zone into calculation units was quite essential as the aggregated values of different hydrodynamic, oceanographic, and socioeconomic variables within each calculation unit express the protection capacity or exposure or protection demand of that particular location within the coastal zone. Through these processes to assess and map protection capacity or exposure or protection demand for the entire coast of Greece, the delineated coastal zone has been divided into 45,533 blocks to generate calculation units, where each block has an area of not more than 1 km^2 (Figure 24). Then the blocks which are perpendicular to the coastline have been merged into the calculation units that divide the coastline in every 1 km. Through this merging process, the delineated coastal zone is divided into 7,358 calculation units (Figure 25). The delimited coastal zone is not straight; it is comprised of many curves and, in some cases, a curve inside a curve. For those cases, perpendicular blocks can be selected from at least two sides (Figure 26). Calculation units for the curved areas have been generated by merging all the blocks that are within the perpendicular blocks of both sides (Figure 26). In the delineated coastal zone some areas identified with an elevation of more than 100m. Some calculation units have been divided by those higher elevation areas into two segments where one segment lost its direct connection with the other segment which is connected with the coastline. For the convenience of the analysis and maintaining the continuity of the calculation unit, those parts of the calculation unit were removed which are not directly connected to the coastline (Figure 27).

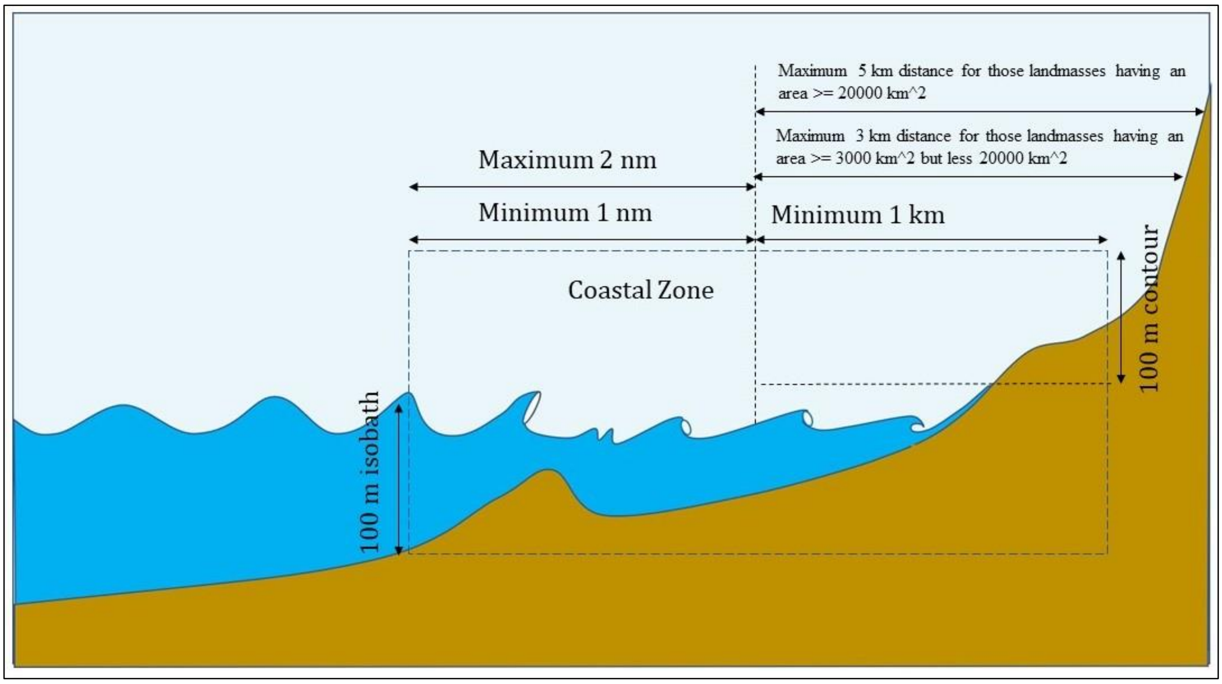


Figure 23: Coastal zone delineation for this study

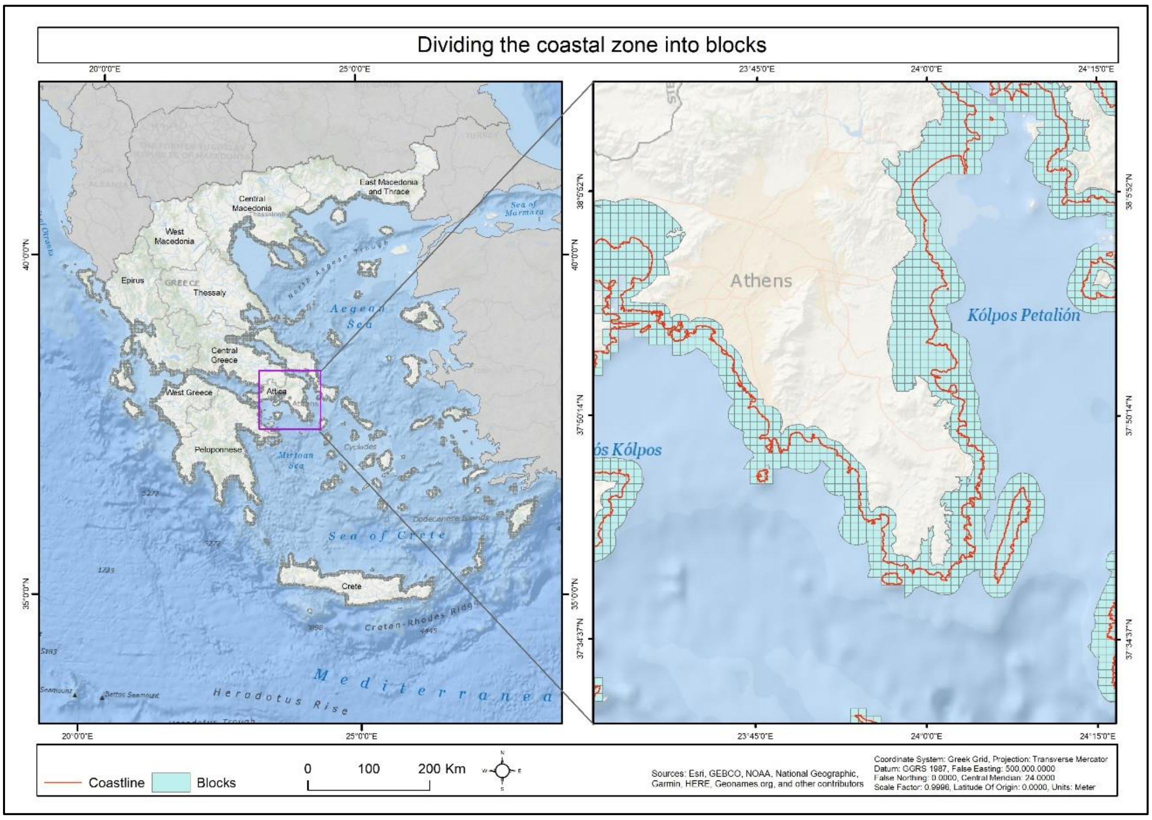


Figure 24: Dividing the coastal zone into 1*1 km blocks

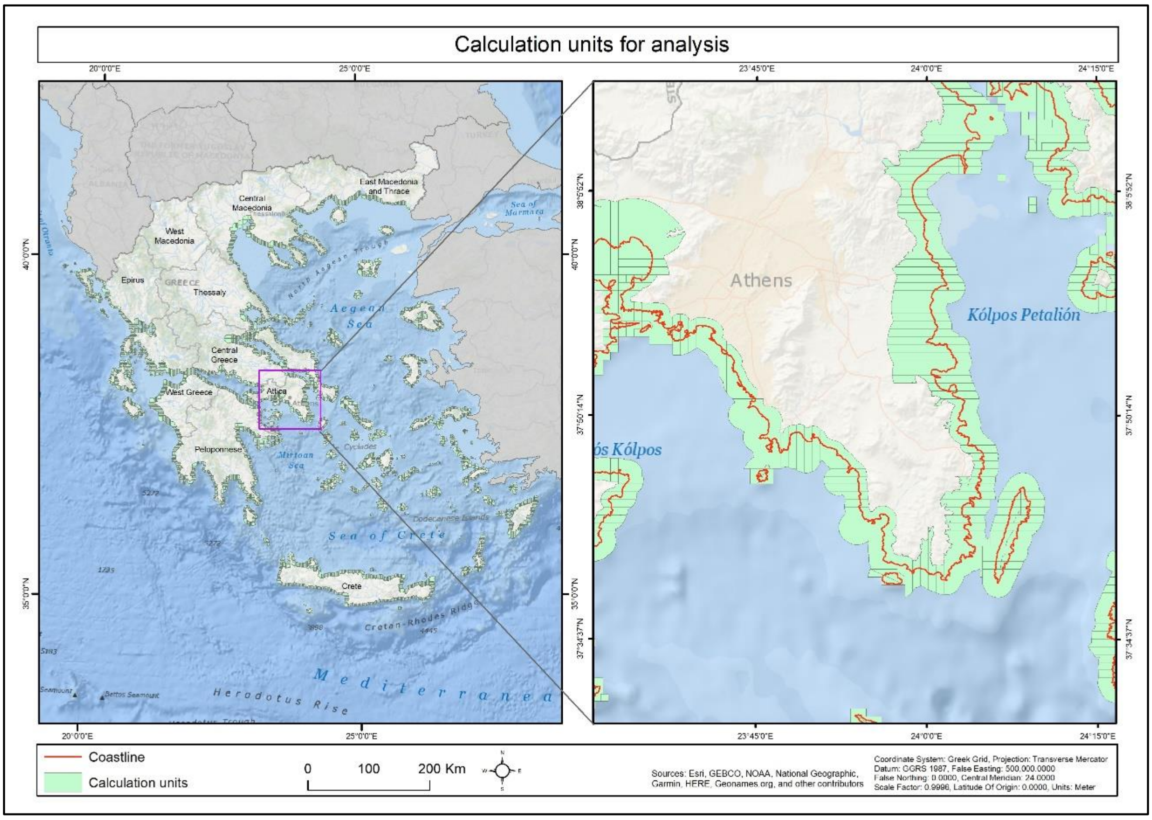


Figure 25: Calculation units for analysis

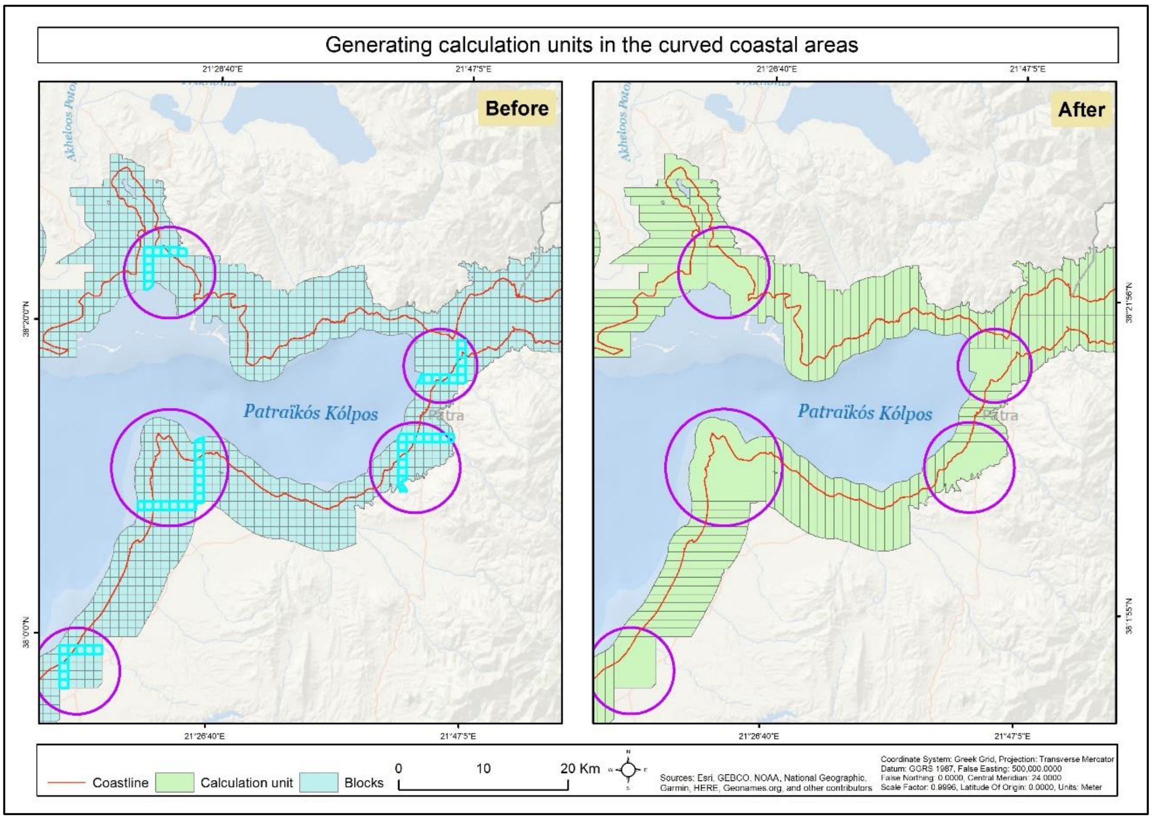


Figure 26: Merging perpendicular and associated blocks to generate calculation units

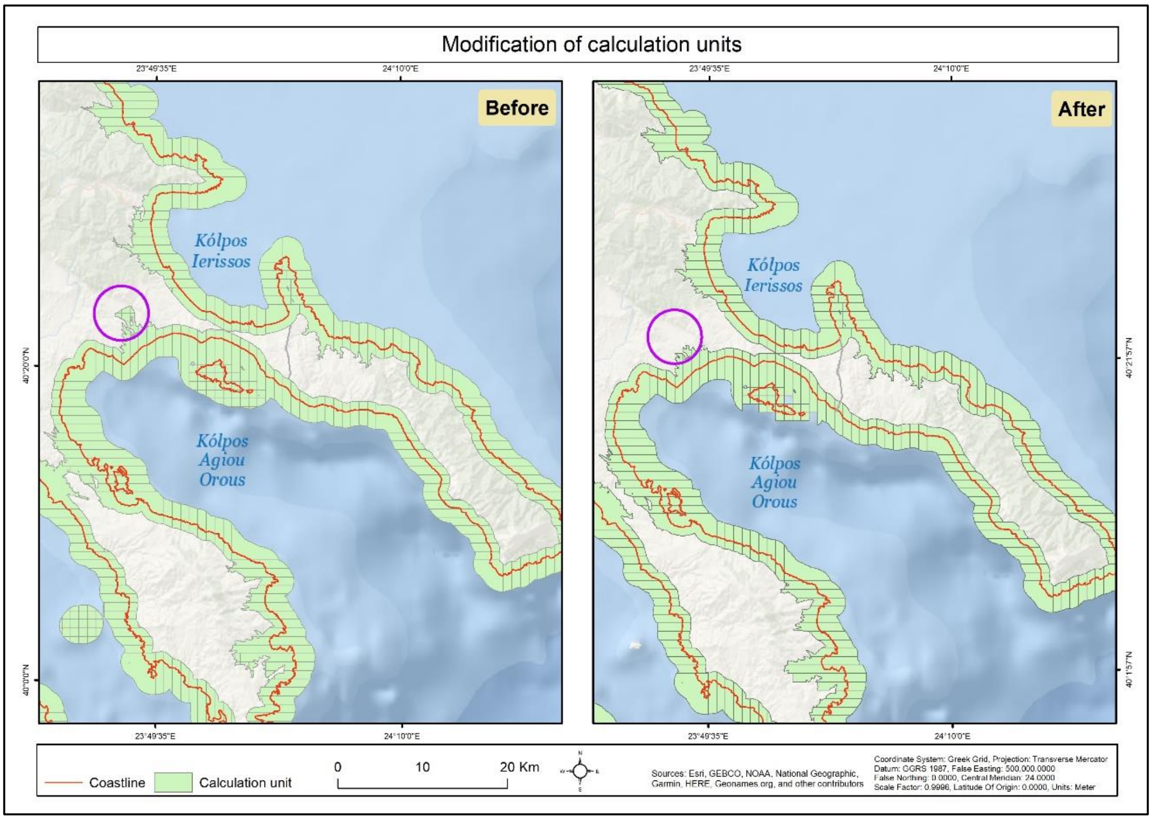


Figure 27: Removing segments of calculation units that are separated from the calculation unit which is connected to the coastline

3.2. Conceptual framework

This section investigates different aspects of the cascade framework to understand the downscaling mechanism of the regional level model to the national scale. The ecosystem service cascade framework links biodiversity and ecosystem structure and the processes generated from them for human well-being by recognizing the flow of services from the ecosystem (Haines-Young & Potschin, 2012). In the real world, the links are not linear or straightforward but complex and multidimensional, which resemble a cascade relationship between the environmental and socio-economic side of ecosystem services (Haines-Young & Potschin, 2010). Figure 28 depicts the conceptual framework used in this study adapted from the ecosystem service cascade framework (Liquete et al., 2013b, Burkhard & Maes, 2017), which illustrates biophysical structure, ecosystem function, and human well-being as elements of the ecosystem services supply chain and link of those structure with the coastal protection capacity, coastal protection exposure and coastal protection demand indicators. In the cascade framework, the function of the ecosystem is determined by the biophysical structure and process of the ecosystem which determines the capacity of an ecosystem to provide services. Mentioning ecosystem function as a subset or intermediate between ecosystem process and service, de Groot, (1992) defined ecosystem function as the "capacity of ecosystems to provide goods and services that satisfy human needs directly and indirectly". In this study, the function of the coastal ecosystem that generates protection for the coast from inundation or erosion is being represented through the coastal protection capacity indicator. On the other hand, the projected need for that function for coastal protection has been represented by the coastal protection exposure indicator which depends on the climatic, hydrodynamic, and oceanographic condition of the coast. The coastal protection capacity and coastal protection exposure indicators provide an indication of coastal protection service flow. The coastal protection ecosystem service flow will be higher where the coast has a higher protection capacity than the exposure and the use of this service will be higher where coast is exposed and also have protection capacity. Finally, the estimated needs of coastal protection service which depends on the socio-economic condition of the coast has been represented by coastal protection demand indicator. This is further connected with the coastal protection service benefit which is the use of service for coastal protection from human-wellbeing perspective. For instance, a coastal zone can have different biophysical structures such as mangroves or wetlands, which may have the capacity to slow down the wave actions or storm surge. This function of this specific ecological structure may have the potential to modify the intensity of flooding in that area, which can also be beneficial for humans. But whether this specific function will be considered ecosystem service or not will depend on whether this control of flood is considered a benefit for the people of that area. People or society will value to what extent this function is important for them which will ultimately determine the overall ecosystem service generated from that coastal area (Haines-Young & Potschin, 2010).

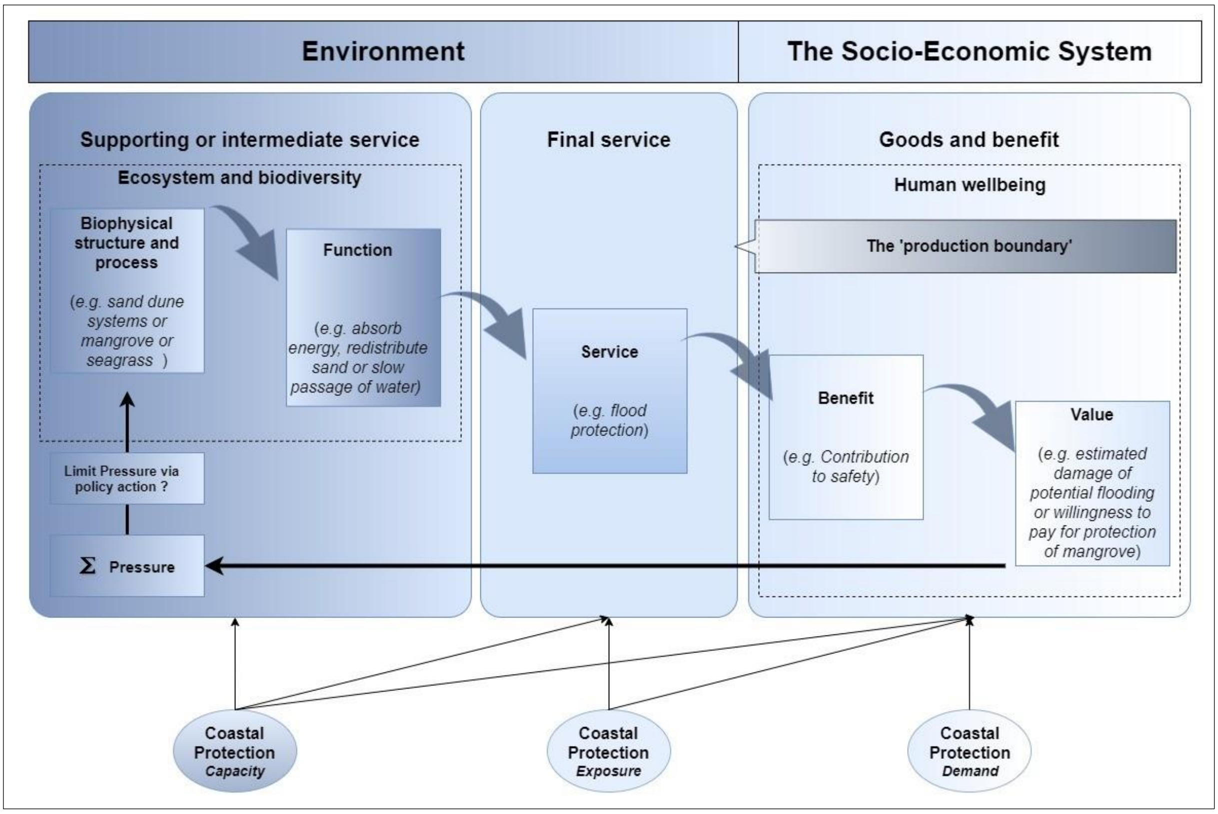


Figure 28: Conceptual framework of this study based on cascade model (adapted from Liquete et al., 2013b, Burkhard & Maes, 2017)

3.3. Methodological workflow

The cascade framework is useful to determine nature's capability to provide ecosystem services for human wellbeing. It also considers those institutional and social activities that influence the state of ecosystems and their potential to provide services. Following the cascade framework, this research aims to assess ecosystem services for coastal protection through coastal protection capacity, coastal protection exposure, and coastal protection demand indicators, which have been assessed and mapped by following a series of processes (Figure 29). At first, to assess those indicators, different relevant variables have been identified from the literature study. The coastal zone of Greece has also been delineated based on literature findings and considering the hydrodynamic, oceanographic, and climatic conditions of the Greek coast. The variables of indicators have derived from both quantitative and qualitative data, which indicates the biophysical and socio-economic condition of the coastal areas of Greece. Data have been collected for the identified variables from different online accessible sources. Collected data have been cleaned, manipulated, harmonized, and normalized for statistical and spatial operations. Expert opinion has been taken through an online survey to weigh the chosen variables and their subtypes. Finally, the outcomes of spatial and statistical operations have been used to assess the coastal protection capacity, exposure, and demand by using specific equations.

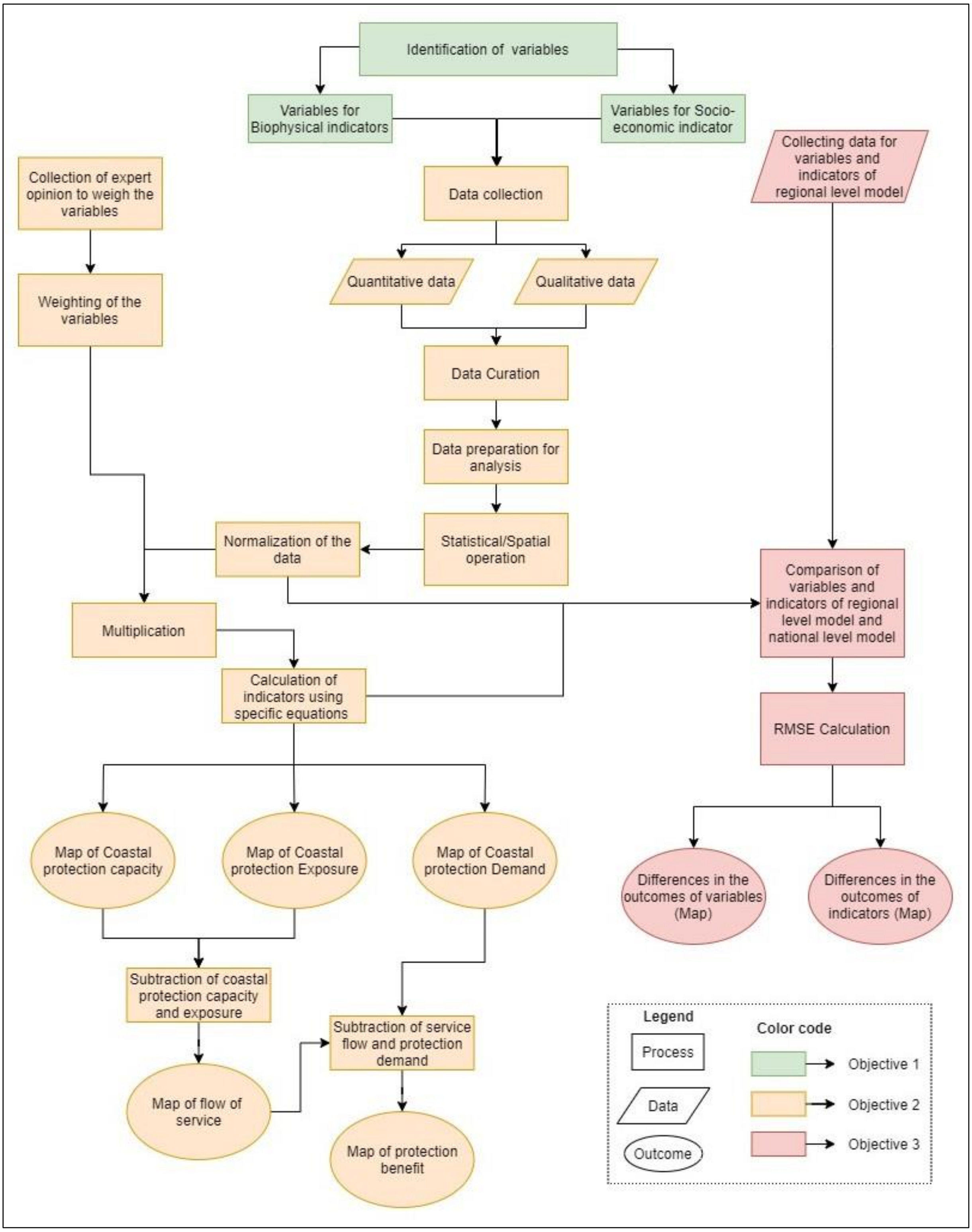


Figure 29: Workflow of the research

3.4. Data management

3.4.1. Variable selection

For this research work, 22 variables have been identified for three indicators (Table 4). Among those variables, the Digital Elevation Model (DEM) of Greece and bathymetry of the Aegean, the Ionian, and the

Mediterranean Sea have been used to demarcate the coastal zone of Greece for this study. Moreover, based on the literature study (Liquete et al., 2013a, Liquete et al., 2013b, Guisado-Pintado et al., 2016, Trégarot et al., 2021), variables such as slope, geomorphology, submarine habitat, emerged habitat, and sediment accretion rate have been chosen to assess coastal protection capacity indicators. To assess the coastal protection exposure indicator, eight variables, namely sea-level rise, storm surge height, wave regime, tidal range, wind speed, ocean current (eastward and northward), and seawater potential temperature, have been identified. Population density, settlement density, transportation network density, port area density, mineral extraction site density, cultural sites and ecological sites density have been used to assess coastal protection demand for the Greek coast.

Table 4: List of selected variables to assess coastal protection capacity, coastal protection exposure, and coastal protection demand.

Variables	Use for indicators/tasks	Use for ecosystem service assessment
DEM	Delimitation of the study area	
Bathymetry		
Slope	Coastal Protection Capacity	Capacity, flow, and benefit
Geomorphology		
Submarine habitats		
Emerged habitats		
Sediment accretion rate		
Sea level rise	Coastal Protection Exposure	Flow and benefit
Storm surge height		
Wave regime		
Tidal range		
Wind speed		
Eastward ocean current		
Northward ocean current		
Sea water potential temperature		
Population density	Coastal Protection Demand	Benefit
Settlements (residential, industrial, commercial)		
Cultural site		
Transportation network (roads, railway)		
Ports (airports, ports)		
Areas of high ecological values		
Mineral extraction site		

3.4.2. Data downloading and cleaning

The data of the variables of all the three indicators are in both raster and vector format. Data has been downloaded from various online sources and after downloading the data, depending on the format and use of the data, different procedures have been followed (Figure 30). Most of the downloaded data were in NetCDF format, which has been converted to tiff format using either Python programming or QGIS 3.16.2 as tiff format is easily interoperable. Missing values of those raster data have been filled up using ArcGIS 10.7 software.

Based on the requirements of the analysis process missing values of the vector data have been filled or information has been merged or only the required portion has been selected. A detailed description of the data downloading, and cleaning process is given in Figure 30.

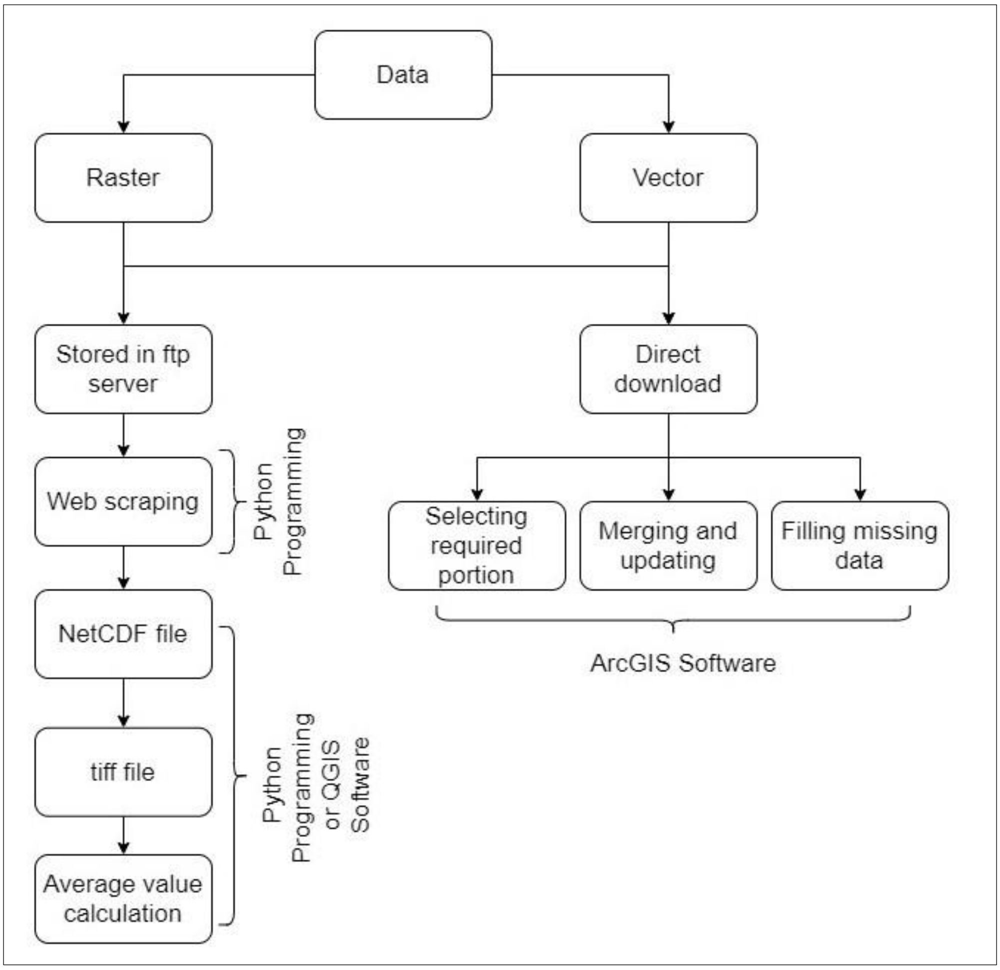


Figure 30: Data download and cleaning process

3.4.2.1. DEM

Digital Elevation Data (DEM) data have been downloaded from the Copernicus Land Monitoring Service website. These data are distributed in several grided areas. To cover the entire area of Greece, data from two Grids namely, 'E50N20' and 'E50N10' have been downloaded directly by clicking on a specific link. Both the files have been combined with the mosaic technique using ArcGIS 10.7.1 software. Then a subset has been created using the international boundary shapefile of Greece. After that, the projection of this data has been changed to Greek Grid. The unit of the data is meter.

3.4.2.2. Bathymetry

Bathymetry data have been downloaded directly from the "General Bathymetric Chart of the Oceans" (GEBCO) website. This is the latest product of this website which is known as GEBCO_2020 Grid. This data is a fusion of land topography with measured and estimated seafloor topography with a spatial resolution of 15 arc seconds. It uses version 2 of the SRTM15+ data set as its base.
This Data has been downloaded in tiff format. After downloading the data, a subset of this data has been created by using the Exclusive Economic Zone (EEZ) shapefile of Greece to cover only the necessary area. After that projection has been changed to Greek Grid. The unit of the data is meter.

3.4.2.3. Slope

The slope of Greece has been generated from the downloaded mosaiced DEM file using ArcGIS software where 'output measurement' and 'method' for creating slope has been chosen as 'Degree' and 'PLANAR' respectively. The unit of the data is degree.

3.4.2.4. Geomorphology

Geomorphology data have been downloaded directly from the European Environmental Agency website. It is a regional scale data set (for the entire Europe). The required portion has been extracted by clipping with the Greece International boundary shapefile. After that, the projection of the data has been changed to Greek Grid.

This data has several attribute columns, among which 'CEMOV' is one of them, representing the detailed geomorphology types. In this dataset, 13 types of distinct geomorphology classes have been identified. But in some areas, information about geomorphology types was missing. As it is essential to have continuous information of the entire coast, missing geomorphology data have been filled by inserting the nearby geomorphology data. It has been done using the spatial join technique where the match option was "CLOSEST". A new attribute column has been created with the corrected and updated geomorphology data and named 'CEMOV2'.

3.4.2.5. Seabed habitat

Seabed habitat data have been downloaded directly from the EMODnet Seabed Habitats website. Downloaded data was for the entire Mediterranean Sea. The required portion has been extracted using the EEZ shapefile.

Different columns of the attribute table of this data represent different seabed conditions. But there was some information missing in several areas. Missing data have been filled using the value of nearby location. For this, the Spatial join technique has been used, and the 'CLOSEST' option has been chosen for matching criteria.

A separate column has been created named 'SCH' in the attribute table. In this column, a broad classification has been created based on the information of the 'substrate' column of the file. 'Fine mud', 'Fine mud or Sandy mud or Muddy sand' and 'Muddy sand' have been combined into a single class named 'Shallow muds'. 'Posidonia oceanica' and 'Dead mattes of posidonia' have been combined into 'Seagrass meadows'. The 'Sand' and 'Sandy mud' have been combined into 'Shallow sands' and 'Coarse & mixed sediment' has been remained unchanged.

3.4.2.6. Emerged habitats

Emerged habitat data have been downloaded from the Copernicus Land Monitoring Service website. This data is widely known as Corine land cover data. Data of 2018, which is the updated one, has been downloaded for this study directly using the specific link.

The datasets cover entire Europe. A subset was created using the international boundary shapefile of Greece. After that, the projection has been changed to Greek Grid.

In this dataset, the land cover of Greece is divided into 42 classes. To identify the distinct emerged habitat type, some of those landcover classes have been merged into a single emerged habitat type class (Table 5).

Table 5: Name of emerged habitat types and associated landcover classes

Emerged Habitat type class	**Landcover class**
Beaches, dunes, sands	Beaches, dunes, sands
Coastal lagoons	Coastal lagoons
Estuaries	Estuaries

Forests	Broad-leaved forest
	Coniferous forest
	Mixed forest
Fruit trees	Fruit trees and berry plantations
	Olive groves
Heterogeneous agricultural areas	Complex cultivation patterns
	Land principally occupied by agriculture, with significant areas of natural vegetation
	Agro-forestry areas
Open spaces with little or no vegetation	Green urban areas
	Bare rocks
	Sparsely vegetated areas
	Burnt areas
Pastures	Pastures
Permanent crops	Permanently irrigated land
	Rice fields
	Annual crops associated with permanent crops
Scrub or herbaceous vegetation	Vineyards
	Natural grasslands
	Moors and heathland
	Sclerophyllous vegetation
	Transitional woodland-shrub
Water courses	Water courses
	Sea and ocean
Wetlands	Inland marshes
	Peat bogs
	Salt marshes
	Salines
	Water bodies

3.4.2.7. Sediment accretion rate

Sediment accretion data have been downloaded from the EMODnet Geology website. This data is originally produced within the EMODnet-Geology project (2009-2012) and updated during EMODnet III Geology (2017 – 2019). It is the compiled and harmonized data from all available information on the rate of sedimentation in European maritime areas. The information on sedimentation rates is presented as point-source information.

After selecting the points that fall under the EEZ shapefile, the IDW interpolation technique has been used to get a continuous raster file. To conduct this interpolation, ArcGIS software has been used and cell size has been changed to 100*100 meters. After that, the projection has been changed to Greek Grid. The unit of the data is cm/year.

3.4.2.8. Mean sea level

Mean sea-level anomaly data have been collected from the aviso+ website. This mean sea level (MSL) data is the average sea surface height of all the oceans, with respect to a reference. This data is the "Reference" product of MSL that was computed from the data received from Jason-1, Jason-2, and Jason-3 satellite series.

The MSL data was stored in an FTP server of the aviso+ website. For this thesis, monthly average mean sea level anomaly data from 1993 to 2019 have been collected from the FTP server.
Originally this data was in NetCDF format. Using a Python script (Code snippet 1), all the 322 NetCDF files have been downloaded from the FTP server and converted to tiff files. Then a mean from monthly average sea level data has been calculated using those files. After that, a subset has been created using the EEZ boundary shapefile of Greece. Then the projection of the subset file has been changed to Greek Grid. It has been identified that generated mean raster file does not cover the entire study area. To have continuous data throughout the coastline, missing portion of this data has been filled using the focal statistics tool. This tool has been chosen as it generates a raster where the value of each cell of this newly created raster comes from the statistical value (ex: mean or sum) of the neighbouring cell of the input raster. After that, cell size has been resampled to 1000*1000 meters using the 'Bilinear' interpolation technique (Figure 31) considering the length of the calculation unit, which is also 1000 m. Bilinear interpolation technique has been chosen as it works better for continuous data such as mean sea level, ocean current, tidal amplitude, etc. The unit of the data is meter.

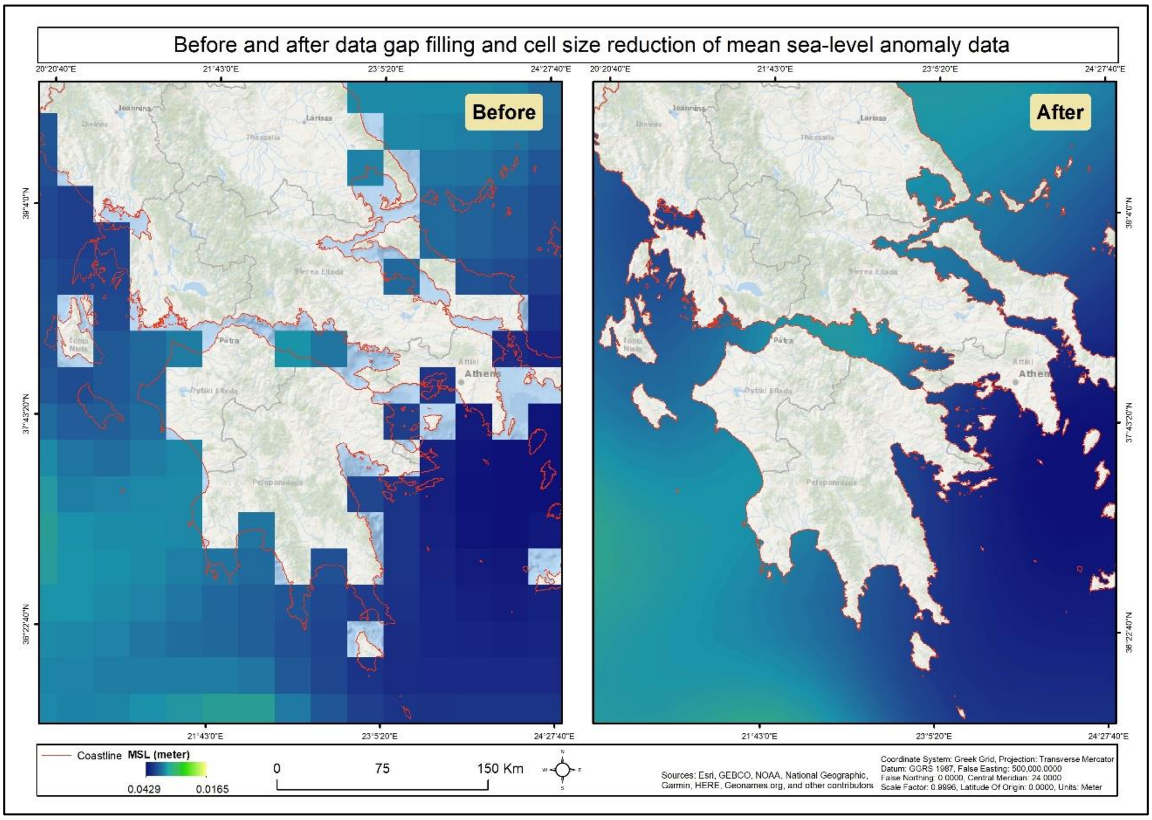


Figure 31: Before and after conducting focal statistics and resampling of mean sea-level anomaly data

3.4.2.9. Storm surge height

Storm surge height data have been downloaded from Copernicus Climate Data Store. This dataset was produced with the Global Tide and Surge Model (GTSM) version 3.0, combined with winds and sea surface pressure from the 'EC-EARTH_DMI-HIRHAM5' dataset for the period of 1977-2005 (ECMWF, 2021). Here surge is calculated as the residual between modelled total water level and modelled tide-only derived level. As most of the values are negative, it has been assumed that the negative value means that, the tide height is higher than the total water level at that time, which may indicate surge height condition. This historical data was in NetCDF format. Spatial coverage was for entire Europe. A Python script (Code snippet 2) has been used to download the data through API requests and convert those downloaded NetCDF files into CSV files after selecting the necessary portion of the data. Those CSV files contain latitude and longitude values of points and associated surge height values. It contains the mean surge height of each point location from 1977-2005. The mean surge height from 1977 to 2005 has been calculated from those mean yearly surge height files. After that, a point shapefile has been created from this CSV file using ArcGIS software. Then IDW interpolation technique has been used to get a continuous raster file. To conduct this interpolation, again, ArcGIS software has been used, and cell size has been changed to 100*100 meters. After that, the projection has been changed to Greek Grid. The unit of the data is meter.

3.4.2.10. Wave significant height

Wave significant height data have been downloaded from the Copernicus Marine Service website. This data is the nominal product of the Mediterranean Sea Waves Forecasting system, composed of hourly wave parameters at 1/24° horizontal resolution covering the Mediterranean Sea and extending up to -18.125W into the Atlantic Ocean (Korres et al., 2019).

Hourly data were stored in an FTP server. Data of 2019 and 2020 have been downloaded from this FTP server in NetCDF format using Python script (Code snippet 5). This data has several variables, among which the 'sea_surface_wave_significant_height (SWH)' variable has been converted to tiff files. After that, a mean wave height has been calculated from all these (more than 17000) downloaded tiff files.

Finally, a subset file has been created using EEZ shapefile and reprojected to Greek Grid. Data were missing in some portion near central Greece, which have been filled up using focal statistics technique, and cell size has been resampled to 1000*1000 meters considering the length of the calculation unit (Figure 32). The unit of the data is meter.

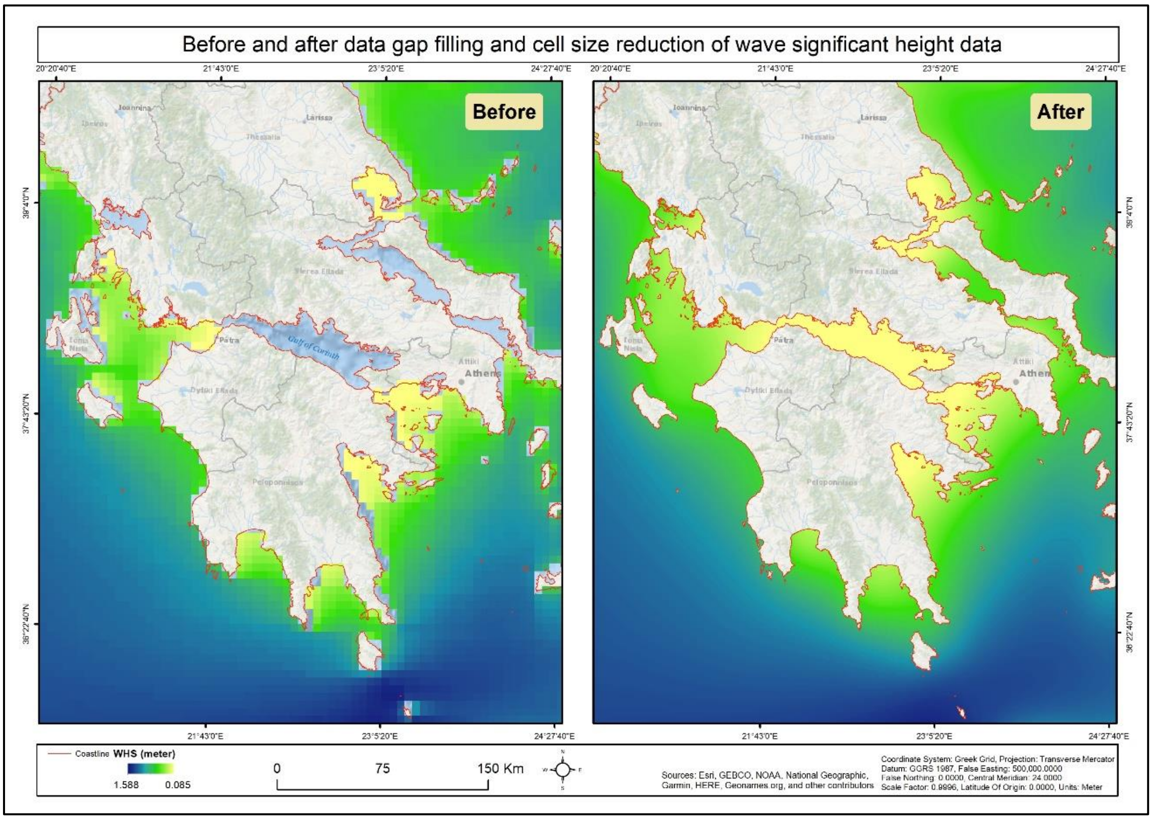


Figure 32: Before and after conducting focal statistics and resampling of wave significant height data.

3.4.2.11. Tidal amplitude

Tidal amplitude data have been downloaded from the Aviso+ website. It is a global tide data named FES2014. FES2014 is the last version of the FES (Finite Element Solution) tide model developed in 2014-

2016. This data has 34 tidal constitutes, among which 'M2' has been chosen for this study which represents the tidal condition.

Data were stored in the FTP server in NetCDF format. From 34 tidal components, M2 has been selected from the NetCDF file and has been converted into tiff files using Python script (Code snippet 4). After converting to a tiff file, a subset has been created using EEZ shapefile, and projection has been changed to Greek Grid. After that, missing data have been filled with the focal statistics technique, and cell size has been reduced to 1000*1000 meters (Figure 33) using the bilinear interpolation technique to match with the length of the calculation unit. The unit of the data is meter.

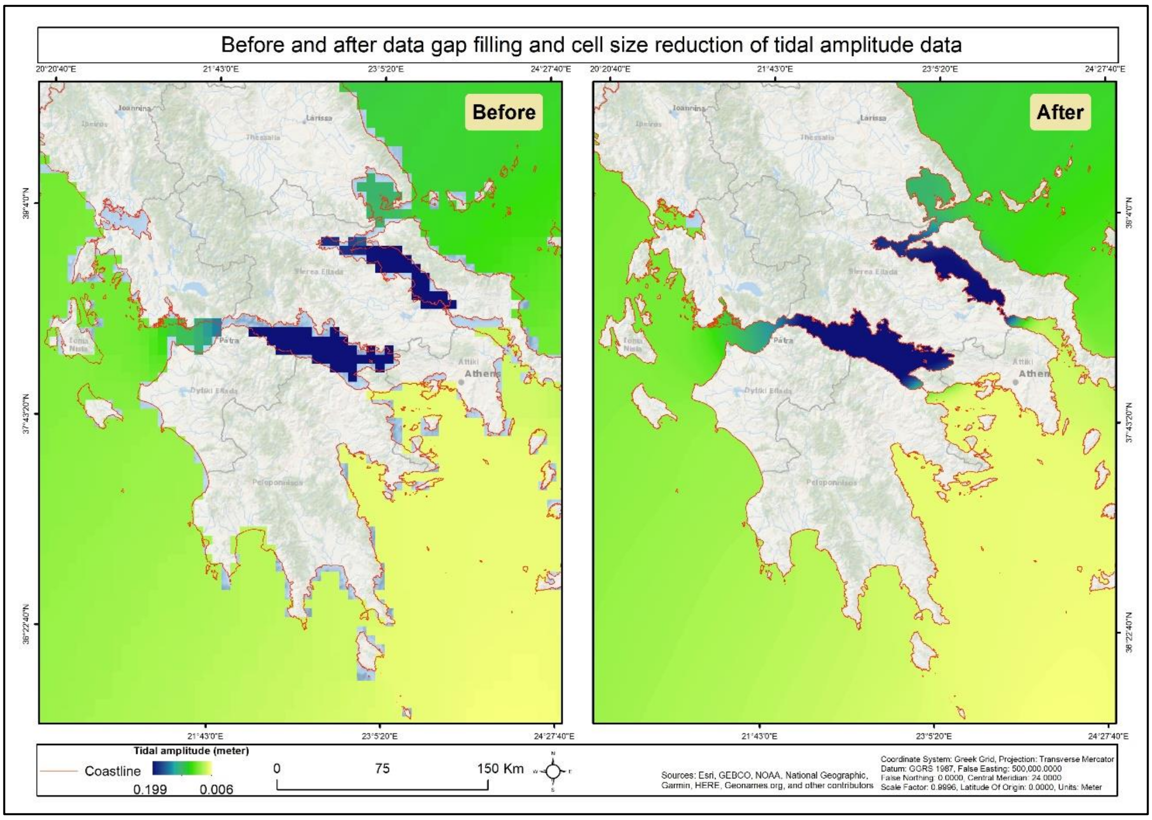


Figure 33: Before and after conducting focal statistics and resampling of tidal amplitude data.

3.4.2.12. Wind speed

Wind speed data have been downloaded from the Copernicus Marine Service website. It represents wind speed over the ocean on a global scale. This data was stored in an FTP server. A Python script has been used to download monthly average wind speed data from 2007 to 2019 (Code snippet 6). Data were in the NetCDF format. It has been converted to tiff files using QGIS software. Then mean wind speed has been calculated from those files. After that, a subset has been created using EEZ shapefile and projection has been changed to Greek Grid, then missing data were filled, and cell size has been resampled to 1000*1000 meters (Figure 34). The unit of the data is meter/second.

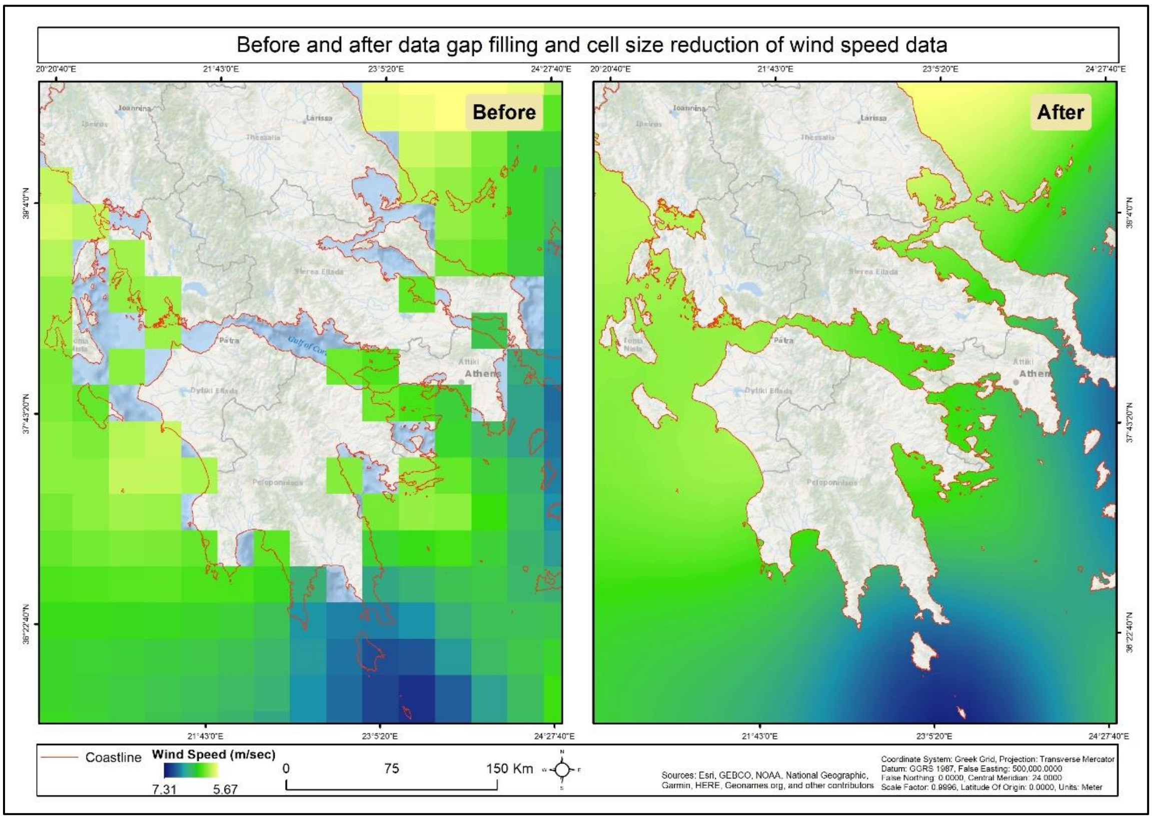


Figure 34: Before and after conducting focal statistics and resampling of wind speed data.

3.4.2.13. Ocean current (eastward and northward)

Northward and eastward ocean current data have been downloaded from the Copernicus Marine Service website. It represents the ocean current velocity in both the eastward and northward directions. Data were stored in an FTP server. A Python script has been used to download monthly average ocean current data from 2018 to 2020 (Code snippet 3). Data were in the NetCDF format. It has been converted to tiff files using QGIS software. Then average eastward and northward ocean currents have been calculated separately from those tiff files. After that, subset files have been created using EEZ shapefile. Then projection has been changed to the Greek Grid. Data have been checked thoroughly to ensure that it covers the entire study area. Any missing portion has been filled using the focal statistics technique and cell size has been resampled to 1000*1000 meters to match with the length of the calculation unit (Figure 35 and Figure 36). The unit of the data is meter/second.

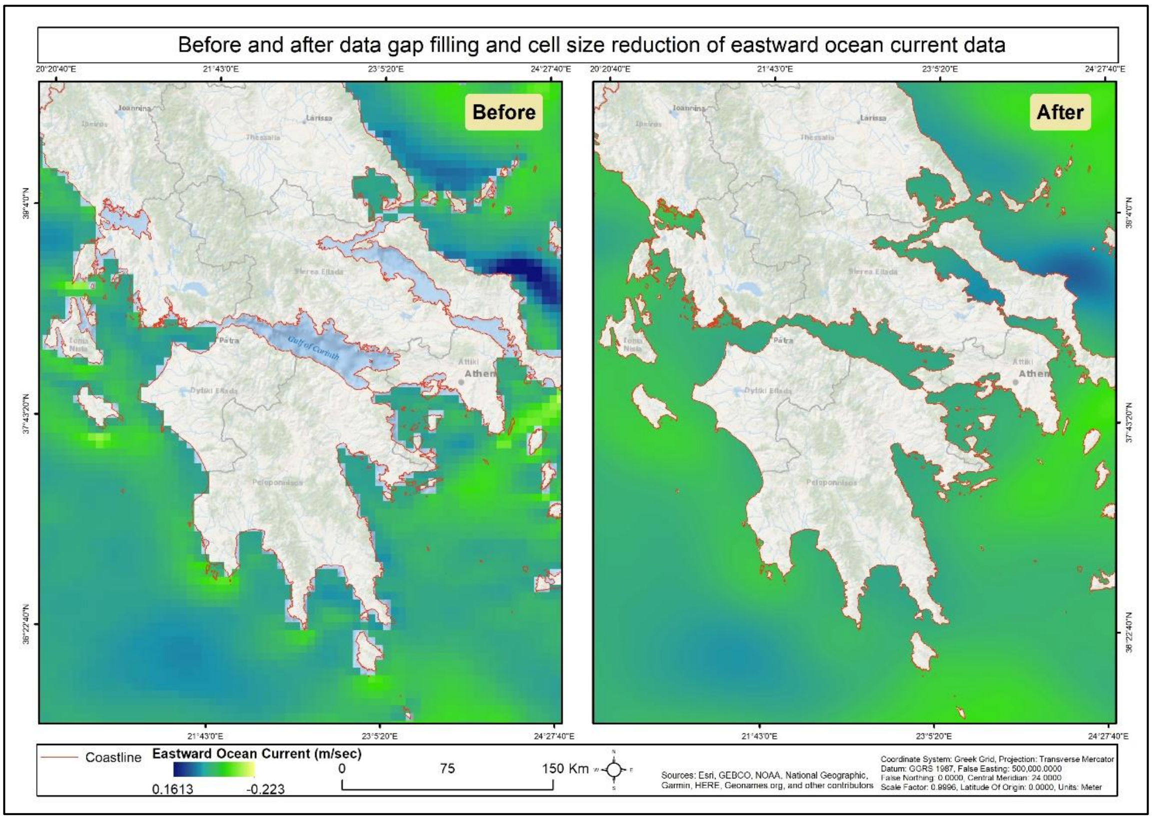


Figure 35: Before and after conducting focal statistics and resampling of eastward ocean current data.

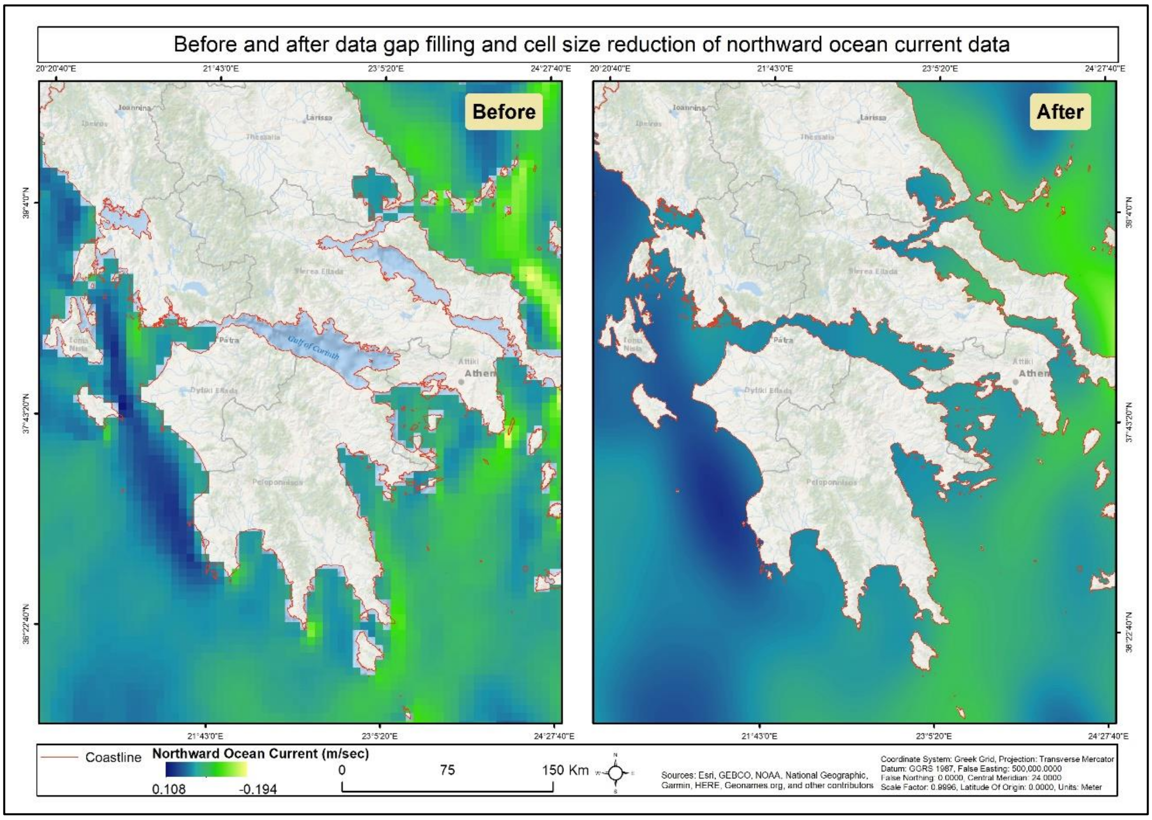


Figure 36: Before and after conducting focal statistics and resampling of northward ocean current data.

3.4.2.14. Seawater potential temperature

Seawater potential temperature data have been downloaded from the Copernicus Marine Service website. Data were stored in an FTP server. A Python script has been used to download monthly average data from 2018 to 2020. Data were in the NetCDF format. It has been converted to tiff files using QGIS software. Then average seawater potential temperature has been calculated separately from those tiff files. After that subset file has been created using EEZ shapefile. Then projection has been changed to Greek Grid, the missing portion has been filled, and cell size has been reduced to 1000*1000 meter (Figure 37). The unit of the data is Celsius.

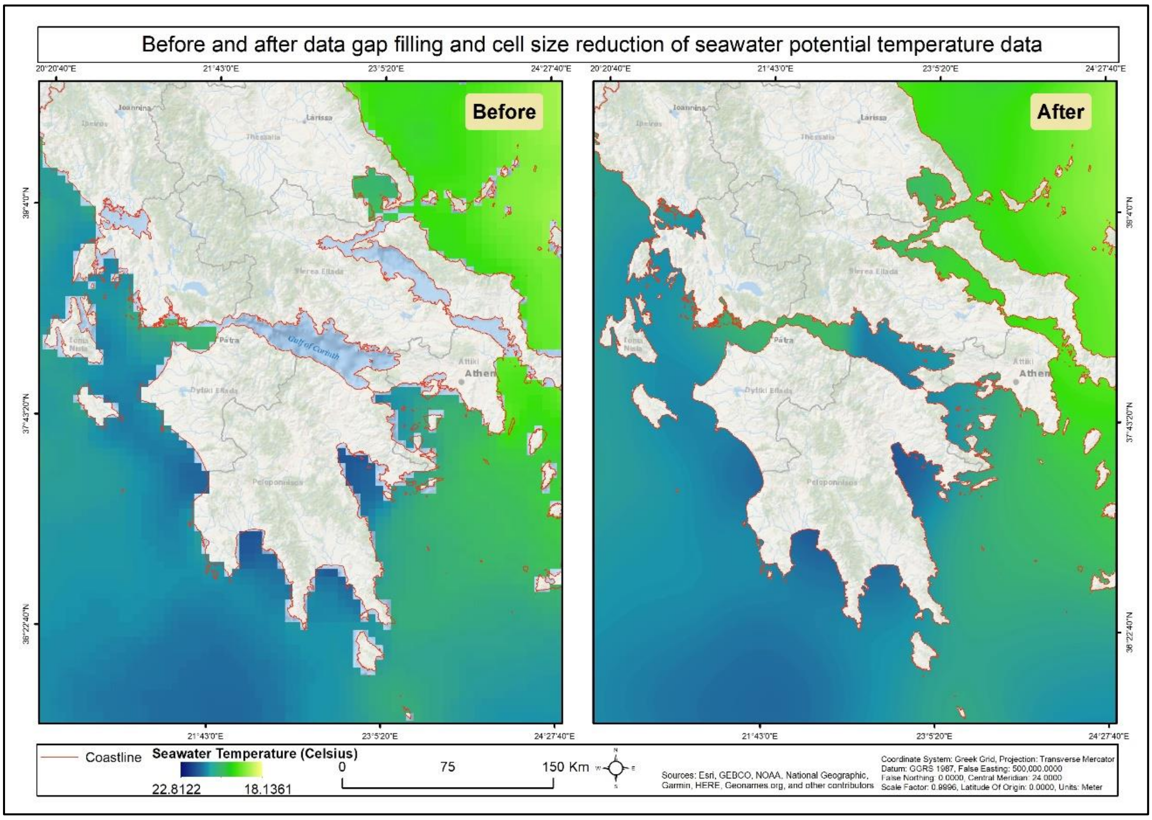


Figure 37: Before and after conducting focal statistics and resampling of seawater potential temperature data.

3.4.2.15. Population density

The municipality shapefile has been downloaded from the GIS in Greece Website. Then population data of 2011 of the same municipality level have been collected from the Greek Statistical Authority website. After checking the population data of 2011, it has been found that there was a mismatch between the municipality shapefile and population data at the municipality level, and it has been identified that the population data of several municipalities were merged into one municipality. To allocate the data properly among all the municipalities, municipality boundaries have been merged based on the available information about the municipality of the Greek Statistical Authority website.

For example, the population of LIMNOU and AGIOU EVSTRATIOU municipality has been given combinedly in 2011. But the boundaries of these two municipalities were shown separately in the shapefile that has been downloaded from the GIS in Greece Website. To match with the data of 2011, the boundaries of these municipalities have been merged into a single municipality boundary and named after the municipality mentioned in the data of 2011.

Then population data of 2011 have been joined to the previously downloaded shapefile using ArcGIS software. After that, the projection has been changed to the Greek Grid, and population density has been calculated.

3.4.2.16. Settlements, cultural sites, transport network, ports, mineral extraction sites

These data have been downloaded from the Copernicus Land Monitoring Service website. These data are widely known as Corine land cover data. Data of 2018, which is the updated one, have been downloaded for this study.

Originally this dataset is for the entire Europe from which a subset has been created using Greece's international boundary shapefile. After that, the projection has been changed to Greek Grid.

In this dataset, the landcover of Greece is divided into 42 classes from which artificial landcover types have been identified.

Artificial landcover has six divisions. To make the data more accurate, open street data have been merged with this dataset. For example, building shapefile from the open street map and similar landcover types have been merged into a single landcover type for better assessment of coastal protection demand. 'Continuous urban fabric', 'Discontinuous urban fabric', 'Industrial, commercial units', 'Dump sites', 'Construction sites' from landcover class and building shapefile from the open street map have been merged into a single class which has been named as 'Residential/ Industrial/commercial' unit.

'Sport' and 'leisure' facilities class from landcover data have been converted to point shapefile then have been merged with cultural sites shapefile from open street maps and World Heritage Site shapefile and has been named as Cultural site unit.

Apart from this, 'Road and rail networks' and associated land class from landcover data have been merged with road network shapefile from the open street map and has been named as Road and rail network.

Other artificial surface landcover types-, 'Mineral extraction sites', 'Port areas', and 'Airport' has been remained unchanged.

3.4.2.17. Ecologically important sites

Ecological important site data have been downloaded from the European Environmental Agency website. The required point features have been extracted using Greece's international boundary shapefile. Then projection has been changed to Greek Grid.

3.5. Expert opinion

In order to weigh the variables to assess the coastal protection of the Greek coast through three indicators, expert opinion has been collected. An expert is a person who can provide critical and firm information about any particular topic which is unclear or unknown to others (Barley & Kunda, 2006). The knowledge of an expert develops through education, training, research, skills and also can be based on personal experiences (Burgman et al., 2011). Burgman et al., (2011) identified three distinct types of expertise in experts. According to him, when experts share the knowledge of their domain, it is known as substantive expertise, when experts accurately provide their judgment in a particular format (such as probabilities) it is called normative expertise, and when they extrapolate and adapt to the new circumstances, it is known as adaptive expertise (Burgman et al., 2011). The precision and confidence of the judgment define the quality of an expert's judgment (Cooke, 1991, O'Hagan et al., 2006). Giving an opinion on any topic with precision and confidence is not easy. Ericsson, (1996) indicated that "deliberate practice" is essential for providing an accurate opinion.

In this research work, a person with substantive expertise having high precision and confidence in judgment has been considered as an expert who also:

- Has educational background and research experience (minimum 5 years) in the marine environment and/or marine and coastal ecosystem service domain of Greece.

- Has published research articles on marine ecosystem or marine environment-related topics.
- Has used oceanographic, ecological, and climatic data for research purposes.

Identifying the required number of experts for getting a proper opinion on the research work is not straightforward. Increasing the number of experts will indeed decrease the bias risk (Drescher et al., 2013) but it will also increase the chance of disagreement. Campagne, Roche, Gosselin, Tschanz, & Tatoni, (2017) suggested that an expert panel should have at least 10 experts to have a quorum which can be increased up to 15 to 20 experts for the optimal result (Campagne & Roche, 2018, O'Neill, Osborn, Hulme, Lorenzoni, & Watkinson, 2008, Uddin & Warnitchai, 2020, Czembor, Morris, Wintle, & Vesk, 2011). An ecosystem service study in Sweden suggests that around five experts are sufficient enough to assess the ecosystem service condition of any area (Armoškaitė et al., 2020). In the ecosystem service study, the number of experts depends on the availability of experts and the focus of the study. Moreover, in this type of study, it is more important to have a confident response than a higher number of responses. Considering these, it has been finalized that opinion of a minimum of five experts is sufficient to have useful insight about the selected variable and indicators for this study.

For taking expert opinion, a semi-structured questionnaire has been developed (Appendix 1). All the variables that have been identified for coastal protection capacity, coastal protection exposure, and coastal protection demand has been included in this questionnaire and experts were asked to weight each variable according to their protection capacity, capacity to create exposure for the Greek coast and generating demand for protection. Moreover, through the survey, experts were asked to provide weights separately to the sub-types of geomorphology, emerged habitat, and seabed habitat. These weights have helped to rank the variables or subtypes of variables which ultimately helped to assess the coastal protection capacity, exposure, and demand indicators for the Greek coast. The expert has been requested to assign weights to the variables and subtypes of variables (when applicable) on a scale of 1 to 4 where "1 = very low, 2 = low, 3 = moderate capacity, 4 = high".

After getting feedback from the experts' weight for each variable has been converted to a scale of 1 using equation 1.

$$x = \frac{\sum X}{\sum Xi} \quad (1)$$

Where x is the weight that will be converted to a scale of 1, X is the sum of the weight of each variable from all experts, and Xi is the sum of all the summed weights of all the variables.

3.6. Modelling ecosystem services for coastal protection

Modelling of ecosystem services to assess the coastal protection of the Greek coast through coastal protection capacity, coastal protection exposure, and coastal protection demand indicator has been started by preparing the data of each variable by filling up the missing data and/or reducing the cell size, etc. In the modelling process, all the outcomes from variables or indicators have been stored in the calculation unit shapefile against the 'calculation ID' of each calculation unit. Raster data of some variables of coastal protection exposure indicator such as sea level anomaly, wave height, tidal amplitude, ocean current, and seawater potential temperature has some missing value in some areas. After filling up the missing value, the cell size has been reduced so that each cell falls within one calculation unit. The mean value of each variable of the coastal protection exposure indicator has been calculated for each calculation unit. Each calculation unit intersects with each variable and to calculate the mean value of each variable within the intersecting part of the calculation unit, the "Zonal Statistics" tool of ArcGIS software has been used. This process has generated an attribute table file for each variable which contains the calculation unit ID and the corresponding mean value of that variable within that calculation unit boundary. Then this table file has been joined with the actual calculation unit shapefile using calculation ID as a matching field to join. From this newly created shapefile, those calculation units which still have the null value have been identified and separated from this shapefile so that this shapefile only contains the calculation unit with values. After that, another new shapefile has been created that only contains the null value. Then the null value of this shapefile has been filled up by the mean value of the nearest calculation unit using the spatial join technique where the matching option was "CLOSEST". In spatial join, both the shapefiles which has mean value against each calculation unit and which doesn't, have been used. After that, another shapefile has been created by joining the original shapefile (which contains the mean value) and the shapefile whose null value has just been filled. This shapefile contains the calculation ID and mean value of the variable without any null or missing value. Then the information from this shapefile has been transferred to the original calculation unit shapefile using the "Join and Relate" technique where the matching option was "calculation ID". Through this repetitive process, the mean value of each variable of coastal protection exposure indicator within the demarcated coastal zone has been stored in the calculation unit shapefile (Figure 38).

The same techniques have been used for the slope and sediment accretion rate variables of the coastal protection capacity indicator. Through this process mean slope and sediment accretion rate value for each calculation unit has been extracted and finally stored in the calculation unit shapefile. (Figure 38). The data type of the other three variables (geomorphology, seabed habitat, and emerged habitat) of this indicator is qualitative which has been converted to quantitative data type following a series of processes. Data of emerged habitat has been extracted from Corine landcover data, then it has been converted to vector format from raster format. Then this newly created emerged habitat shapefile has been intersected with the calculation unit shapefile. After this intersection, each calculation unit now has information for one or more than one subtype of emerged habitat. After that, the area of each subtype of emerged habitat and the total area of those subtypes of emerged habitat within each calculation unit has been calculated. Then the calculated area of each type of emerged habitat has been divided by the total area of those subtypes of emerged habitat within each calculation unit. Through this process, a proportional value for each emerged habitat type within each calculation unit has been generated. After that, each proportional value of each subtype within each calculation unit has been multiplied with its respected weight that comes from expert opinion. Finally, all the multiplied values of different subtypes of emerged habitat within each calculation unit have been summed to have a single weighted value of emerged habitat for each calculation unit (Figure 38). The same process has been followed to extract the weighted value of the seabed habitat variable for each calculation unit. Also, to extract the weighted value of the geomorphology variable for each calculation unit the same process has been followed with some minor differences. In emerged habitat or for seabed habitat variables, the area of each subtype within each calculation unit has been calculated but for geomorphology variable instead of area the length of each type of geomorphology within each calculation unit has been calculated. Following the similar process, the length of each type of geomorphology has been divided by the total length of each type of geomorphology within each calculation unit. Through this process, similar to emerged habitat or seabed habitat variables a proportional value for each type of geomorphology has been generated which has been multiplied with the respected weight of each type of geomorphology. Finally, all the multiplied values of each geomorphology type within each calculation unit have been summed to have a single weighted value of geomorphology for each calculation unit (Figure 38). These weighted values of emerged habitat type, seabed habitat type, and geomorphology have been transferred to the calculation unit shapefile using the "Join and Relate" technique where the matching option was "calculation ID".

To assess coastal protection demand, the density of the variables of the coastal protection demand indicator in each calculation unit has been calculated. For instance, the population density for each calculation unit has been extracted by intersecting the calculation unit shapefile with the population density of municipalities shapefile. In this process, some calculation units intersected with more than one municipality. For those calculation units average population density has been calculated using the ArcGIS dissolve tool (Figure 38). Other variables of this indicator that represents the artificial landcover types of the Greek coast are settlements, ports, transportation networks, mineral extraction sites, and cultural sites. Data of these variables are in vector format and each of these shapefiles has been intersected with the calculation unit shapefile separately. In this study, the density of settlement, ports, mineral extraction sites, transport network, cultural site and ecologically important sites variables has been calculated against the size of the calculation unit. For this, area of settlements, ports, mineral extraction sites in each calculation unit has been calculated. Then the calculated area of these variables has been divided by the area of each calculation unit to get the density of these variables in each calculation unit. For transport network density, after intersecting the transport network shapefile with the calculation unit shapefile, the length of the transport network within each calculation unit has been calculated. After that, this length has been divided by the area of each calculation unit to get the density of the transport network in each calculation unit. (Figure 38). For cultural sites and ecologically important sites, a similar process has been followed where both point shapefiles have been intersected with the calculation unit separately. After the intersection, each calculation unit contains the number of cultural sites and ecologically important sites separately in its attribute table. The density of the cultural site and the ecologically important site has been calculated for each calculation unit by dividing the total number of cultural or ecologically important sites in each calculation unit with the area of each calculation unit (Figure 38). Finally, all these density values of each variable of coastal protection demand indicator have been transferred to the calculation unit shapefile using the "Join and Relate" technique where the matching option was "calculation ID".

After that, values of all the variables in each calculation unit have been normalized using the min-max equation (equation 2) to make the variables dimensionless. The values of variables have been normalized so those values don't have any absolute meaning rather they can be used for comparative analysis of coastal protection capacity, coastal protection exposure, and coastal protection demand indicators of the Greek coast.

$$Normalized\ value\ (xn) = \frac{x - min}{max - min} \tag{2}$$

Where x is the value that will be normalized, min and max is the minimum and maximum value of each variable.

After extracting the normalized value of each variable within each calculation unit, coastal protection capacity, coastal protection exposure, and coastal protection demand have been calculated using the following equation, 3, 4, and 5, respectively.

$$CP_{cap} = W_{geo} \times geo + W_{slo} \times slo + W_{eh} \times eh + W_{sh} \times sh + W_{sar} \times sar \tag{3}$$

$$CP_{exp} = W_{slr} \times slr + W_{ssh} \times ssh + W_{wsh} \times wsh - W_{tide} \times tide + W_{wind} \times wind + W_{eoc} \times eoc + W_{noc} \times noc + W_{spt} \times spt \tag{4}$$

$$CP_{dem} = W_{popn} \times popn + W_{set} \times set + W_{trans} \times trans + W_{ports} \times ports + W_{mes} \times mes + W_{cul} \times cul + W_{eco} \times eco \tag{5}$$

CP_{cap}, CP_{exp}, and CP_{dem} refer to the coastal protection capacity, coastal protection exposure, and coastal protection demand indicators. And 'geo' refers to the value of geomorphology, 'slo' refers to the value of the slope, 'eh' refers to the value of the emerged habitat type, 'sh' refers to the value of the seabed habitat type, and 'sar' refers to the value of the sediment accretion rate, 'slr' refers to the value of the sea level rise, 'ssh' refers to the value of the storm surge height, 'wsh' refers to the value of the wave significant height, 'tide' refers to the value of the tidal amplitude, 'wind' refers to the value of the wind speed, 'eoc' refers to the value of the eastward ocean current, 'noc' refers to the value of the northward ocean current, 'spt' refers to the value of the potential seawater temperature, 'popn' refers to the value of the population density, 'set' refers to the value of the settlement density, 'trans' refers to the value of the transportation network density, 'ports' refers to the value of the port area density, 'mes' refers to the value of the mineral extraction sites density, 'cul' refers to the value of the cultural sites density, 'eco' refers to the value of the ecologically important sites density variables in each calculation unit. The 'W' in the equations refers to the weight of the associated variable that comes from expert opinion.

In the above equations, additive aggregation techniques have been used because of simplicity in aggregation, assumed linear relationships among variables, and capacity to deal with both positive and negative weight. In the coastal exposure demand indicator, the tidal amplitude variable has a minus sign in the formula as Liquete et al., (2013b) suggested that tides develop a protective buffer zone around the coastal zone which made it contribute negatively to coastal exposure.

After that, coastal protection service flow has been calculated by subtracting the value of the coastal protection exposure indicator from the coastal protection capacity indicator in each calculation unit. The coastal protection benefit has been calculated by subtracting the value of the coastal protection demand indicator of each calculation unit from the value of the coastal protection service flow of the respected calculation unit (Figure 38).

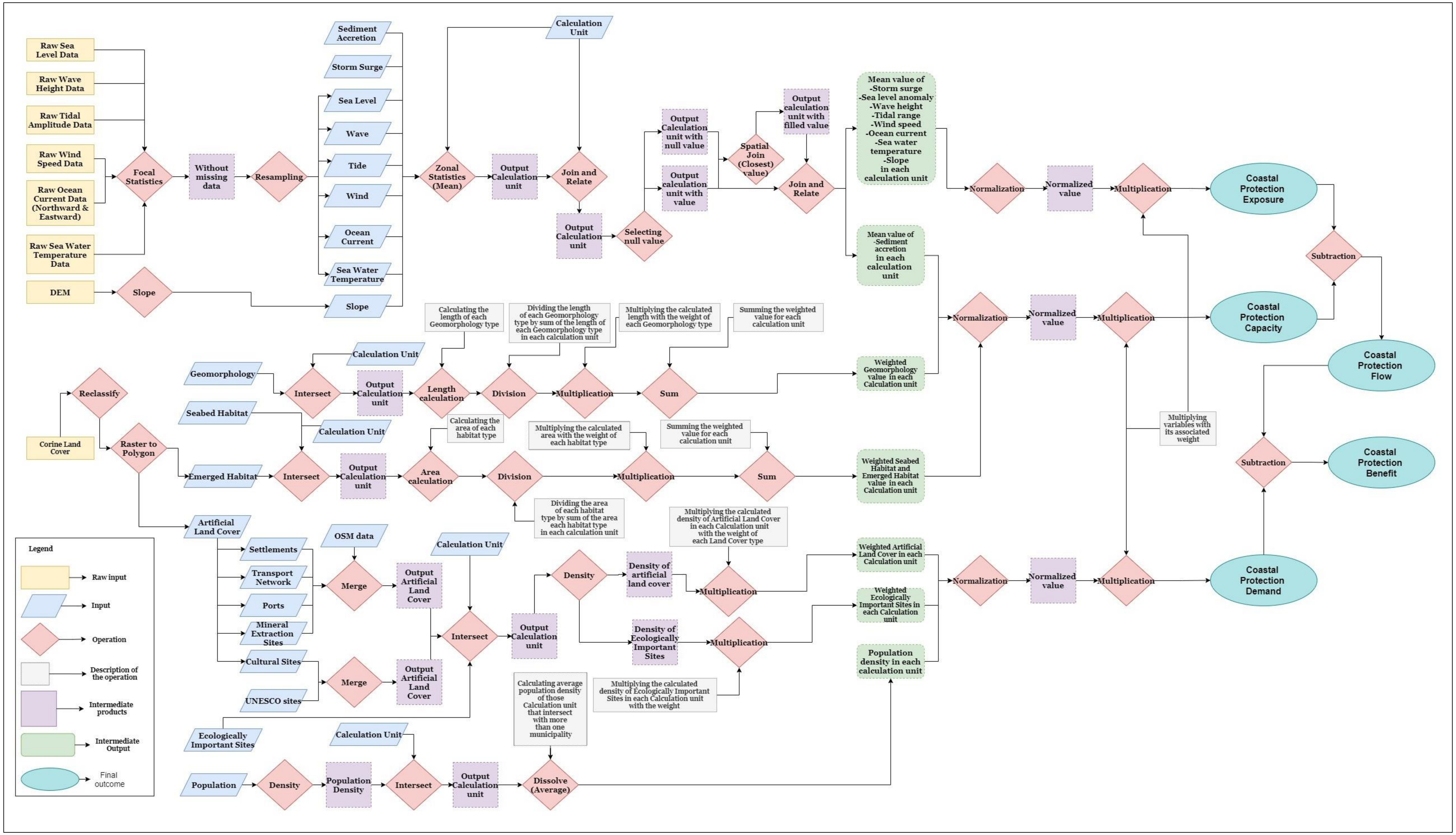


Figure 38: Workflow to assess coastal protection capacity, exposure, demand, service flow and benefit of the coastal areas of Greece

3.7. Evaluation of regional level model

To compare the outcome of the regional level model with the outcome of the downscaled national-level model, the outcome of the regional level model has been transferred to the corresponding calculation unit of the national level model. For this, the calculation unit shapefile of the national model has been intersected with the calculation unit shapefile of the regional model. After this process, each calculation unit of the national level model has got the values of variables and indicators of the regional level model. But some calculation units of the national level model have intersected with more than one calculation unit of the regional level model due to the mismatch of the boundary shape and area. In such cases, the average of those values of the regional level model has been calculated for that calculation unit of the national level model (Figure 39). Moreover, in the national level model, a more detailed coastal boundary than the regional level model has been considered for the analysis. In the comparison process, only that portion of the coastal boundary has been considered which matches in both the model.

After having data from both models in each calculation unit, a comparison has been conducted between variables that are present in both models to detect significant variations. The indicators of both models are the same, so a comparison of indicators has also been conducted. For comparison of variables and indicators, root mean square error (RMSE) estimation (equation 6) has been used. RMSE shows the deviation that occurred from the regional level model to the national level model. Besides, areas which have similarity and dissimilarity in both the model have been highlighted and mapped from RMSE value.

$$RMSE = \sqrt{\sum_{i=0}^{N} \frac{(x_i - \hat{x}_i)}{N}} \qquad (6)$$

Where, x_i = value from the regional level model, $\hat{x}_i$ = value from the national level model. N = number of cells considered to calculate the mean. i = that specific calculation unit.

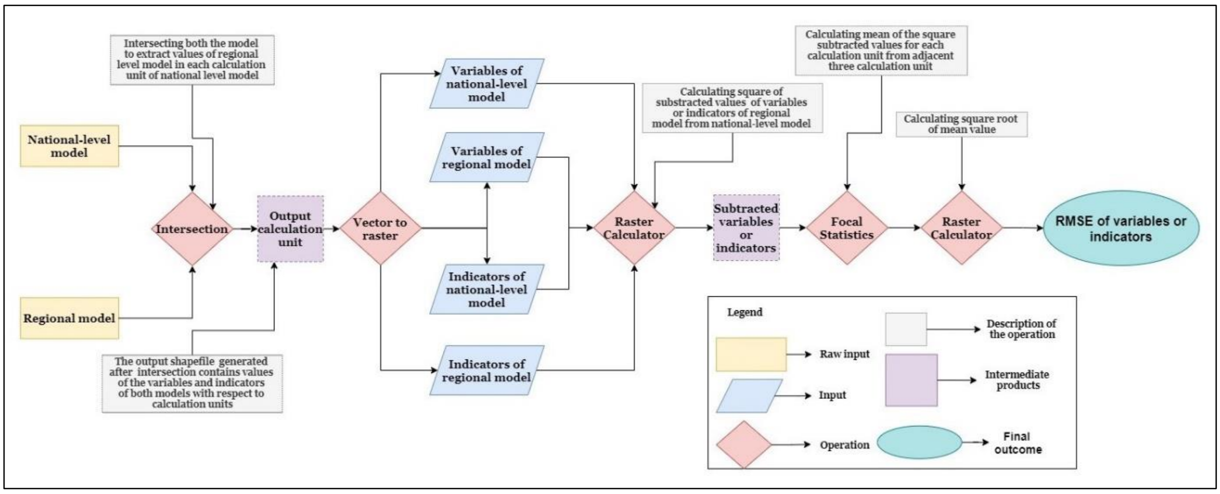


Figure 39: Workflow to compare the regional and national level model

To calculate RMSE for the variables, raster files have been created for each variable from each model. Then the square of the difference of the same variables between the regional and the national level model has been calculated. After that focal statistics tool of ArcGIS has been used to calculate the mean of the calculated difference by developing a 3*3 moving kernel or window. As this, 3*3 kernel creates more cell outside the actual input cell, only the required portion has been kept by masking the outcome of focal statistics with the input national level raster boundary (Figure 39). Finally, the square root has been calculated from the mean value for each cell (equation 7). The same process has been followed to calculate the RMSE of the ecosystem service flow indicators (Figure 39).

$$Difference = Square\,(\text{"}Coastal\ protection\ capacity/exposure\ /demand\ indicator\ of\ regional\ level\ model\text{"} - \text{"}Coastal\ protection\ capacity/exposure\ /demand\ indicator\ of\ national\ level\ model\text{"})$$

$$RMSE = Square\ Root(Focal\ Statistics(Difference, NbrRec\mathrm{tan}gle(3,3, CELL), \text{"}MEAN\text{"}, \text{""}))$$
(7)

4. RESULTS

4.1. Coastal zone

In this study, coastal protection as an ecosystem service of Greece has been assessed through coastal protection capacity, coastal protection exposure, and coastal protection demand indicator. These indicators have been assessed using 20 variables. To accommodate only the coastal characteristics of Greece in the modelling process, a coastal zone has been demarcated based on the criteria described in the Methodology section (Figure 23). This zone covers the entire Greek coast, which has a total area of 36914.19 km². The demarcated coastal zone has been divided into three types based on three different criteria. Type 1 covers the coast of mainland Greece and Peloponnese which landmasses are more than 20,000 km², Type 2 covers the coast of Crete islands and Chalcis which landmasses ranges between 3,000 km² and 20,000 km² and Type 3 covers the rest of the areas of the Greek coast which landmasses are less than 3,000 km² (Figure 40).

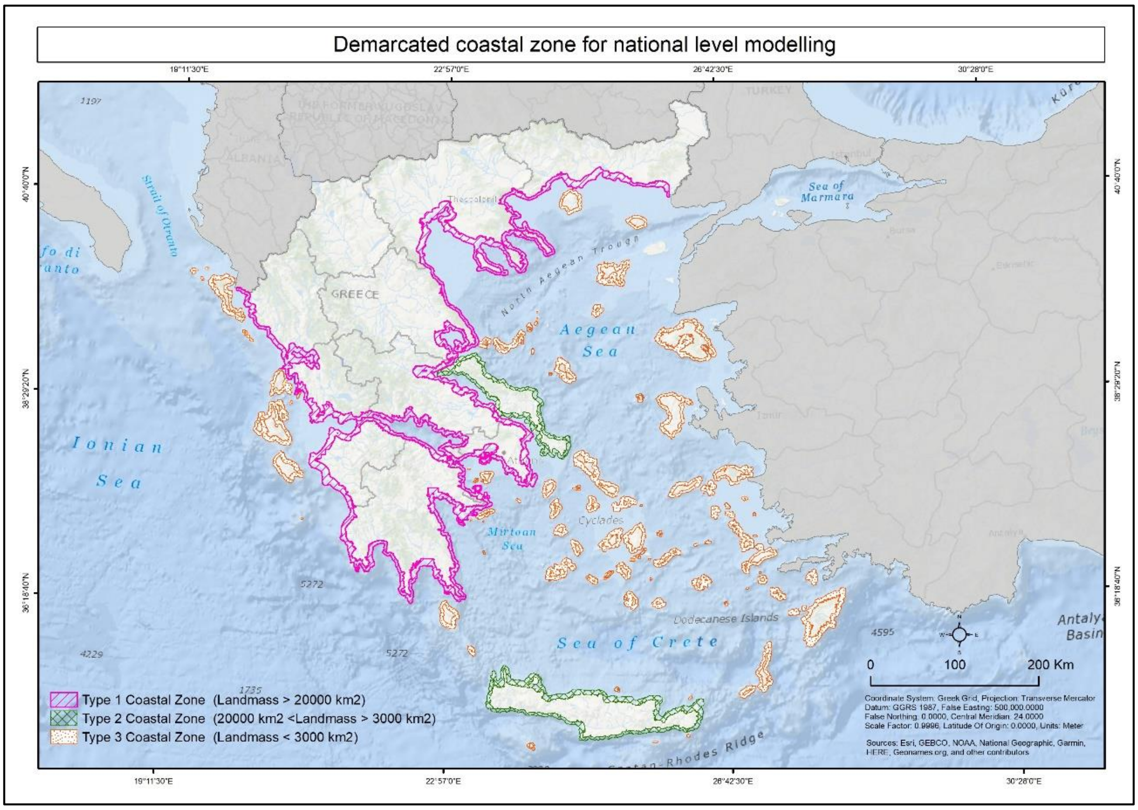


Figure 40: Demarcated coastal zone of the national level model

The coastal zone that has been demarcated for the regional level study is different from the national one. In regional level study maximum 50 km inland distance from the coast has been considered which covers many inland parts of Greece especially in the Central Macedonia and Eastern Macedonia and Thrace area (Figure 41). Moreover, in the regional level model, many small islands could not be considered for modelling purpose which has been incorporated in the national level model.

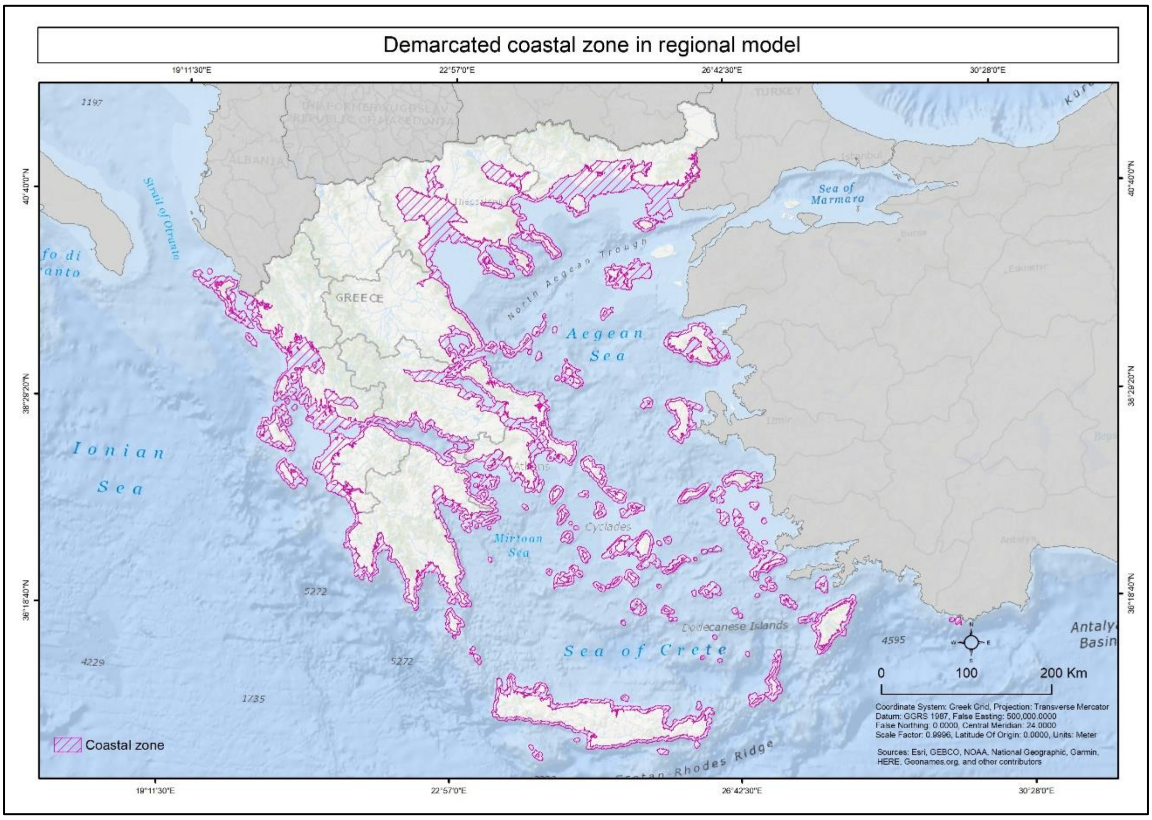


Figure 41: Demarcated coastal zone of the regional level model (Collected from the regional level study of Liquete et al., (2013b)).

4.2. Expert elicitation outcomes

The significance and contribution of all the selected variables in terms of coastal protection have been weighted using expert opinion. Initially, 38 experts have been identified among which the profile of only 12 experts fully matched the selection criteria. The prepared questionnaire was sent to them via email. Among those 12 experts, seven experts responded, took the survey, and gave weight to the variables of each indicator.

The weight of each variable has been converted to a scale of 1 using equation 1. For instance, the sum of the weight (X) of the geomorphology variable is 26, which has been divided by the sum of the weight of all the summed variables (Xi), which is 119 to get the weight for this variable on a scale of 1 (Table 6). For all the variables and also for the subtypes of geomorphology, seabed habitat, and emerged habitat variables, the same formula has been used to convert the weight to a scale of 1 (Table 7, Table 8, Table 9, Table 10 and Table 11).

Table 6: Weights of the variables of coastal protection capacity indicator given by the experts

SN	Geomorphology	Slope	Emerged Habitat	Seabed Habitat	Sediment Accumulation Rate	Total (Xi)
Expert 1	3	3	2	3	3	14
Expert 2	4	4	4	4	4	20
Expert 3	4	3	3	3	4	17
Expert 4	4	2	2	4	3	15
Expert 5	4	4	2	3	4	17

Expert 6	3	3	4	4	4	18
Expert 7	4	4	2	4	4	18
Sum of weight of each variable (X)	26	23	19	25	26	119
Weight of each variable on a scale of 1	0.218	0.193	0.160	0.210	0.218	1

Table 7: Weights of the variables of coastal protection exposure indicator given by the experts

SN	Sea level rise	Storm surge height	Wave height	Tidal range	Wind Speed	Eastward Ocean Current	Northward Ocean Current	Sea Water Potential Temperature	Total (Xi)
Expert 1	4	3	4	3	4	1	1	1	21
Expert 2	2	3	3	2	3	1	1	1	16
Expert 3	1	4	3	2	4	2	2	1	19
Expert 4	4	4	4	2	2	1	1	1	19
Expert 5	4	4	3	1	3	2	2	1	20
Expert 6	4	4	3	4	2	1	1	1	20
Expert 7	3	2	3	3	2	2	2	2	19
Sum of weight of each variable (X)	22	24	23	17	20	10	10	8	134
Weight of each variable on a scale of 1	0.164	0.179	0.172	0.127	0.149	0.075	0.075	0.060	1

Table 8: Weights of the variables of coastal protection demand indicator given by the experts

SN	Population Density	Settlements (residential, industrial, commercial)	Cultural site	Transport network (roads, railway)	Ports (airports, ports)	Areas of high ecological values	Mineral extraction site	Total (Xi)
Expert 1	4	4	4	4	4	4	1	25
Expert 2	4	2	4	4	4	4	1	23

Expert 3	4	4	3	3	4	3	2	23
Expert 4	4	4	4	4	4	4	2	26
Expert 5	3	4	3	4	4	4	1	23
Expert 6	4	4	4	3	4	4	4	27
Expert 7	3	3	3	4	4	2	2	21
Sum of weight of each variable (X)	26	25	25	26	28	25	13	168
Weight of each variable on a scale of 1	0.155	0.149	0.149	0.155	0.167	0.149	0.077	1

Table 9: Weights of the subtypes of seabed habitat variable given by the experts

SN	Seabed Habitat subtypes [Coarse & mixed sediment]	Seabed Habitat subtypes [Seagrass meadows]	Seabed Habitat subtypes [Shallow muds]	Seabed Habitat subtypes [Shallow sands]	Total (Xi)
Expert 1	4	3	2	3	12
Expert 2	3	4	2	3	12
Expert 3	3	4	2	1	10
Expert 4	3	4	1	1	9
Expert 5	2	4	3	1	10
Expert 6	2	4	1	1	8
Expert 7	4	4	2	2	12
Sum of weight of each variable (X)	21	27	13	12	73
Weight of each variable on a scale of 1	0.288	0.370	0.178	0.164	1

Table 10: Weights of the subtypes of geomorphology variable given by the experts

SN	Rocks and/or cliffs made of hard rocks (little subject to erosion)	Rocks and/or cliffs with small beaches	Conglomerates and/or cliffs made of material subject to erosion: presence of rock waste and sediments (sand pebbles on the strand)	Small beaches separated by rocky capes	Developed beaches (length of the beach > 1 km) with strands made of coarse sediments: gravels or pebbles	Developed beaches with sandy strands: fine to coarse sand	Coastlines made of soft non-cohesive sediments	Strands made of muddy sediments: "waddens" and intertidal marshes with "slikkes and schorres"	Harbour areas	Coastal embankments for construction purposes (e.g. by emplacement of rocks earth etc.)	Soft strands with "beach rock" on intertidal strands	Soft strands of heterogeneous category grain size	Soft strands of unknown category grain size	Total (Xi)
Expert 1	2	3	3	3	2	2	2	1	1	1	1	2	2	25
Expert 2	4	3	1	2	3	3	1	4	2	1	3	3	2	32
Expert 3	4	3	3	2	2	2	1	1	4	3	2	1	1	29
Expert 4	4	4	1	2	1	1	1	1	3	2	3	2	1	26
Expert 5	4	3	3	2	2	1	1	2	4	4	3	2	2	33
Expert 6	4	4	3	3	3	1	1	1	3	3	3	1	1	31
Expert 7	4	3	3	1	1	1	1	1	1	1	1	1	1	20
Sum of weight of each variable (X)	26	23	17	15	14	11	8	11	18	15	16	12	10	196
Weight of each variable on a scale of 1	0.133	0.117	0.087	0.077	0.071	0.056	0.041	0.056	0.092	0.077	0.082	0.061	0.0510	1

Table 11: Weights of the subtypes of emerged habitat variable given by the experts

SN	Arable land	Beaches, dunes, sands	Coastal lagoons	Estuaries	Forests	Fruit trees	Heterogeneous agricultural areas	Open spaces with little or no vegetation	Pastures	Permanent crops	Scrub or herbaceous vegetation	Water courses	Wetlands	Total (Xi)
Expert 1	3	3	1	1	2	2	4	3	3	3	3	1	1	30
Expert 2	1	4	4	4	1	1	1	4	1	1	3	4	4	33
Expert 3	1	4	3	3	4	1	2	1	2	2	3	4	4	34
Expert 4	1	1	4	4	4	2	2	1	1	2	2	1	4	29
Expert 5	2	2	1	1	3	2	2	2	2	3	3	1	1	25
Expert 6	1	2	1	4	4	3	1	1	1	3	2	2	2	27
Expert 7	1	3	2	2	1	1	1	1	1	1	1	1	1	17
Sum of weight of each variable (X)	10	19	16	19	19	12	13	13	11	15	17	14	17	195
Weight of each variable on a scale of 1	0.051	0.097	0.082	0.097	0.097	0.062	0.067	0.067	0.056	0.077	0.087	0.072	0.087	1

All the experts who have weighed the variables are quite familiar with the ecosystem services concept and have a substantial amount of work experience in coastal areas of Greece. Out of seven experts, four experts have marine ecology background, two have oceanography and one expert has physical geography background. Six out of seven experts have a PhD degree in their respective field, and one has an MSc degree with a considerable amount of experience. Out of seven experts, three experts have 10 to 15 years of experience, one expert has 15 to 20 years of experience and the rest of the three experts have more than 20 years of experience in conducting research in the marine and coastal environment domain. All of them contributed to more than 30 research articles and five of them have more than 50 published research articles (based on google scholar search) (Figure 42).

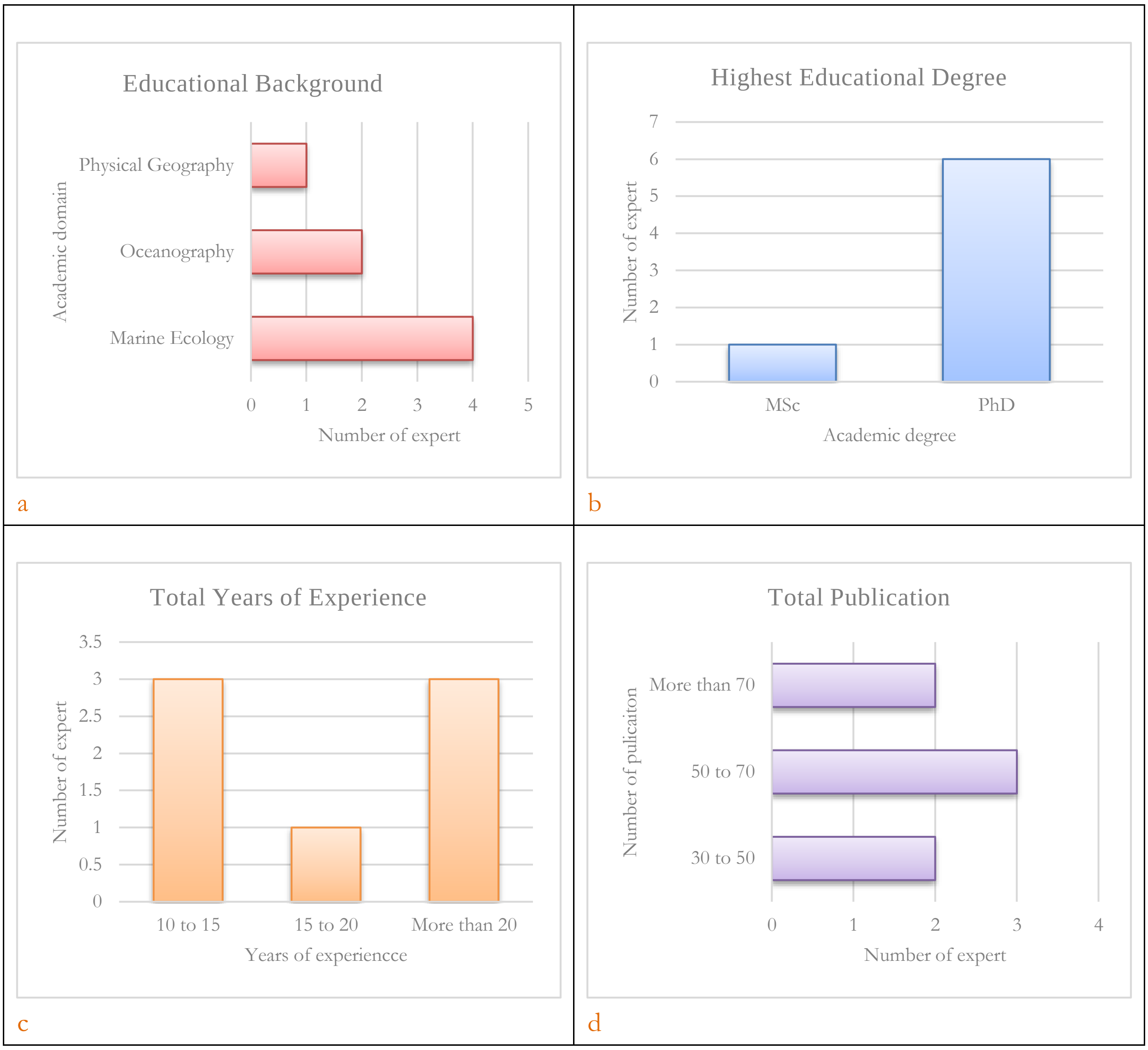


Figure 42: Expert's profile: a) academic background of the experts, b) level of education of the experts, c) work experience of the experts, d) total number of publications by the experts

4.3. Input variables to model coastal protection

4.3.1. Biophysical variables for coastal protection capacity indicator

Coastal protection capacity indicator has been measured using five variables: geomorphology, emerged habitat, seabed habitat, slope, sediment accretion rate. Each of these variables was assigned different weights by experts based on their contribution to coastal protection. According to the provided weights by the experts, geomorphology and sediment accretion rate in the coast have the highest potentiality to protect the coast followed by seabed habitat, slope, and emerged habitat of the coast (Table 12). Among 13 distinct geomorphology types of the Greek coast (DG ENV, 2016) (Figure 7), "Rocks and/or cliffs made of hard rocks (little subject to erosion)" has the highest potential and "Coastlines made of soft non-cohesive sediments" has the least potential for coastal protection based on the provided weight of experts. All the 13 types of geomorphology have been ordered in Table 13 by their protection capacity following the expert opinion. On the other hand, among all the seabed habitat types "seagrass meadows" has been recognized with the highest coastal protection capacity by the experts followed by "Coarse & mixed sediment", "shallow muds" and "shallow sands" (Table 14). In coastal areas of Greece, 13 types of natural land areas have been identified from the Corine landcover map (Figure 9) and which has been ordered in Table 15 according to their protection capacity following the expert opinion. "Beaches, dunes, sands", "Estuaries" and "Forests" have been recognised by the experts with the highest potentiality to provide coastal protection.

Table 12: Weights of the variables of coastal protection capacity indicator based on expert opinion.

Variable	**Weights of the variable**
Geomorphology	0.218
Sediment accretion rate	0.218
Seabed habitat	0.210
Slope	0.193
Emerged habitat	0.160

Table 13: Weights of coastal geomorphology types of Greece according to their protection capacity based on expert opinion.

Geomorphology Types	**Weight**
Rocks and/or cliffs made of hard rocks (little subject to erosion)	0.133
Rocks and/or cliffs with small beaches	0.117
Harbor areas	0.092
Conglomerates and/or cliffs made of material subject to erosion: presence of rock waste and sediments (sand pebbles on the strand)	0.087
Soft strands with "beach rock" on intertidal strands	0.082
Small beaches separated by rocky capes	0.077
Coastal embankments for construction purposes (e.g., by emplacement of rocks earth etc.)	0.077
Developed beaches (length of the beach > 1 km) with strands made of coarse sediments: gravels or pebbles	0.071
Soft strands of heterogeneous category grain size	0.061
Developed beaches with sandy strands: fine to coarse sand	0.056
Strands made of muddy sediments: "waddens" and intertidal marshes with "slikkes and schorres"	0.056
Soft strands of unknown category grain size	0.051
Coastlines made of soft non-cohesive sediments	0.041

Table 14: Weights of coastal seabed habitat types of Greece according to their protection capacity based on expert opinion.

Seabed habitat types	Weight
Seagrass meadows	0.370
Coarse & mixed sediment	0.288
Shallow muds	0.178
Shallow sands	0.164

Table 15: Weights of coastal emerged habitat types of Greece according to their protection capacity based on expert opinion

Emerged habitat types	Weight
Beaches, dunes, sands	0.097
Estuaries	0.097
Forests	0.097
Scrub or herbaceous vegetation	0.087
Wetlands	0.087
Coastal lagoons	0.082
Permanent crops	0.077
Water courses	0.072
Heterogeneous agricultural areas	0.067
Open spaces with little or no vegetation	0.067
Fruit trees	0.062
Pastures	0.056
Arable land	0.051

Values of the variables of coastal protection indicator for each calculation unit have been extracted after following a series of processes (Figure 38). The average weighted value of geomorphology, emerged habitat type, seabed habitat type, slope, and sediment accretion rate in each calculation unit are 0.092, 0.078, 0.191, 11.755, and 0.199 respectively (Table 16). The southeastern coastal zone of Thessaloniki and southwestern coastal zone of Western Greece has a lower mean slope in the overall study area whereas the northern coastal area of Argostoli, the southern coastal area of Lefkada city, Cyclades islands, the southern coastal zone of Crete island, the central and southeastern coastal zone of Peloponnese region of Greece have relatively higher mean slope (Figure 43).

The higher weighted value of geomorphology can be seen in the southern coastal zone of Central Greece, the southeastern coastal zone of the Peloponnese region. Medium to high mean values of geomorphology variable has been visible in the southern coastal zone of Crete and some of the islands of Cyclades islands. Medium to low geomorphology value has persisted in the coast of Central Macedonia and Eastern Macedonia and Thrace, the western coastal zone of Peloponnese, the northwestern coastal zone of Western Greece, the small islands of Cyclades islands, Rhodes, Lesvos, Epirus, and Ionian islands region (Figure 44). "Seagrass meadows" is the most common seabed habitat type throughout coastal Greece with sparse distribution of "shallow sand" and "shallow mud" in some parts of the coast (Figure 8). Area with high weighted seabed habitat value can be found in the northern coastal zone of Western Greece, the southern coastal zone of Attica, and some islands of Cyclades and Ionian islands (Figure 45).

The natural landscape of coastal Greece is quite heterogeneous since forest, different scrub, and herbaceous vegetation, fruit trees are more commonly seen (Figure 9). The higher weighted value of emerged habitat type variable has been seen in some southern coastal zone of Central Greece especially near mount Athos, the northeastern coastal zone of Chalcis, the southern coastal zone of Central Greece and Attica and some coastal part of Ionian islands. Low to medium weighted value of emerged habitat variable can be seen in most of the southern coastal zone of Central Greece, the southern and southwestern coastal zone of Peloponnese, near Malian Gulf, some coastal parts of Ionian islands, some northern coastal areas of Crete island, and in coastal areas Lesvos and Rhodes islands (Figure 46).

The rate of sedimentation in the coastal areas of Greece is very low. Most of the coastal areas have no to very little occurrence of sedimentation. The sedimentation rate is relatively higher in the Ambracian Gulf area, the southern coastal zone of Central Macedonia especially near the Thessaloniki city area, and the southeastern coastal zone of Thessaly. Medium to high sedimentation is seen in the southern coastal zone of Attica, the southeastern coastal zone of Central Greece, both sides of coastal Chalcis, and the southern coastal zone of Eastern Macedonia and Thrace. Medium to low sedimentation can be seen in both sides of the Gulf of Corinth, the entire coast of Western Greece, and the western coastal zone of Peloponnese. Very little to no sedimentation is observable in the coastal areas of the Crete, Cyclades islands, Rhodes, Samos, Chios and Lesvos island (Figure 47).

Table 16: Summary statistics of the variables of coastal protection indicator

	Geomorphology	**Emerged Habitat**	**Seabed Habitat**	**Slope**	**Sediment Accretion**
Min	0.041	0.051	0.164	0.000	0.007
Max	0.133	0.097	0.370	40.617	1.066
Mean	0.092	0.078	0.191	11.755	0.199
Standard Deviation	0.024	0.009	0.033	7.449	0.166
First Quartile	0.077	0.070	0.170	5.652	0.038
Median	0.087	0.079	0.179	10.905	0.195
Third Quartile	0.117	0.085	0.196	16.869	0.291

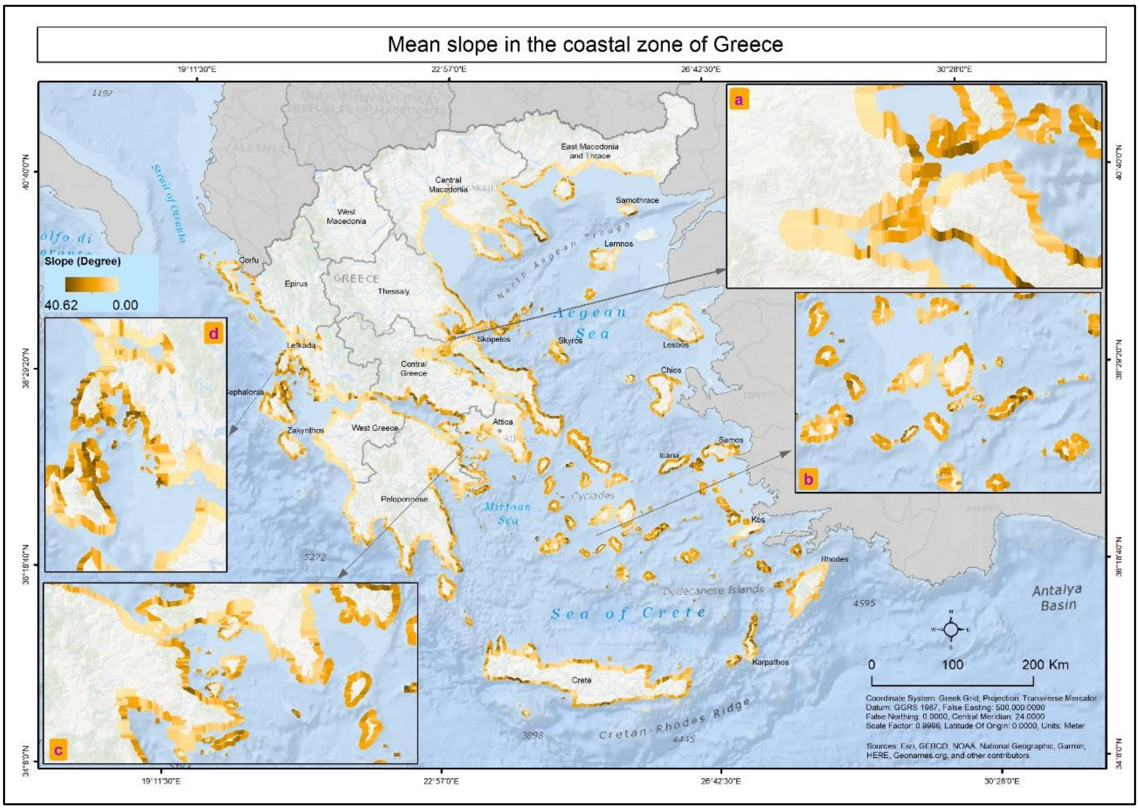


Figure 43: Mean slope in the coastal zone of Greece. Inset maps are the zoomed view of slope variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

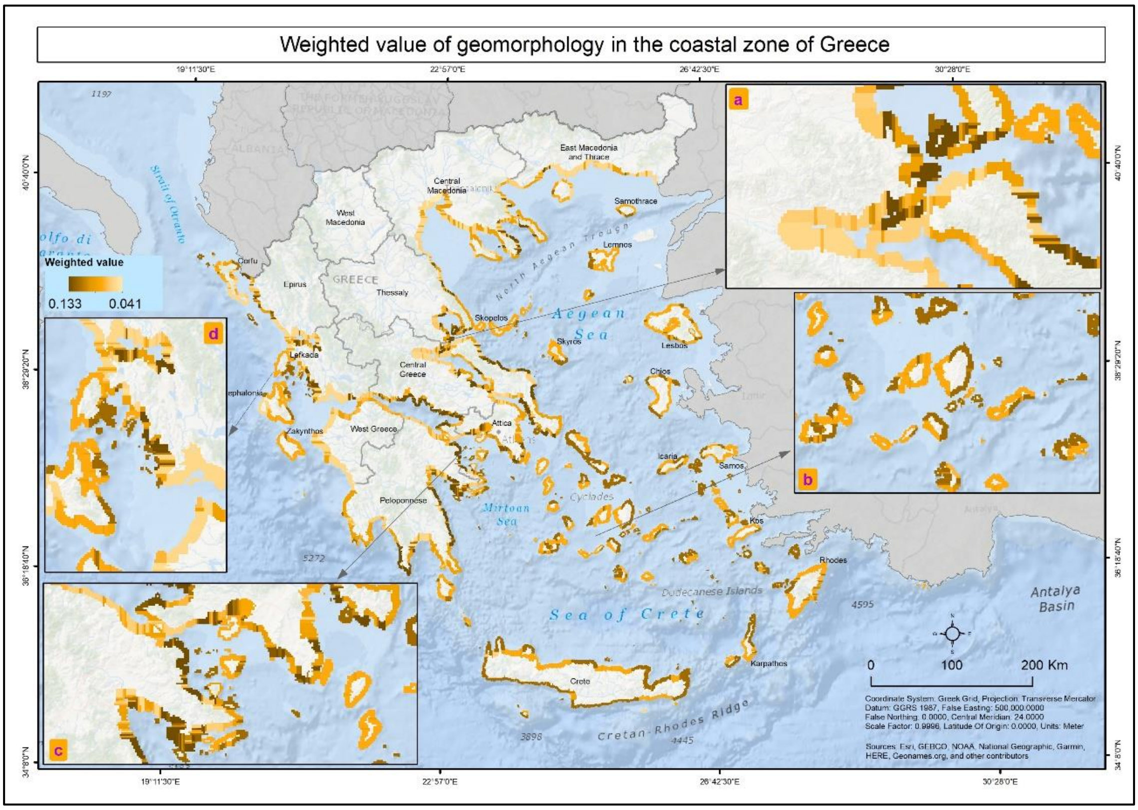


Figure 44: Weighted value of geomorphology variable in terms of coastal protection in the coastal zone of Greece. Inset maps are the zoomed view of geomorphology value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and south eastern Peloponnese and d) Ionian islands area.

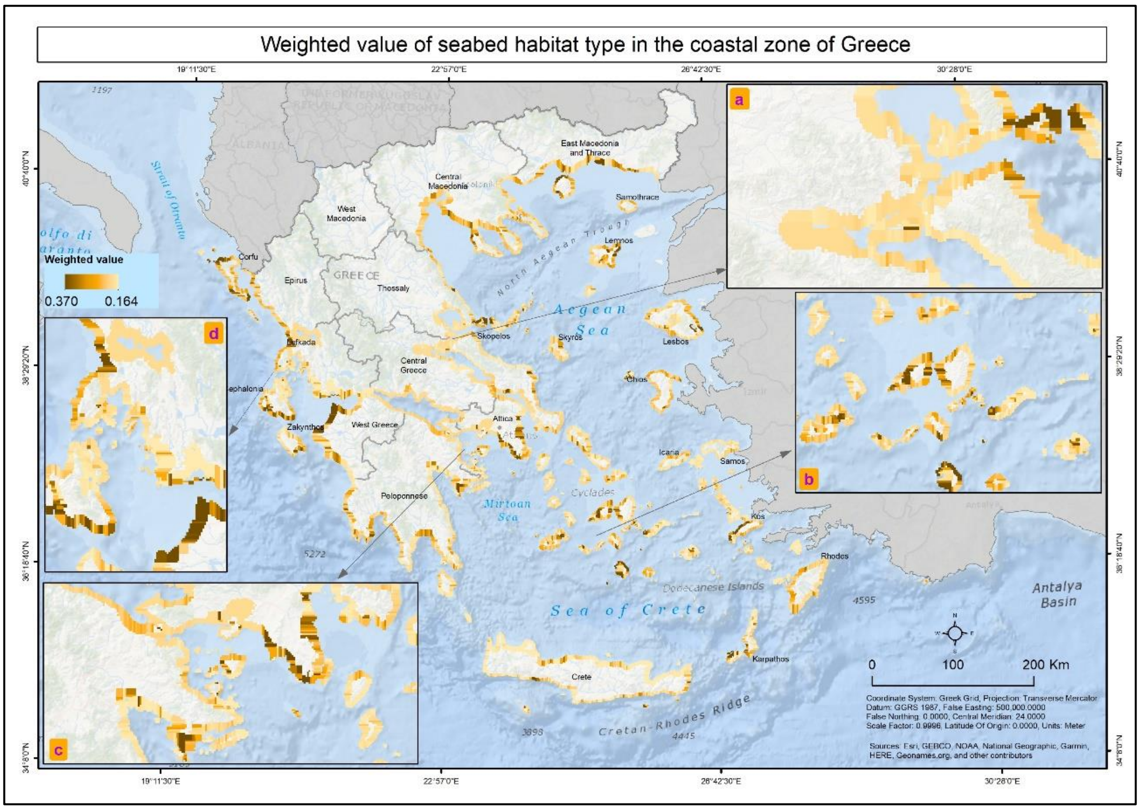


Figure 45: Weighted value of seabed habitat variable in terms of coastal protection in the coastal zone of Greece. Inset maps are the zoomed view of seabed habitat value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands and northwestern Western Greece.

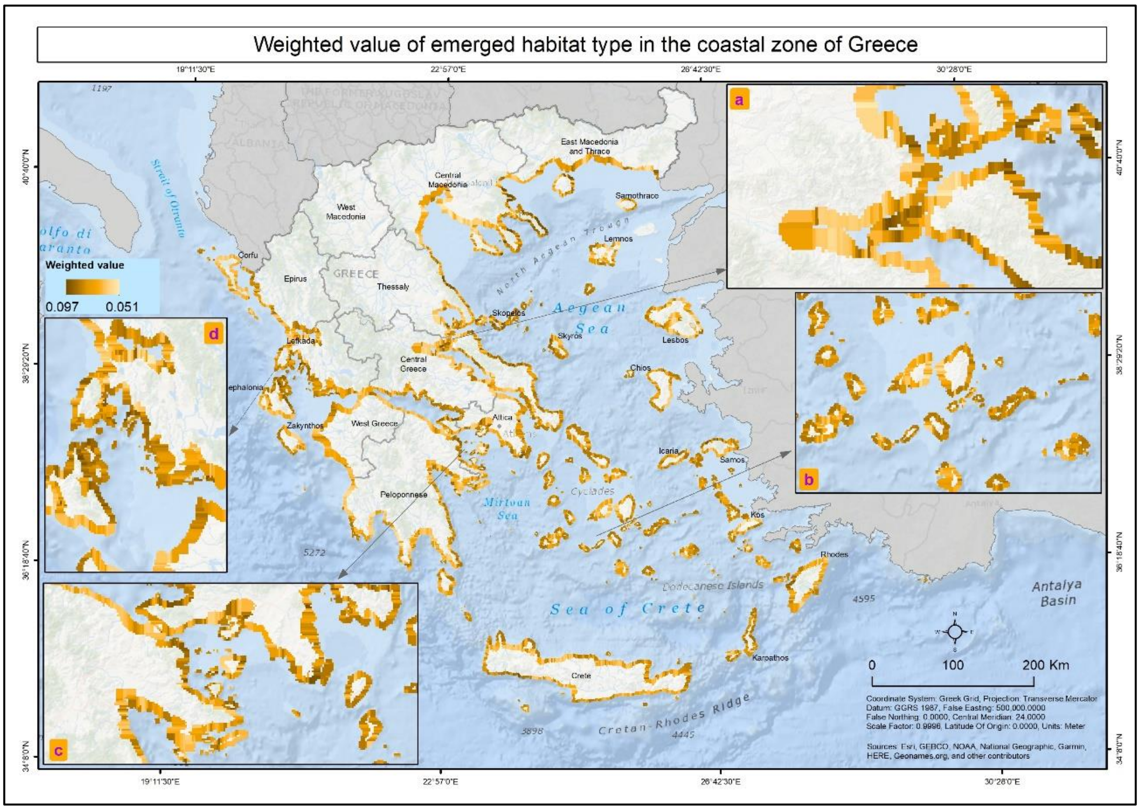


Figure 46: Weighted value of emerged habitat type variable in terms of coastal protection in the coastal zone of Greece. Inset maps are the zoomed view of emerged habitat value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and south eastern Peloponnese and d) Ionian islands area.

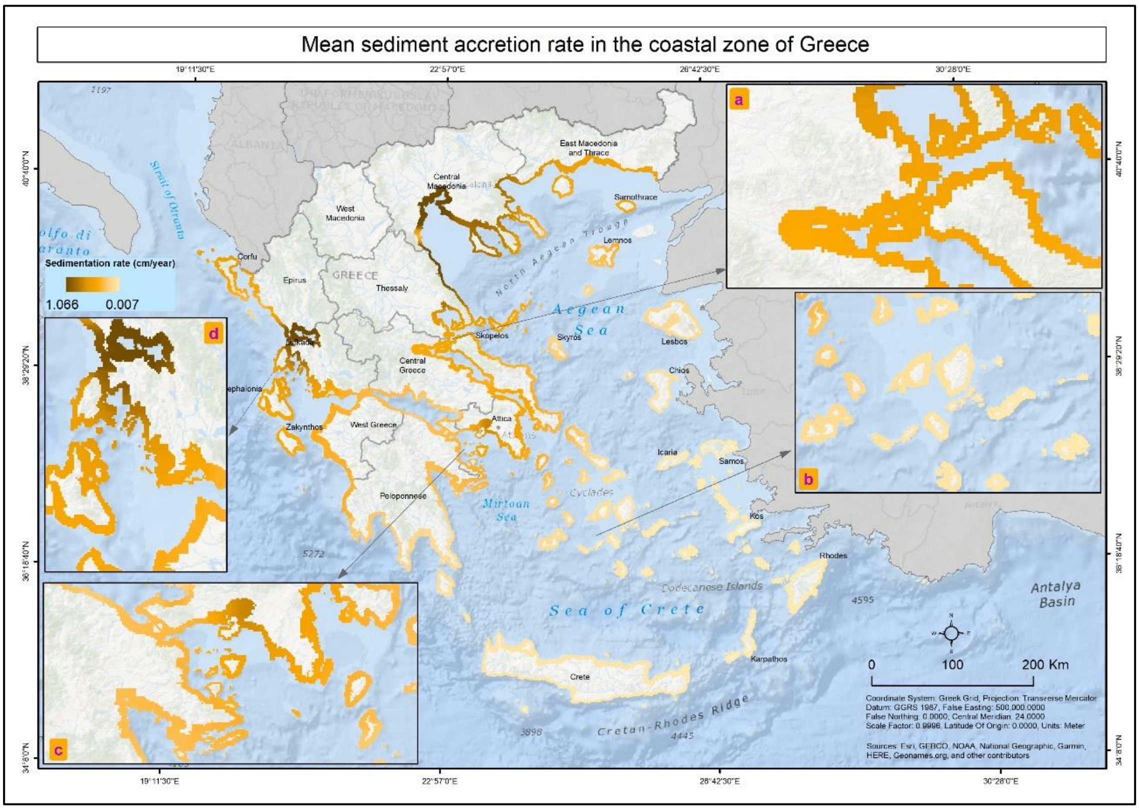


Figure 47: Mean sediment accretion rate in the coastal zone of Greece. Inset maps are the zoomed view of sediment accumulation rate value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and south eastern Peloponnese and d) Ionian islands and Ambracian Gulf area.

4.3.2. Biophysical variables for coastal protection exposure indicator

Eight variables have been identified for calculating coastal exposure indicator which are: storm surge, wave height, sea-level rise, wind speed, tidal range, ocean current and seawater temperature. Among those variables, storm surge height has been recognized by the experts as the one with the higher potentiality to create vulnerability in the Greek coast, followed by wave height, sea-level rise, wind speed, tidal range, ocean current and seawater temperature (Table 17). The mean value of these variables are 0.024, 0.654, 0.038, 6.455, 0.053, 0.023, 0.022, 20.548 respectively (Table 18). From

Table 18 it is visible that the distribution of values for each variable is confined within a small range which indicates that there is no drastic change of values for each variable within the coastal zone.

Table 17: Weights of the variables of coastal protection exposure indicator based on expert opinion

Variable	Weights of the variable
Storm surge height	0.179
Wave height	0.172
Sea level rise	0.164
Wind speed	0.149
Tidal range	0.127
Eastward ocean current	0.075
Northward ocean current	0.075
Sea water potential temperature	0.060

Table 18: Summary statistics of the variables of coastal protection exposure indicator

	Mean Sea Level	**Storm Surge Height**	**Wave Height**	**Tidal Range**	**Wind Speed**	**East ward Ocean Current**	**North ward Ocean Current**	**Seawater Potential Temperature**
Min	0.034	0.016	0.085	0.010	5.679	0.000	0.000	18.510
Max	0.043	0.030	1.423	0.198	7.259	0.189	0.142	22.797
Mean	0.038	0.024	0.654	0.053	6.455	0.023	0.022	20.548
Standard Deviation	0.003	0.003	0.285	0.041	0.478	0.025	0.020	0.713
First Quartile	0.036	0.022	0.418	0.022	5.998	0.006	0.008	20.024
Median	0.038	0.024	0.662	0.047	6.383	0.016	0.016	20.570
Third Quartile	0.040	0.026	0.880	0.073	6.914	0.032	0.031	21.130

Higher mean values of storm surge height and sea level anomaly can be seen in the Cyclades islands to the northern coastal zone of the Crete island (Figure 48 and Figure 49). Medium to low mean storm surge height and low mean sea level anomaly value can be seen in the southern coastal zone of the Crete island, the northern coastal zone of Western Greece and Peloponnese and the southern coastal zone of Central Greece, Central Macedonia and Eastern Macedonia and Thrace (Figure 48 and Figure 49). Similar to storm surge height and mean sea level anomaly, medium to high wave heights value can be seen in the Crete and Cyclades islands (Figure 50). Wave height value is significantly low in the gulf areas such as in the Gulf of Corinth and the north Euboean Gulf. Medium to high wave height value has been visible in the southwestern coastal zone of Western Greece and Peloponnese, the Ionian islands, and the southeastern coastal zone of Central Macedonia and Eastern Macedonia and Thrace (Figure 50). Unlike storm surge height, mean sea level anomaly, and wave height, the tidal range value is very minimal in the Cyclades and Crete islands and the southeastern coastal zone of Peloponnese (Figure 51). The tidal amplitude value is quite strong in the Gulf of Corinth and north Euboean Gulf. Medium to high tidal amplitude value has been visible in the coastal areas of Thessaly, Central Macedonia and Eastern Macedonia and Thrace, Ionian islands, the western coastal zone of Western Greece and Peloponnese, Rhodes, and Lesvos island (Figure 51). Wind speed in the coastal areas of Greece has a very similar pattern with mean sea level anomaly (Figure 49 and Figure 52). Wind speed is quite strong in the northwestern Cyclades islands including Rhodes and Lesvos islands and the western coastal zone of Crete island. Wind speed is relatively low in coastal areas Thessaly, Central and Eastern Macedonia, and Thrace region. A medium to high range of wind speed prevails in the coastal areas of Central and Western Greece, Peloponnese, and Ionian islands (Figure 52). Strong eastward ocean current can be seen in the southern coastal zone of Crete island, Rhodes and Limnos islands (Figure 53). A strong northward ocean current is visible in the southern coastal zone of Chalcis and the northern coastal zone of Andros island (Figure 54). High to medium range of northward ocean current is active in the Ionian islands, the western coastal zone of Peloponnese, the eastern coastal zone of Thessaly and the southern coastal zone of Central Macedonia (Figure 54). A medium to low range of ocean current can be seen in the Gulf of Corinth and north Euboean Gulf and coastal areas of Eastern Macedonia and Thrace (Figure 53 and Figure 54). The variation of seawater temperature is quite minimal throughout the Greek coast. It is relatively high in the southern coastal part than the northern coastal part of Greece. Seawater temperature is relatively higher in the Ionian islands, the western coastal zone of Western Greece and Peloponnese, Crete and

Rhodes islands area than the northern Cyclades islands, coastal areas of Central Greece, Central and Western Macedonia and Thrace (Figure 55).

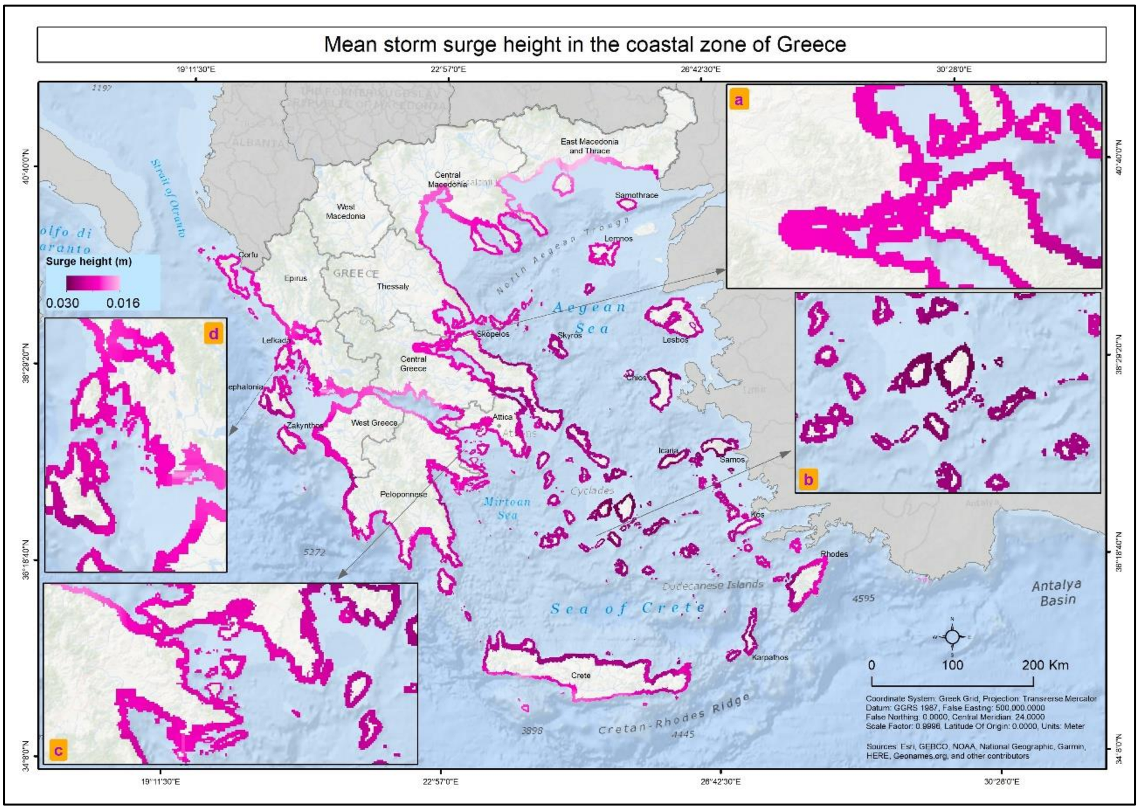


Figure 48: Mean storm surge height in the coastal zone of Greece. Inset maps are the zoomed view of storm surge height value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

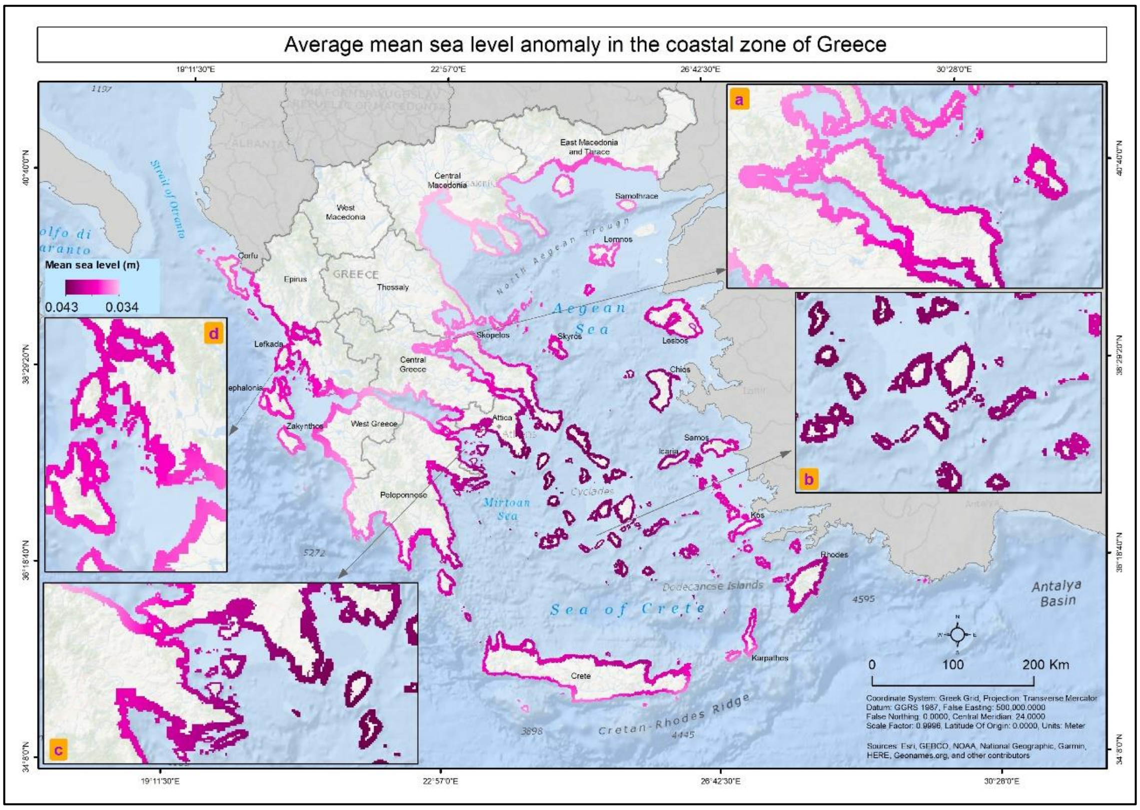


Figure 49: Average mean sea level anomaly in the coastal zone of Greece. Inset maps are the zoomed view of mean sea level anomaly value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and south eastern Peloponnese and d) Ionian islands area.

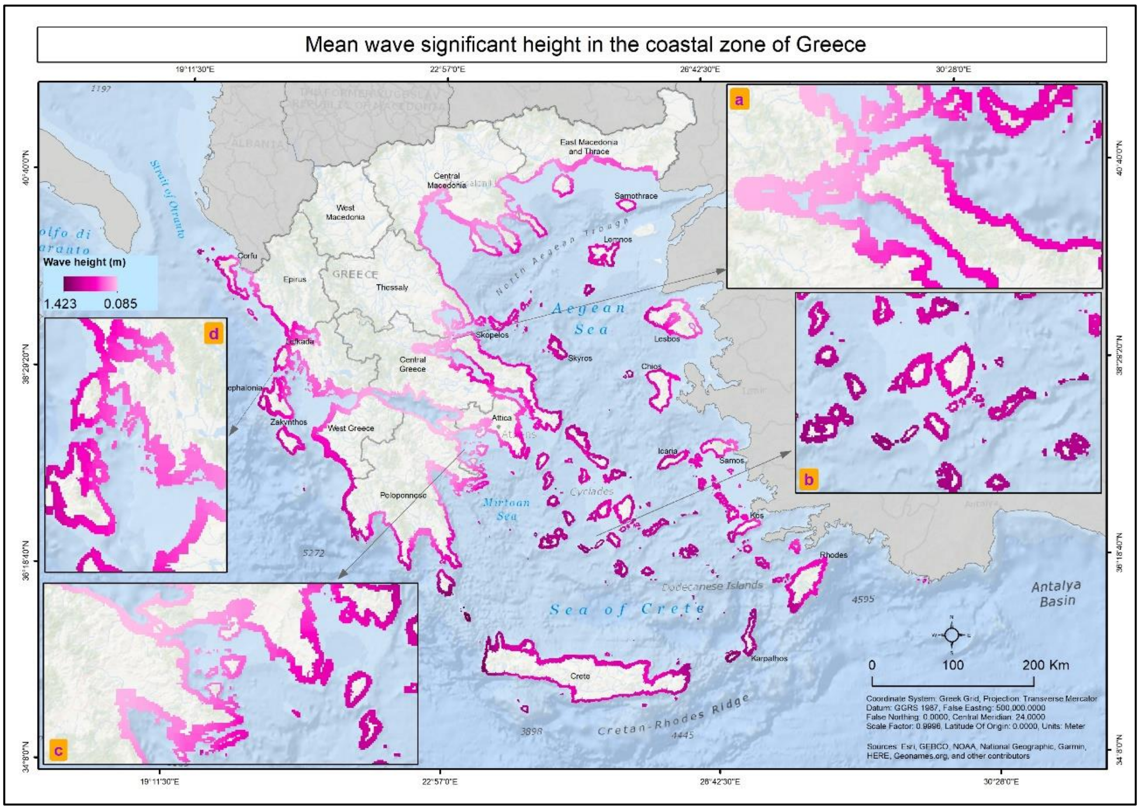


Figure 50: Mean wave significant height in the coastal zone of Greece. Inset maps are the zoomed view of mean wave significant height value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and south eastern Peloponnese and d) Ionian islands area.

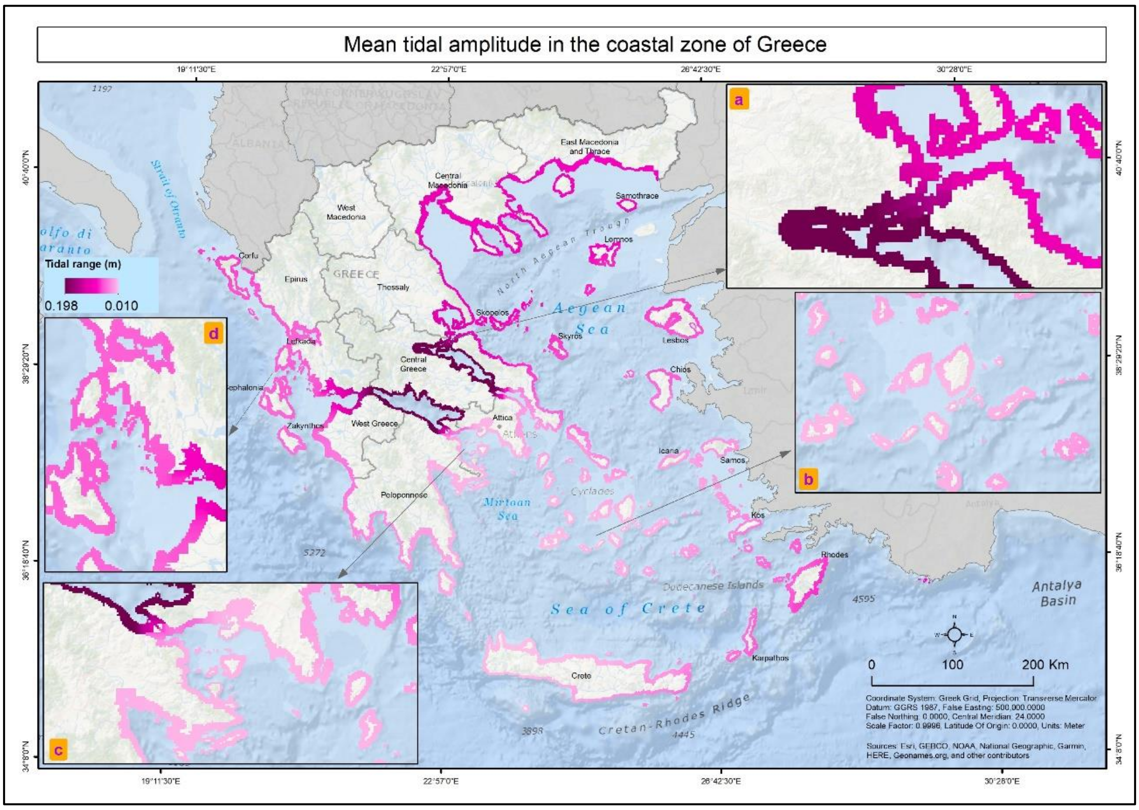


Figure 51: Mean tidal amplitude in the coastal zone of Greece. Inset maps are the zoomed view of mean tidal amplitude value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and south eastern Peloponnese and d) Ionian islands area.

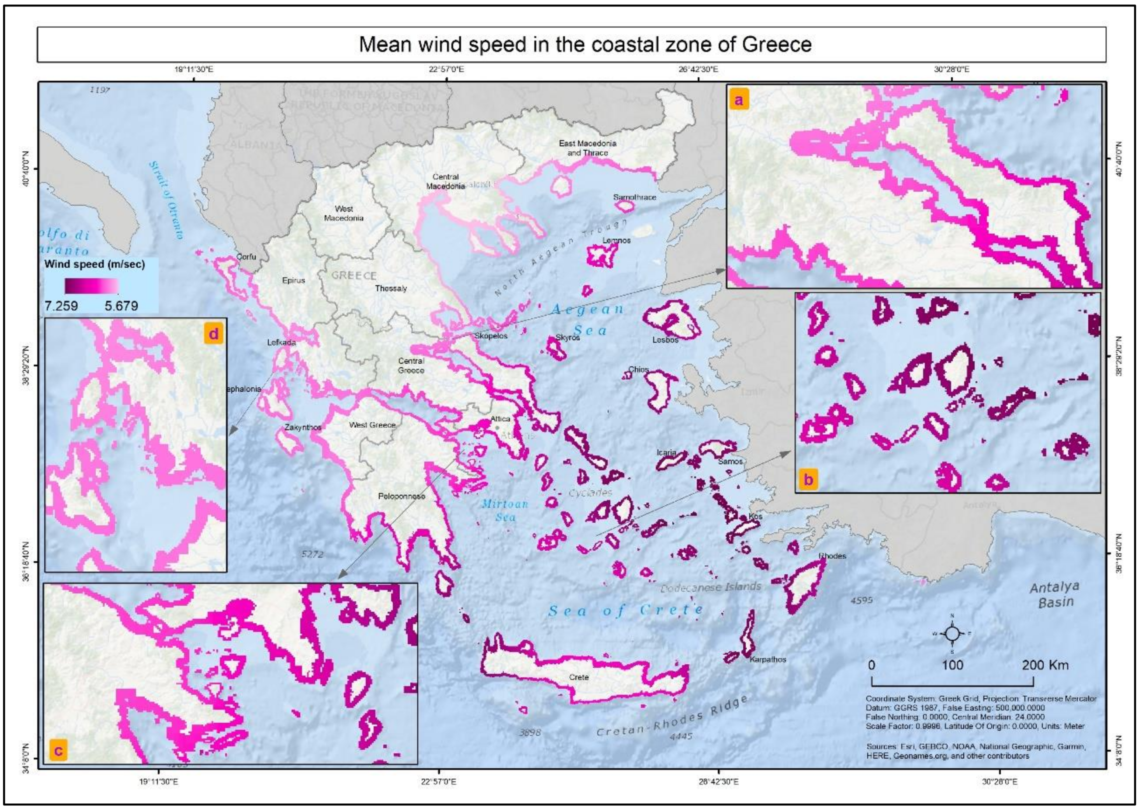


Figure 52: Mean wind speed in the coastal zone of Greece. Inset maps are the zoomed view of mean wind speed value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

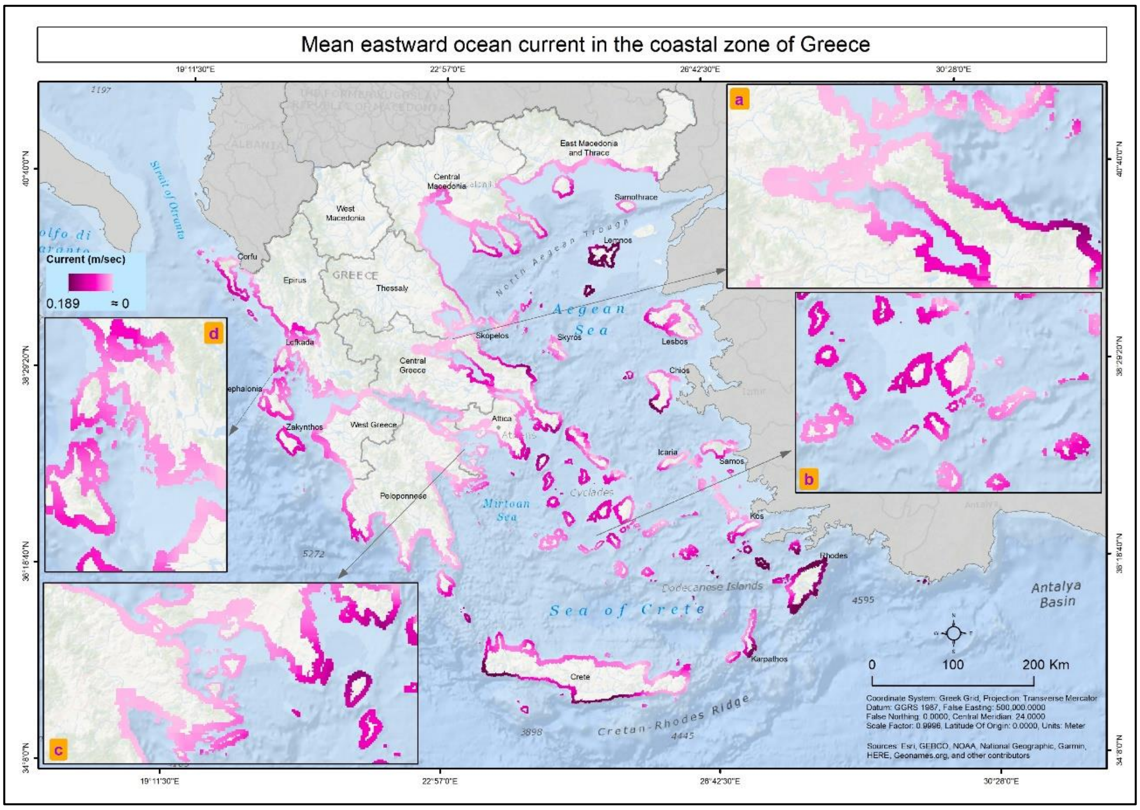


Figure 53: Mean eastward ocean current in the coastal zone of Greece. Inset maps are the zoomed view of mean eastward ocean current value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and south eastern Peloponnese and d) Ionian islands area.

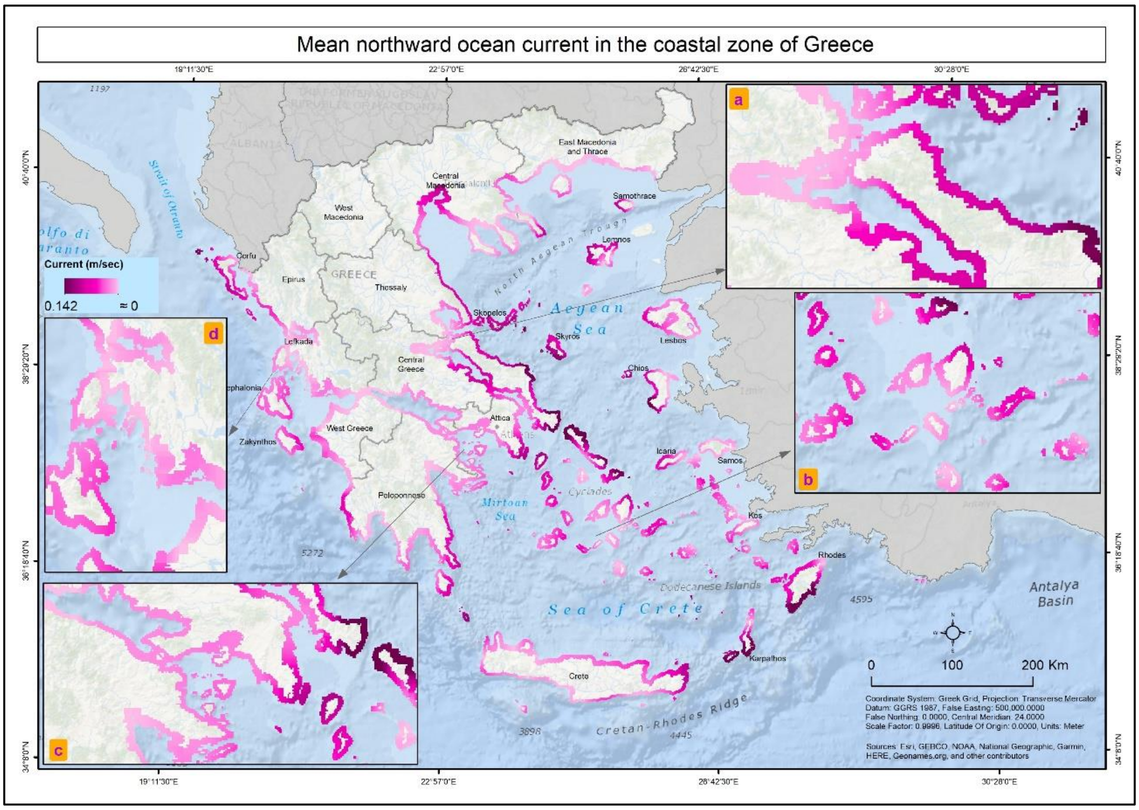


Figure 54: Mean northward ocean current in the coastal zone of Greece. Inset maps are the zoomed view of mean northward ocean current value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and north of Chalcis and d) Ionian islands area.

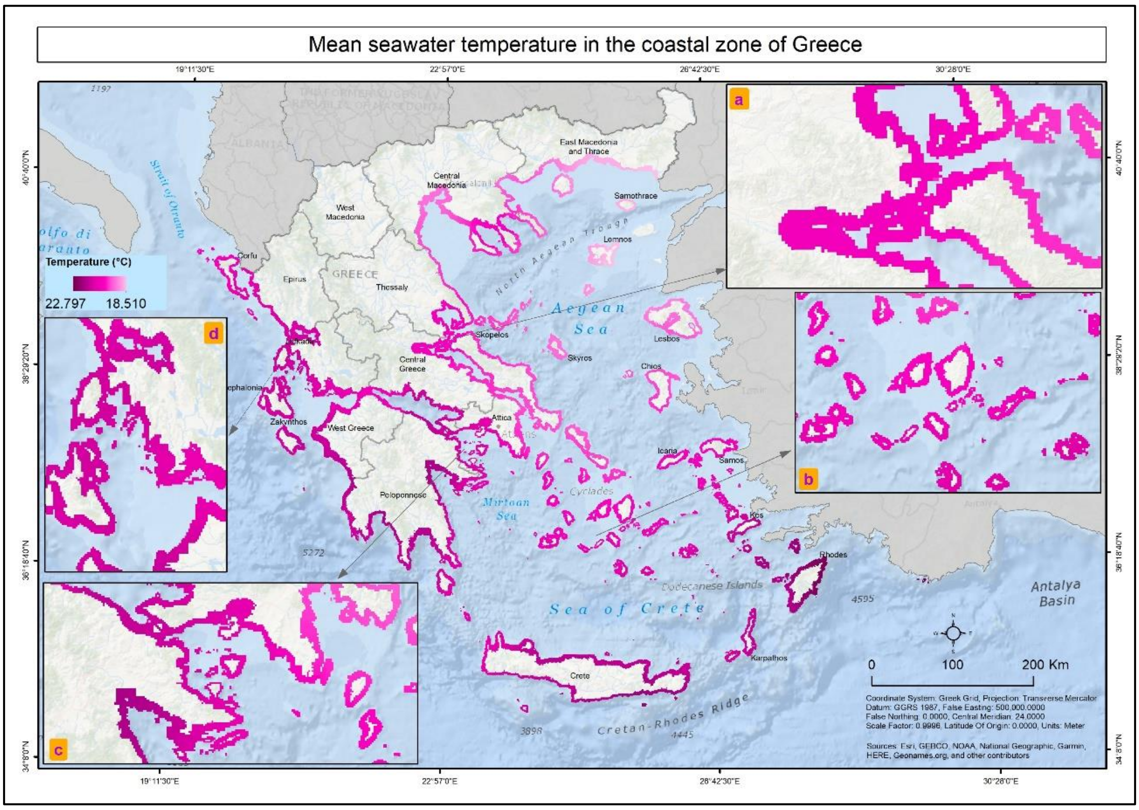


Figure 55: Mean seawater temperature in the coastal zone of Greece. Inset maps are the zoomed view of mean seawater temperature value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and southeastern Peloponnese and d) Ionian islands area.

4.3.3. Socio-economic variables for coastal protection demand indicator

To calculate the coastal protection demand indicator, six variables have been selected namely: population density, settlement area density, transport network density, port area density, cultural sites density, ecologically important sites density and mineral extraction sites density. Among those selected variables port area density got the highest priority from expert opinion in terms of demand analysis followed by population and transport network density, settlement area, cultural sites, and ecologically important sites density, and mineral extraction sites density (Table 19).

Table 19: Weights of the variables of coastal protection demand indicator based on expert opinion.

Variable	Weights of the variable
Port area density	0.167
Population density	0.155
Transportation network (roads, railway) density	0.155
Settlement area density	0.149
Cultural sites density	0.149
Ecologically important sites density	0.149
Mineral extraction sites density	0.077

The average population density in the coastal area is almost 90 persons per square kilometre whereas the average density of the rest of the variables in per square kilometre area of calculation unit is very low which is 1.696, 0.116, 0.052, 0.006, 0.003, and 0.001 for the transport network, settlement area, cultural sites, port area, ecologically important sites, and mineral extraction sites respectively (Table 20). Throughout the coastal zone of Greece, variation in the data of these variables is quite high and not all the areas have data for those variables (Table 20). Which means not all the area have population or port or cultural sites or transport network or even mineral extraction and ecologically important sites.

Table 20: Summary statistics of the variables of coastal protection demand indicator

	Population Density	Settlement Area Density	Cultural Site Density	Transport Network Density	Port Area Density	Ecologically Important Site Density	Mineral Extraction Site Area Density
Min	4.000	0.000	0.000	0.000	0.000	0.000	0.000
Max	15909.250	19.961	6.941	75.845	1.728	1.000	0.322
Mean	90.204	0.116	0.052	1.696	0.006	0.003	0.001
Standard Deviation	520.513	0.646	0.195	4.355	0.065	0.029	0.011
First Quartile	23.000	0.000	0.000	0.000	0.000	0.000	0.000
Median	38.000	0.000	0.000	0.617	0.000	0.000	0.000
Third Quartile	69.000	0.006	0.000	1.796	0.000	0.000	0.000

Population density is extremely high in coastal areas of the Attica and Central Greece region especially near the capital city of Athens compared to other parts of the coastal area. A moderate population density can be seen in the coastal zone of the Ionian islands, the western coastal zone of Western Greece and Peloponnese, some coastal part of Central Macedonia, and in the Crete, Rhodes, and Lesvos islands. Very low population density is seen in the coastal zone of the Cyclades islands, the southern coastal zone of the Peloponnese, Central Macedonia and Eastern Macedonia and Thrace (Figure 56). Similar to population density, settlement area density is also high in the coastal areas of Central Greece especially in Athens and in the Thessaloniki city area. A medium range of settlement area density can be found on both sides of the Gulf of Corinth and the north Euboean Gulf region. No or very low settlement area density is seen in the small islands such as Cyclades islands, Ionian islands, and in the southern coastal zone of Crete island (Figure 57). The density of cultural sites is quite sparse and most of the coastal areas have no cultural site. The northern coastal zone of Crete island, Ionian islands, and coastal areas of southern Attica have more cultural sites density than other coastal areas of Greece (Figure 58). Most of the coastal areas have a good transport network. Transportation network density is higher in the northern coastal zone of Western Greece and Peloponnese and southern coastal zone of Attica, and Central Macedonia. High to medium transport network density can be seen in the coastal zone of the Ionian islands, the western coastal zone of Western Greece and Peloponnese, Central Macedonia and Eastern Macedonia and Thrace and the northern coastal zone of the Crete island. Low to no transport density can be seen in the coastal zone of the Cyclades islands, southern Crete, Rhodes, and Lesvos islands (Figure 59). Coastal areas of Attica and Central Greece have higher port area density than the rest of the coastal areas of Greece and most of the coastal areas have no port (Figure 60). Like port area density, ecologically important sites and mineral extraction sites density are not prominent in coastal Greece (Figure 61 and Figure 62). The northern coastal zone of Crete island, Attica and Peloponnese have higher ecologically important sites density than the rest of the coastal area (Figure 61). The presence of mineral extraction sites in the coastal area of Greece is less than the presence of the ecologically important sites. Density of mineral extraction sites is higher in the northern coastal zone of Attica, near the south Euboean Gulf and some small islands of Cyclades islands (Figure 62).

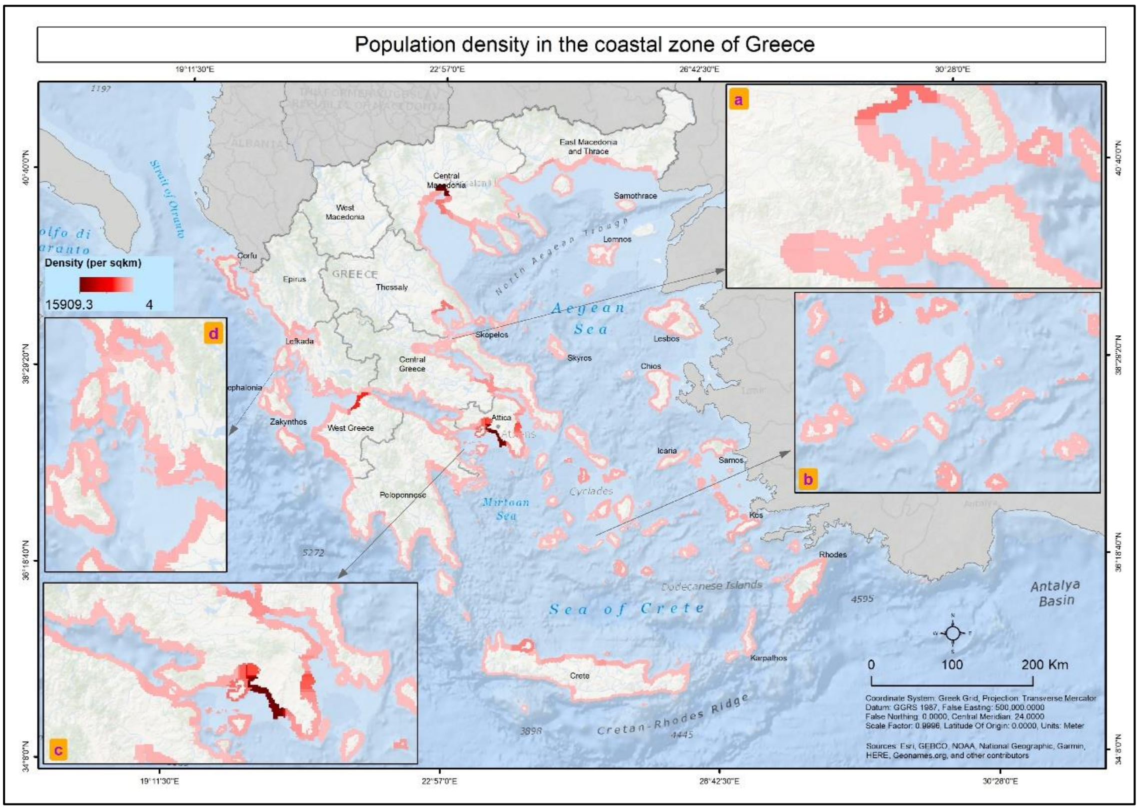


Figure 56: Population density in the coastal zone of Greece. Inset maps are the zoomed view of population density value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica (especially near Athens) and d) Ionian islands area.

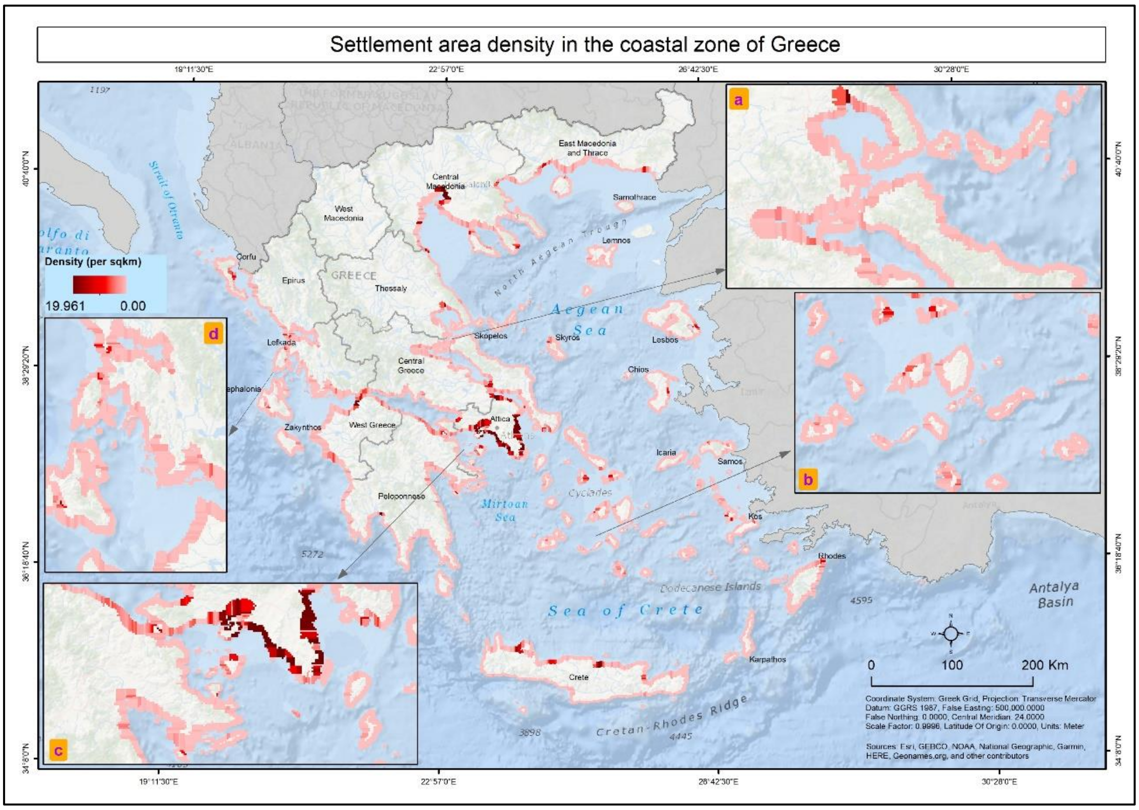


Figure 57: Settlement area density in the coastal areas of Greece. Inset maps are the zoomed view of settlement area density value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica (especially near Athens) and d) Ionian islands area.

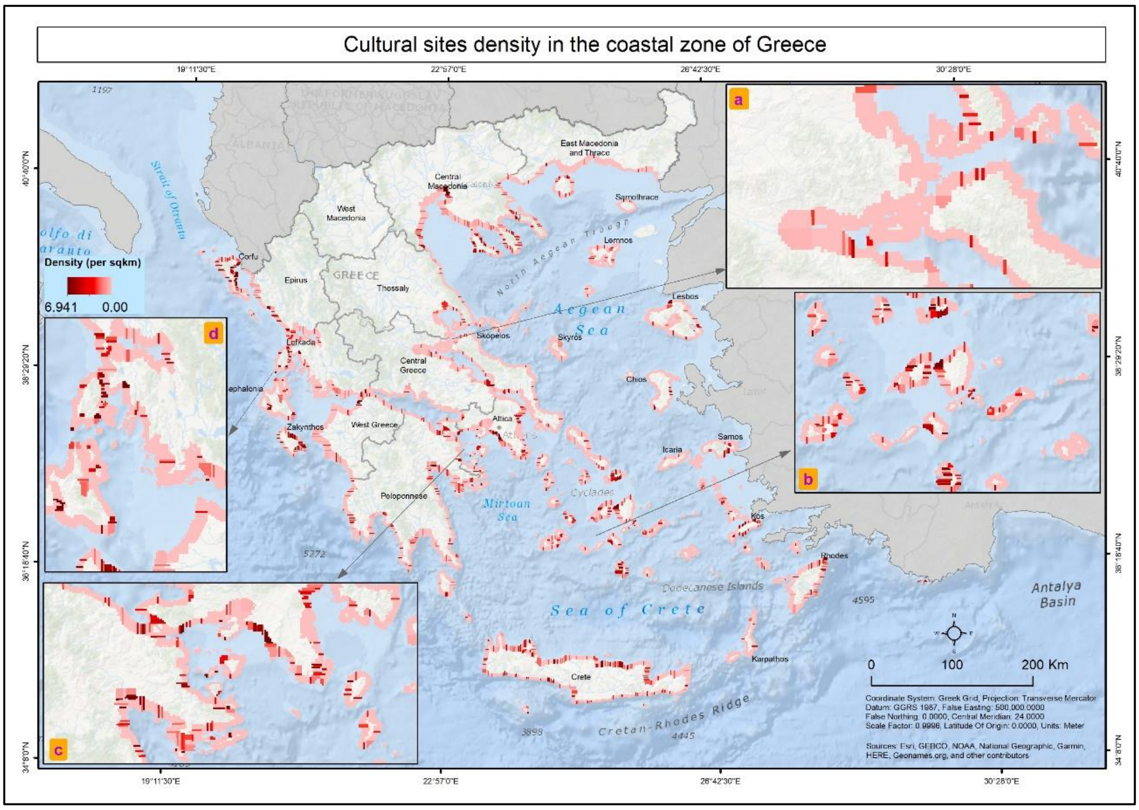


Figure 58: Cultural sites density in the coastal zone of Greece. Inset maps are the zoomed view of cultural sites density value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

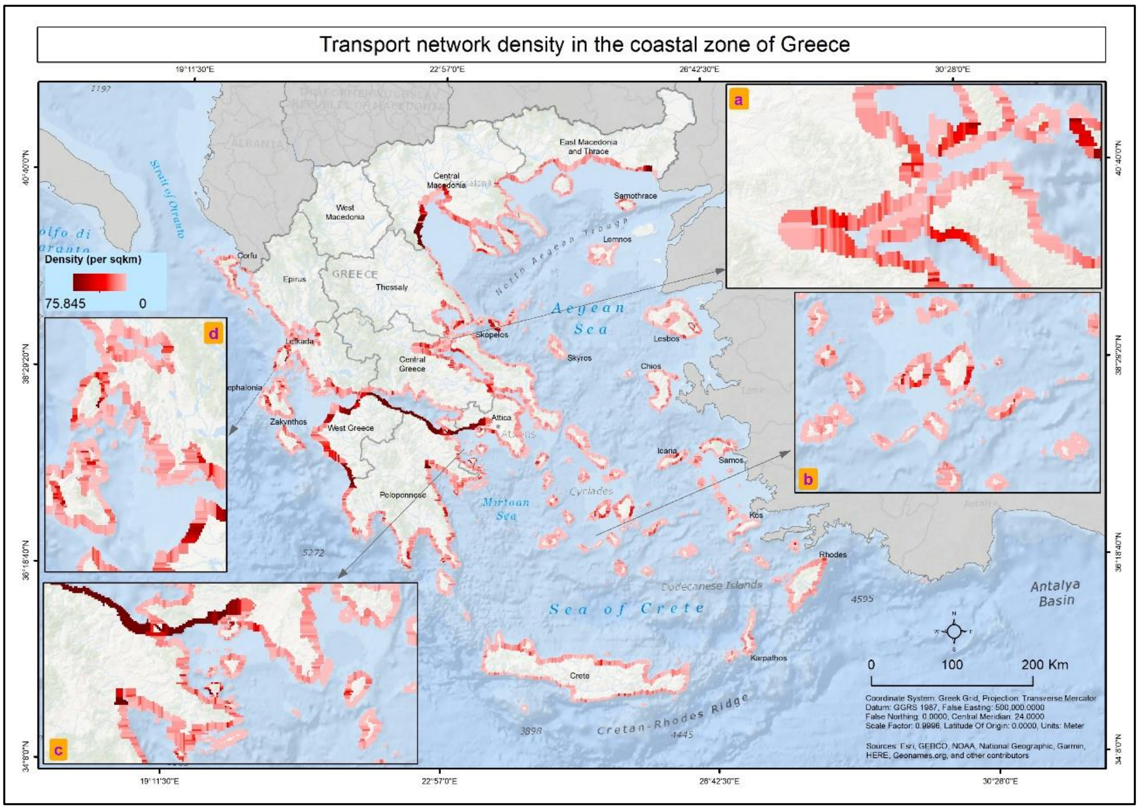


Figure 59: Transport network density in the coastal zone Greece. Inset maps are the zoomed view of transport network density value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and northwestern Peloponnese and d) Ionian islands area.

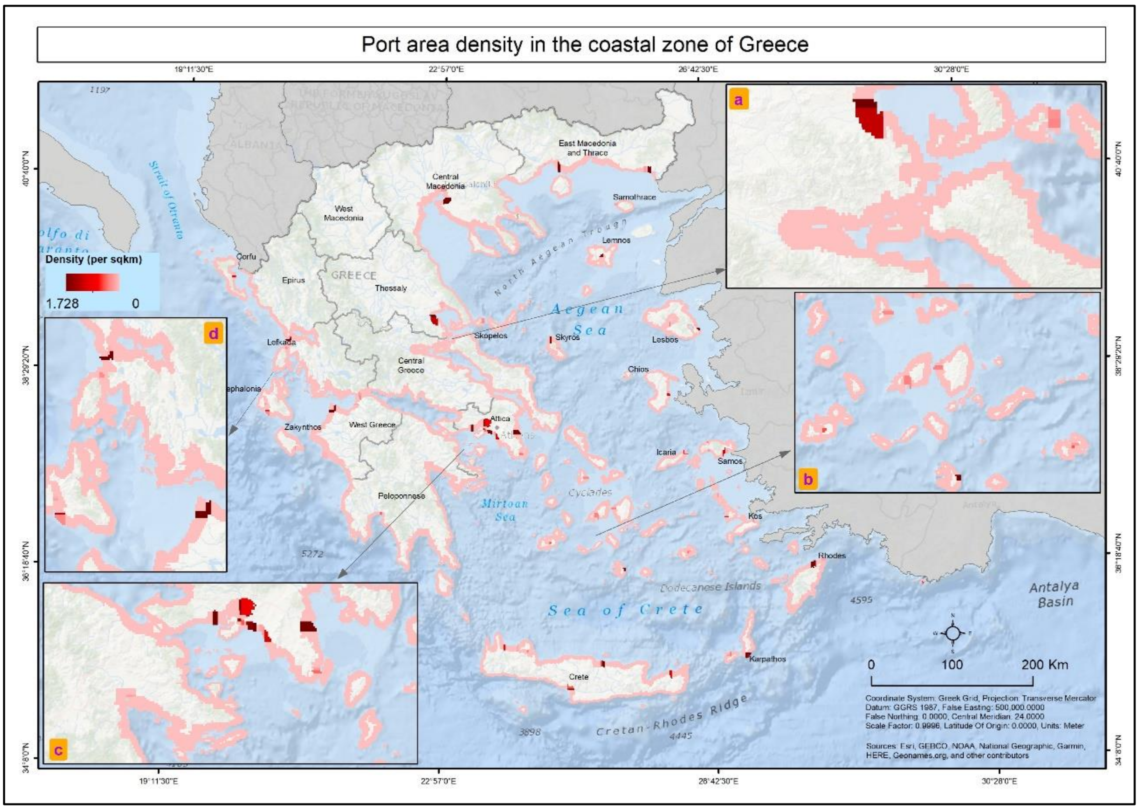


Figure 60: Port area density in the coastal zone of Greece. Inset maps are the zoomed view of port area density value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

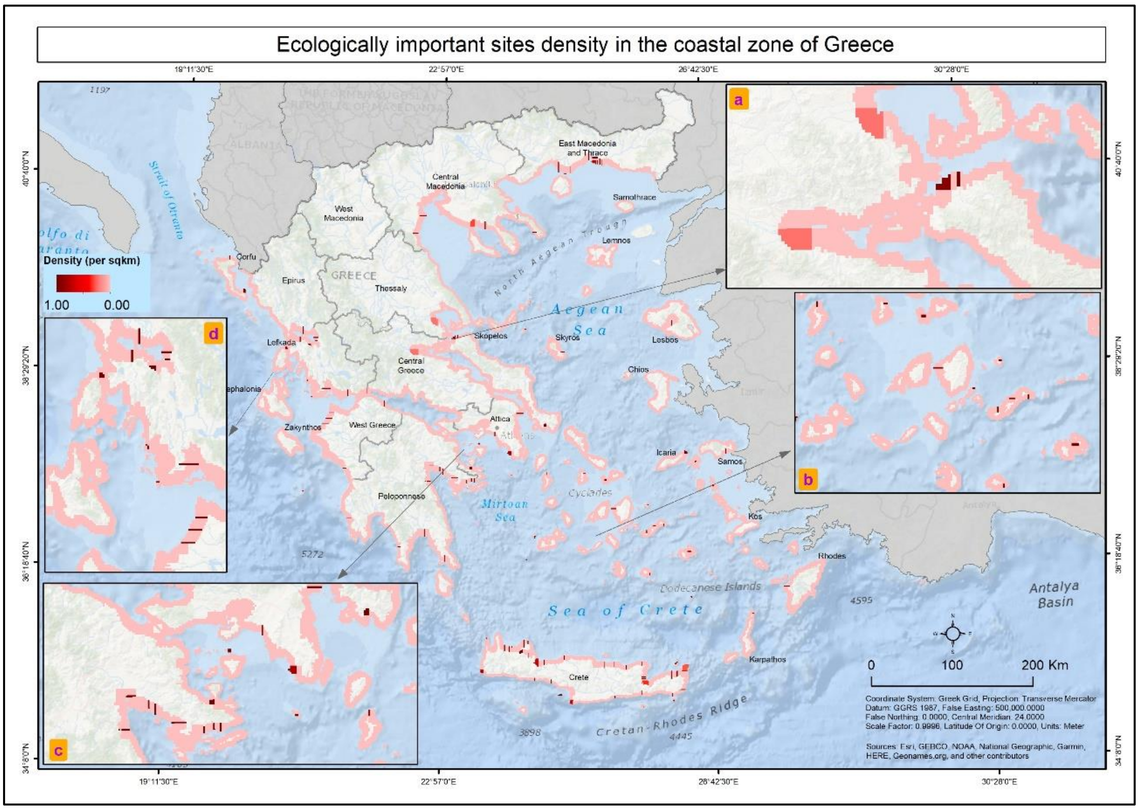


Figure 61: Ecologically important sites density in the coastal zone of Greece. Inset maps are the zoomed view of ecologically important site density value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

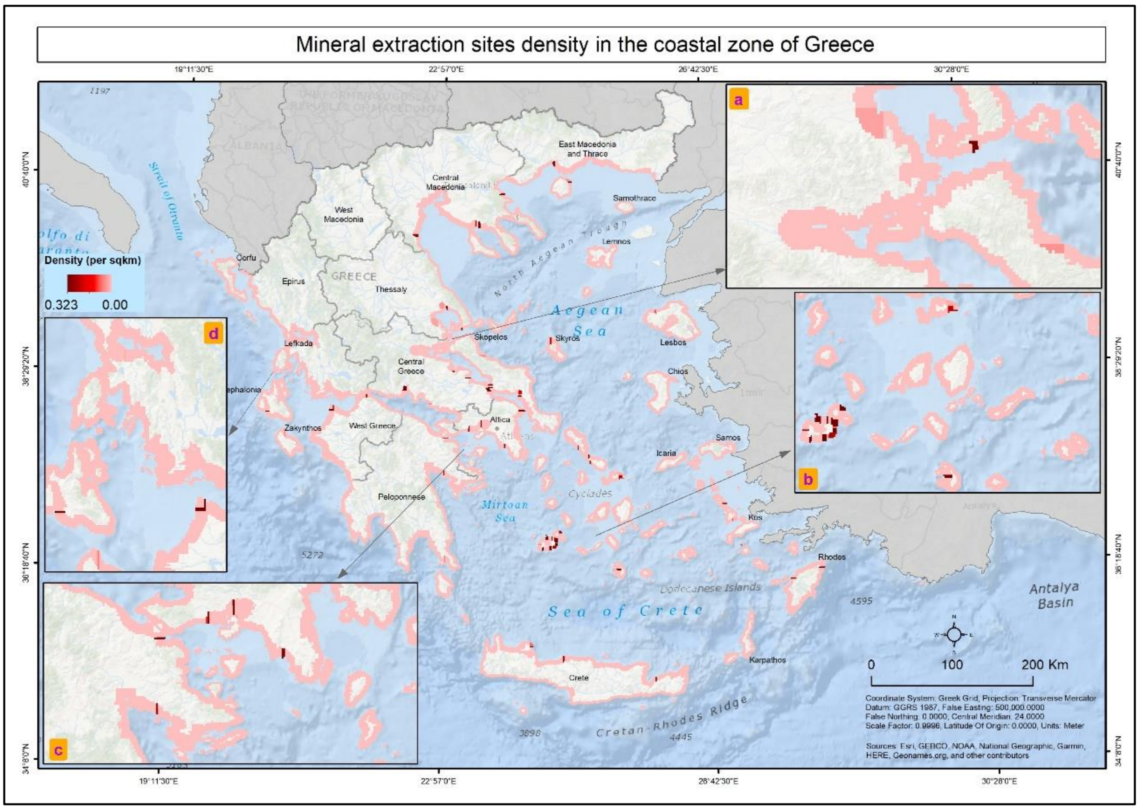


Figure 62: Mineral extraction sites density in the coastal zone of Greece. Inset maps are the zoomed view of mineral extraction site density value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

4.4. Coastal protection in the Greek coast

4.4.1. Coastal protection capacity

After adding the weights of the variables of the coastal protection capacity indicator (Table 12) in equation 3, equation 8 has been generated which has been used to calculate the coastal protection capacity indicator.

$$CP_{cap} = 0.218 \times geo + 0.193 \times slo + 0.160 \times eh + 0.210 \times sh + 0.218 \times sar \quad (8)$$

Coastal protection capacity along the Greek coast has no continuous pattern due to the high variability of data. Different areas of the coast are influenced by different variables. Relatively high protection capacity is present in the southeastern coastal zone of Peloponnese, the southern coastal zone of Central Greece, the southeastern and northwestern coastal zone of Chalcis, the eastern coastal zone of Thessaly, and the southwestern coastal zone of Crete island (Figure 63). High to medium coastal protection capacity has been observed in the coastal zone of Cyclades islands, Ionian islands, some parts of the coastal zone of Central Macedonia and Eastern Macedonia and Thrace, the northeastern coastal zone of Chalkis, the southern coastal zone of Attica, and the southeastern coastal zone of Crete island. Medium to low coastal protection capacity is seen in the northern coastal zone of Gulf of Patras, the northern and western coastal zone of Western Greece and Peloponnese and some southern coastal zone of Peloponnese, the northern coastal zone of Central Greece, both side of the south Euboean Gulf, the south eastern coastal zone of Eastern Macedonia and Thrace, the northern coastal zone of Crete island, majority of the coastal zone of Rhodes and Lesbos islands (Figure 63). Notably, small islands especially islands of Cyclades and Dodecanese islands have a medium to high range of coastal protection capacity and a similar pattern is also visible in the

Sporades and Ionian islands. It is also notable that, the landmasses that are within the Ionian Sea and Cretan Sea have low protection capacity than the Aegean Sea. Moreover, due to choosing the relatively large area as a calculation unit in the curved areas of the coastal zone, continuity of protection capacity pattern has been minimized which is seen in the western coastal zone of Western Greece and Peloponnese (Figure 63). It is also important to note that no drastic change in the pattern is seen in those curved areas which can be considered as the same category with their adjacent area with some difference in values.

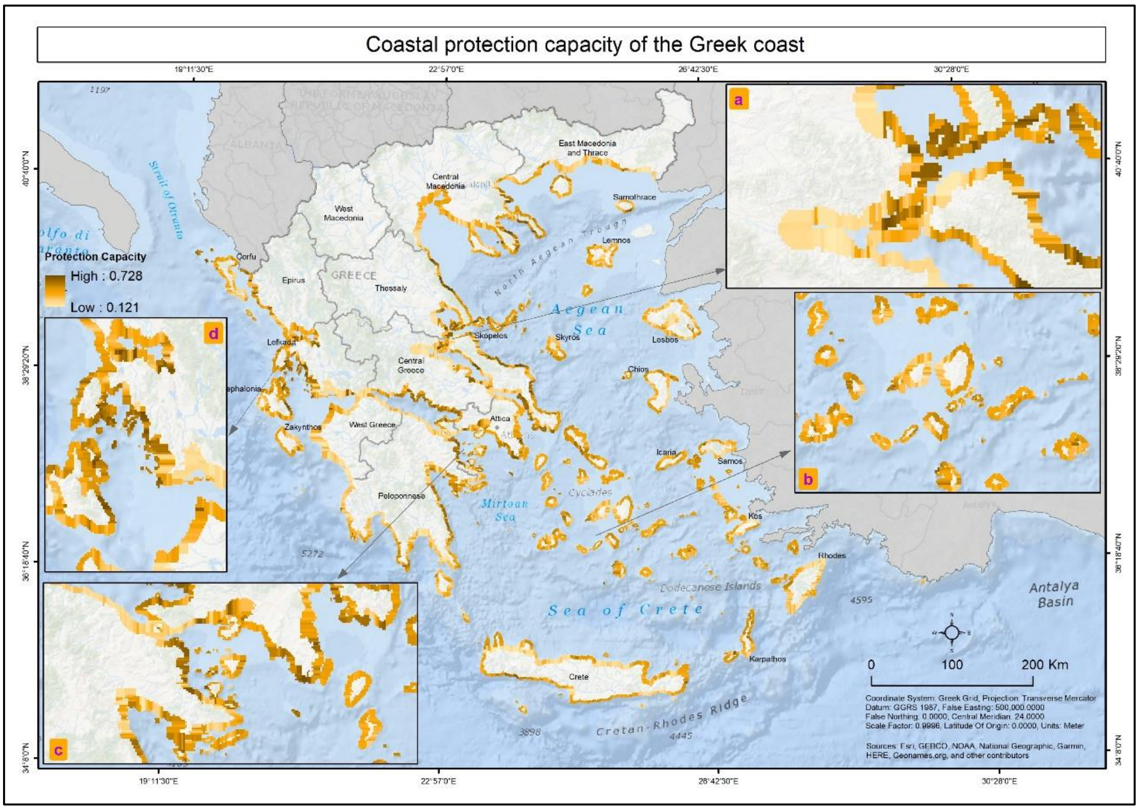


Figure 63: Coastal protection capacity of the Greek coast. Inset maps are the zoomed view of coastal protection capacity value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and south eastern Peloponnese and d) Ionian islands area.

4.4.2. Coastal protection exposure

Similar to the coastal protection capacity indicator, the coastal protection exposure indicator has been calculated using equation 9 which has been generated from equation 4 after adding the weights of the respected variables (Table 17) of the coastal protection exposure indicator.

$$CP_{exp} = 0.164 \times slr + 0.179 \times ssh + 0.172 \times wsh - 0.127 \times tide + 0.149 \times wind + 0.075 \times eoc + 0.075 \times noc + 0.060 \times spt \quad (9)$$

Unlike the coastal protection capacity indicator, the coastal exposure indicator has a continuous and distinct pattern. It is distinguishable that, coastal areas of small islands which are surrounded by ocean such as Cyclades islands, Dodecanese islands, Rhodes island, the northern part of Crete island, Chios and Lesvos islands are highly exposed. On the other hand, coastal zone located in the northern side of the Aegean Sea especially the coastal areas of Thessaly, Central Macedonia and Eastern Macedonia and Thrace, the western part of Pagasetic and north Euboean gulf, and both sides of the Gulf of Corinth and Gulf of Patras have very low exposure value (Figure 64). Medium to low coastal exposure is seen in the coastal zone of the

Ionian islands, the western coastal zone of Western Greece and Peloponnese, the northwestern and southwestern coastal zone of Chalcis, the southern coastal zone of Attica, and Sporades islands (Figure 64). Medium to high coastal exposure is identifiable in the southern coastal zone of Crete island, the southeastern coastal zone of Peloponnese and Attica, the southeastern and northeastern coastal zone of Chalcis, and in Limnos island (Figure 64). The enclosed areas especially the gulf areas and the northern Aegean Sea areas have low exposure whereas open areas such as the Crete Sea, Mirtoan Sea, and Icarian Sea areas have higher exposure (Figure 64). On the other hand, there is no anomaly observed in the pattern or distribution of values in the large-sized calculation units at the curved coastal areas. It might happen as, as all the variables of coastal protection exposure indicator have continuous data and no drastic change has been seen in the pattern of values while calculating the mean value for each calculation unit. Moreover, unlike coastal protection capacity and coastal protection demand indicators, for the variables of coastal protection exposure indicators only the mean value for each calculation unit has been calculated where the size of the calculation unit has no role to play. Due to these reasons, no significant change of values of coastal protection exposure indicator has been observed in the curved areas of the Greek coast where the size of the calculation unit is relatively larger (Figure 64).

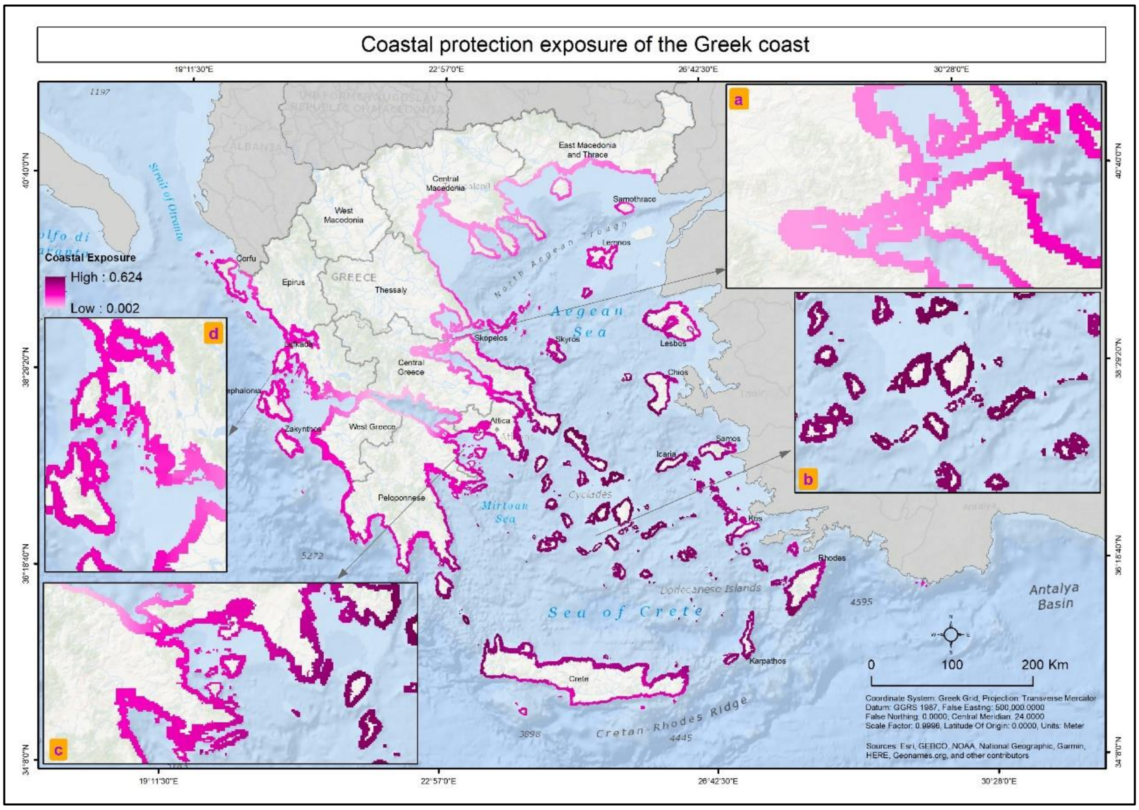


Figure 64: Coastal protection exposure of the Greek coast. Inset maps are the zoomed view of coastal protection exposure value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and south eastern Peloponnese and d) Ionian islands area.

4.4.3. Coastal protection demand

Coastal protection demand indicator has been calculated using equation 10 which comes from equation 5 after adding the weights of each variable (Table 19)of coastal protection demand indicator.

$$CP_{dem} = 0.155 \times popn + 0.149 \times set + 0.155\, trans + 0.167 \times ports + 0.077 \times mes + 0.149 \times cul + 0.149 \times eco \qquad (10)$$

The pattern of coastal protection demand indicator is completely different from the pattern of coastal protection exposure indicator. Most of the areas of the Greek coast have no or very low protection demand due to the absence of either settlements, cultural sites, ecological sites, or mineral extraction sites, or all of these. Moreover, some coastal zone has been identified where protection demand is quite high but the adjacent areas of those areas have very low protection demand (Figure 65). It might happen due to the sparse distribution of the variables of the coastal protection demand indicator. High demand for coastal protection is visible in the southern coastal zone of Attica especially near the capital city Athens and near Thessaloniki city which is known as the port city of Greece (Figure 65). Medium to high coastal protection demand is observable in the northern and western coastal zone of Peloponnese and Western Greece, the southern coastal zone of Central Macedonia, near Pagasetic Gulf area, near Alexandroupolis city, and some areas in the northern part of Crete and Rhodes islands (Figure 65). In the coastal area of small islands such as Cyclades islands, Dodecanese islands, Rhodes, Chios, Lesvos, Lemnos, Sporades, and Ionian islands have medium to low and most cases no protection demand which is also true for the southern part of Crete island (Figure 65).

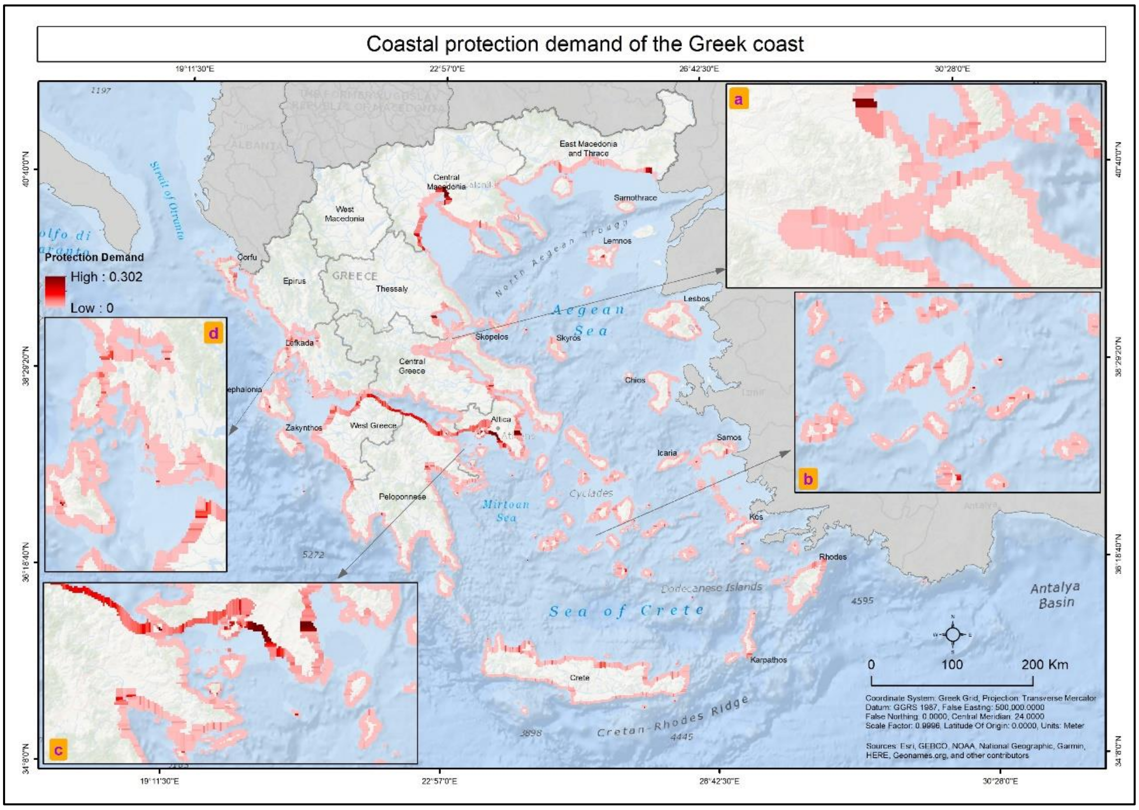


Figure 65: Coastal protection demand of the Greek coast. Inset maps are the zoomed view of coastal protection demand value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and southwestern Peloponnese and d) Ionian islands area.

4.4.4. Coastal protection service flow

The coastal protection service flow is higher in the southern coastal zone of Central Greece, near the north Euboean Gulf and Pagasetic Gulf, some of the area of Central Macedonia and East Macedonia and Thrace. Medium to high service flow is visible in the majority of Central Macedonia, East Macedonia and Thrace, the northern part of Western Greece and Peloponnese, the northern side of Chalcis, and in the Ionian islands (Figure 66). Medium to low service flow can be seen in the western part of Western Greece and Peloponnese, the eastern coastal zone of Peloponnese, entire Attica, the southern coastal zone of Chalcis and Crete island. Very low service flow is observable in Cyclades islands, Rhodes island, Lesvos, Chios, Icaria islands and southern coastal zone of Peloponnese and northern coastal zone of Crete island (Figure 66). In Figure 66 service flow value ranges from negative to positive. The value of Figure 66 has no absolute meaning rather it can be used to compare the service flow of coastal protection. Negative values of service flow mean that the coastal protection capacity of that area is less than the coastal exposure whereas positive value means that the protection capacity is higher than the exposure. The protection capacity and exposure will be the same if the value of any area is zero.

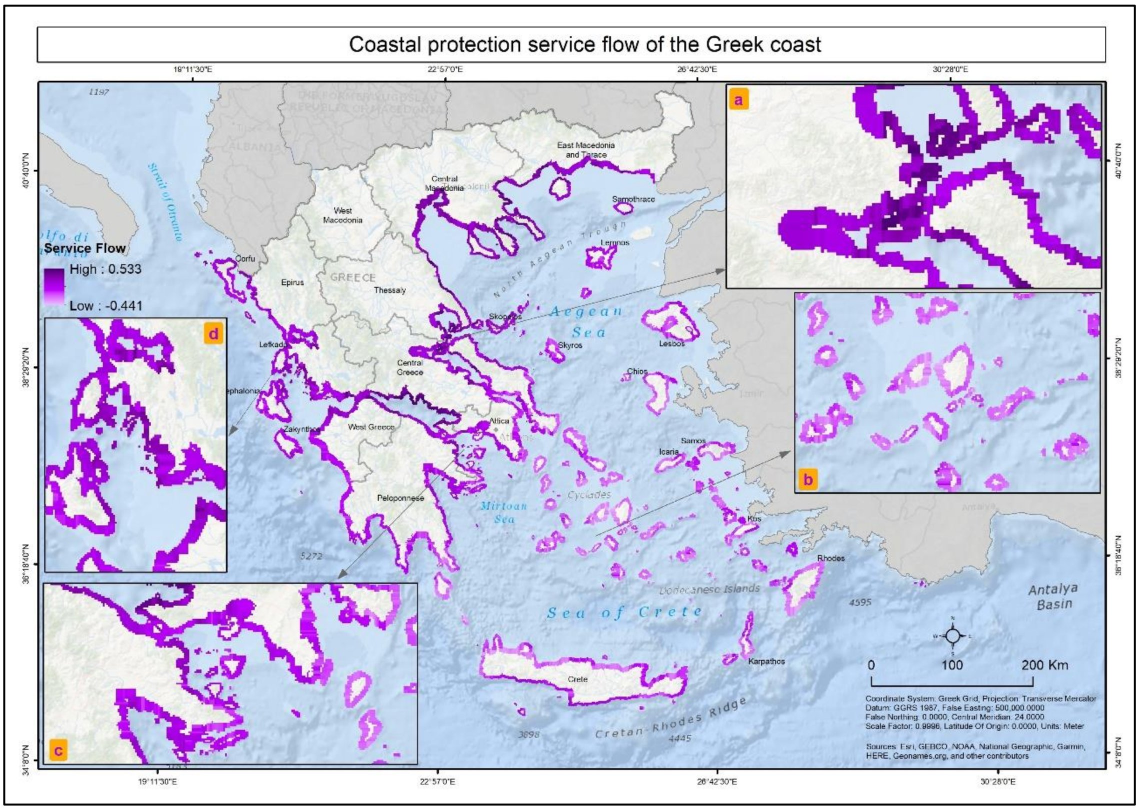


Figure 66: Coastal protection service flow of the Greek coast. Inset maps are the zoomed view of coastal protection service flow value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and south eastern Peloponnese and d) Ionian islands area.

4.4.5. Coastal protection benefit

Similar to the coastal protection service flow, the values of coastal protection benefit range from negative to positive and these values have no absolute meaning in terms of benefit analysis. The negative values mean that the demand is higher than the service flow which is the opposite for the positive values (Figure 67). The coastal protection benefit has a very similar pattern with coastal protection service flow. From Figure 67 it is identifiable that due to the very low demand of coastal protection throughout the Greek coast the benefit of ecosystem service supply is very minimal throughout the coast. Most of the small islands especially the Cyclades islands, Rhodes, Lesvos, Chios, Icaria, Karpathos, the northern part of Attica, and southern part of Peloponnese has received the very low benefit (Figure 67). Moreover, in the high demand area such as in Attica especially near Athens due to medium to low service flow the benefit of coastal protection is mostly low there (Figure 67). The same situation is observable in the western coastal zone of Western Greece and Peloponnese. In the southern coastal zone of Central Greece, and near north Euboean Gulf and Pagasetic Gulf area benefit is much higher as service flow exceeds the human needs (Figure 67). A similar situation is also seen in the coastal zone of Central Macedonia and Eastern Macedonia and Thrace. In the

Ionian islands, the northern coastal zone of Chalcis the service is adequately flowing to meet the demand of that area (Figure 67).

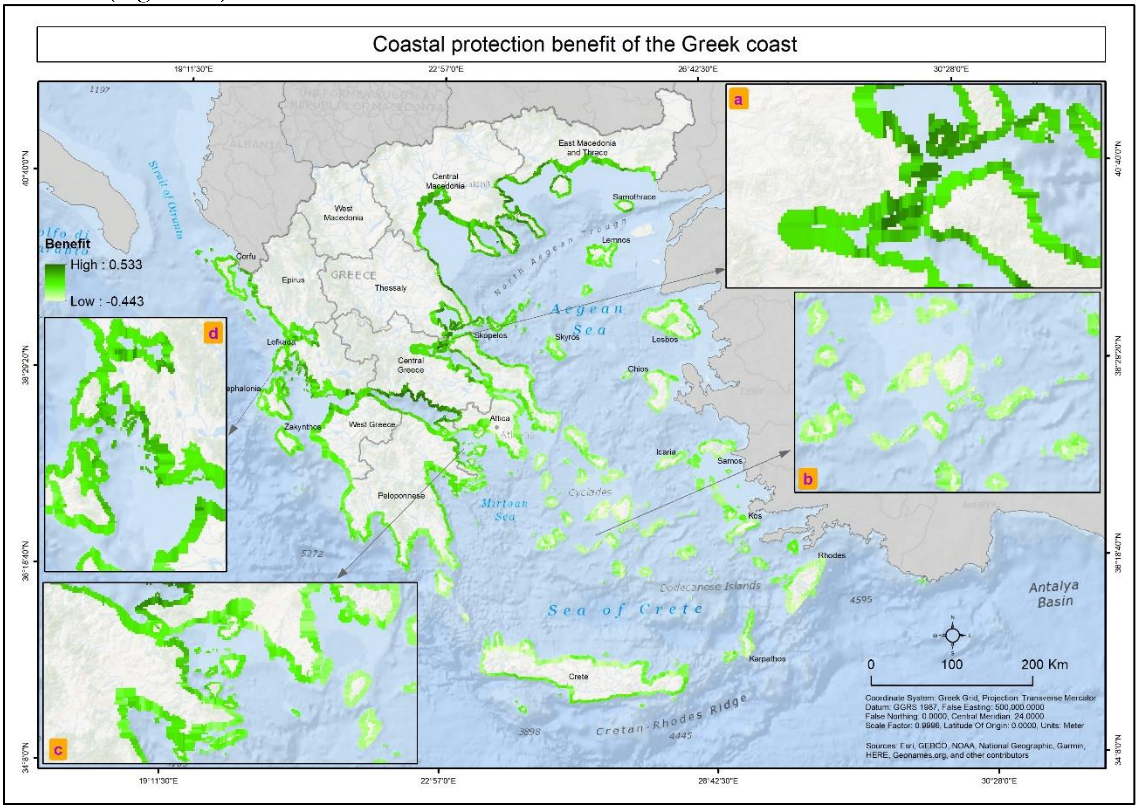


Figure 67: Coastal protection benefit in the Greek coast. Inset maps are the zoomed view of coastal protection benefit value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and south eastern Peloponnese and d) Ionian islands area.

4.5. Comparison of the outcome of the national and regional level model

Coastal protection capacity as an ecosystem service along the European Union (EU) coastal zone has been assessed by Liquete et al., (2013b). In their regional level study, they used the conceptual framework developed by Haines-Young & Potschin, (2012). This thesis study downscaled the original regional level model into the national level of Greece by adapting the same conceptual framework. Both the models have similarities and dissimilarities in terms of variable, indicator structure, and model output. In this section, the comparison has been made both at the variable level and at the indicator level. For the variable level comparison, it was performed only for the variables which are shared in both models.

Table 21: Variables used in the regional and national level model ordered according to their weight (Variables in bold font indicates new addition of variables in the national level model)

Indicator	Variables in national model	Variables in the regional model
Coastal protection capacity	Geomorphology	Geomorphology
	Sediment accretion rate	Slope
	Seabed habitat	Seabed habitat
	Slope	Emerged Habitat
	Emerged habitat	
Coastal protection exposure	Storm surge height	Wave height
	Wave height	Storm surge height

	Sea level rise	Sea level rise
	Wind speed	Tidal range
	Tidal range	
	Eastward ocean current	
	Northward ocean current	
	Seawater potential temperature	
Coastal protection demand	**Port area density**	Population density
	Population density	Transportation network (roads, railway) density
	Transportation network (roads, railway) Density	Artificial surface
	Settlement area density	Cultural site density
	Cultural site density	
	Ecologically important site density	
	Mineral extraction site area density	

In the regional level model, 12 variables have been used to assess three indicators of coastal protection whereas in the national level model more detailed assessment has been conducted using 20 variables for those three indicators (Table 21). In the national level model, sediment accretion rate for coastal protection capacity indicator, wind speed, eastward and northward ocean current, and seawater temperature for coastal protection exposure indicator and port area, ecologically important and mineral extraction sites density for coastal protection demand indicator are the new addition. Besides, variables have also been assigned with different weights based on expert opinion in these two models which indicate the difference in significance of variables in coastal protection (Table 21).

Moreover, both models have some dissimilarities in terms of delineating the coastal zone boundary. Though the minimum extent of coastal zone boundary is similar in both the models, differences are seen in hydrodynamic and social-economic boundary delineation criteria. In the regional level model maximum of 50-meter bathymetry and contour line have been chosen for delineating the boundary whereas in the national-level model this limit has increased to 100 meters for both cases. Again, in the regional level model, the maximum inland boundary has chosen 50 km from coastline whereas in the national level model maximum 3 km and 5 km distance have been considered from the coastal line for two different sets of landmass size (Figure 40 and Figure 41). The total number of calculation units in the regional level model for Greece is 303 with approximately 30 km length of each calculation unit whereas, in the national level model, a total of 7,358 calculation units have been generated with 1 km length of each calculation to cover the entire Greek coast for assessing the coastal protection. Besides, in terms of the indicator structure of both models, the additive aggregation method has been used for constructing and assessing each indicator. The outcomes of both the models have depended largely on the variability of the data of each variable and the assigned weight of those variables. Similar to the differences in weight, each variable in both models has shown differences in terms of value. To understand quantitatively the difference between the two models, RMSE estimate has been used. Among the variables of the coastal protection capacity indicator, the slope variable has a more similar pattern in both the models than any other variables. The slope variable has some significant difference with relatively high RMSE value in the northern coastal zone of Crete island, Cyclades islands, Dodecanese islands and in the northern part of Chalcis (Figure 68 and Appendix 2). This difference is more prominent for geomorphology and seabed habitat variables (Appendix 3 and Appendix 4). The Ionian islands, the western part of Western Greece, north of the Gulf of Patras, the southeastern coastal zone of Central Macedonia and Eastern Macedonia and Thrace have significant difference for geomorphology variable with relatively high RMSE value in two models (Figure 69 and Appendix 3). The northwestern part of Western Greece, the southern part of central Macedonia especially near the Thessaloniki port area and south of the North Euboean Gulf have some similarities in terms of data variation for seabed habitat variable but the rest of the areas have a high difference with relatively high RMSE value in both models (Figure 70 and Appendix 4). Emerged habitat variable showed a more similar pattern than the previously mentioned variables. The notable difference in this variable can be seen in some coastal areas of northern Crete island, the northwestern coastal zone of Western Greece, the southern coastal zone of Central Macedonia and Eastern Macedonia and Thrace with relatively high RMSE value (Figure 71 and Appendix 5).

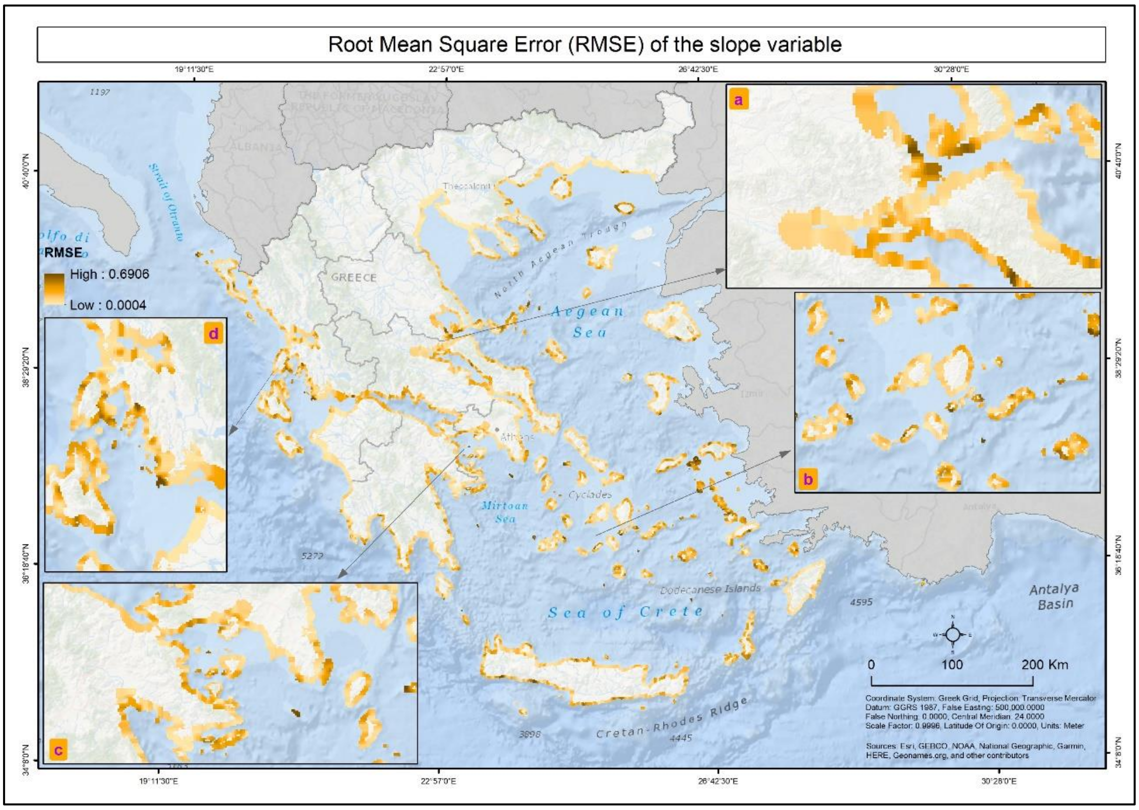


Figure 68: RMSE of slope variable. Inset maps are the zoomed view of RMSE value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

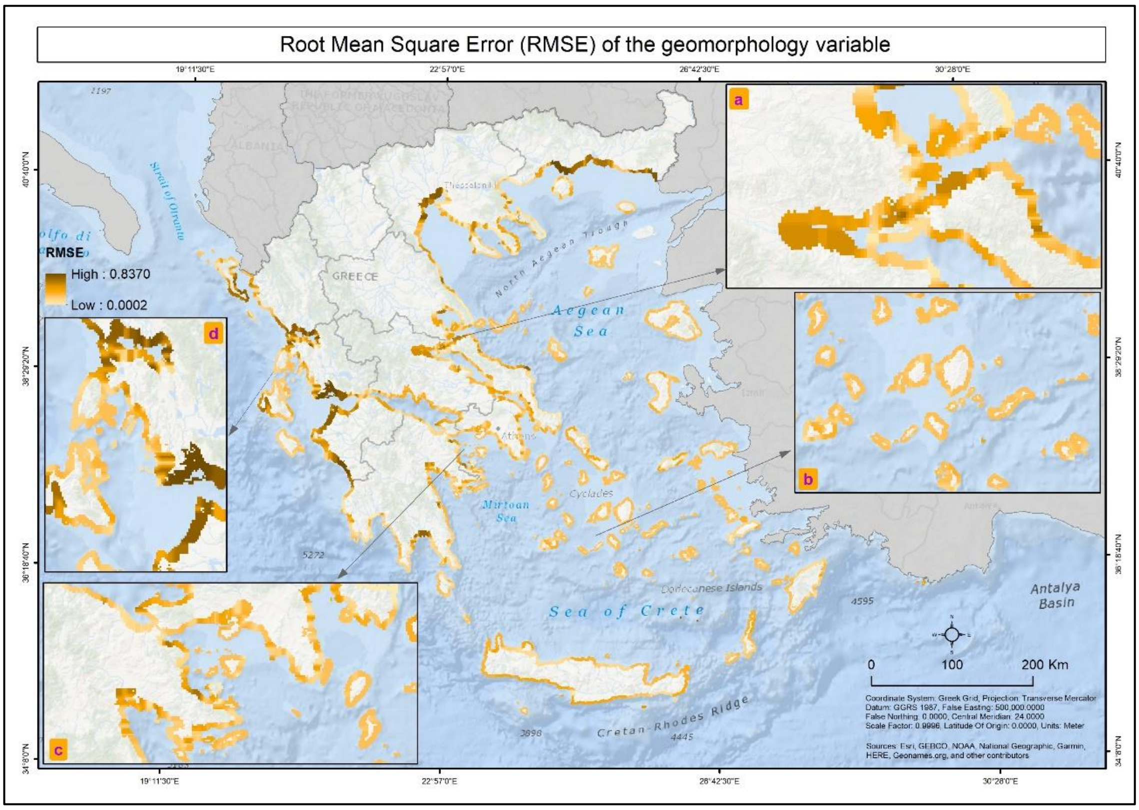


Figure 69: RMSE of geomorphology variable. Inset maps are the zoomed view of RMSE value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and south eastern Peloponnese d) northern Western Greece, Ionian islands, and Ambracian Gulf area

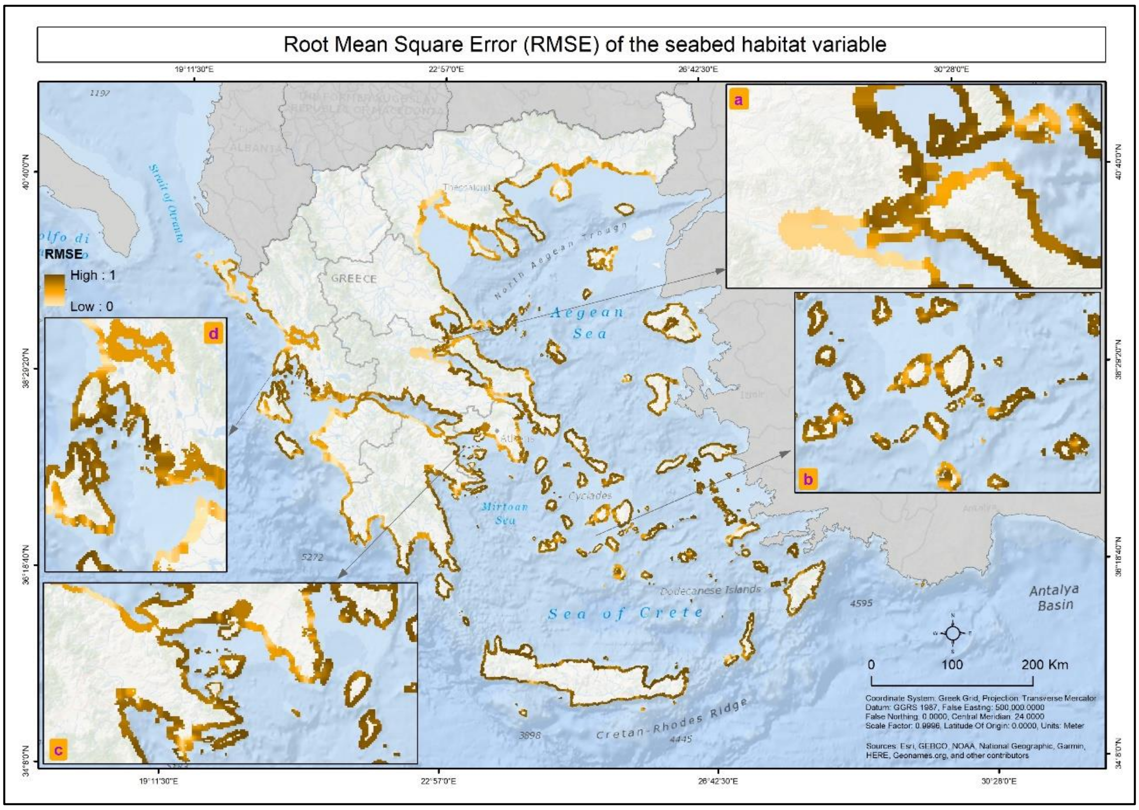


Figure 70: RMSE of seabed habitat variable. Inset maps are the zoomed view of RMSE value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

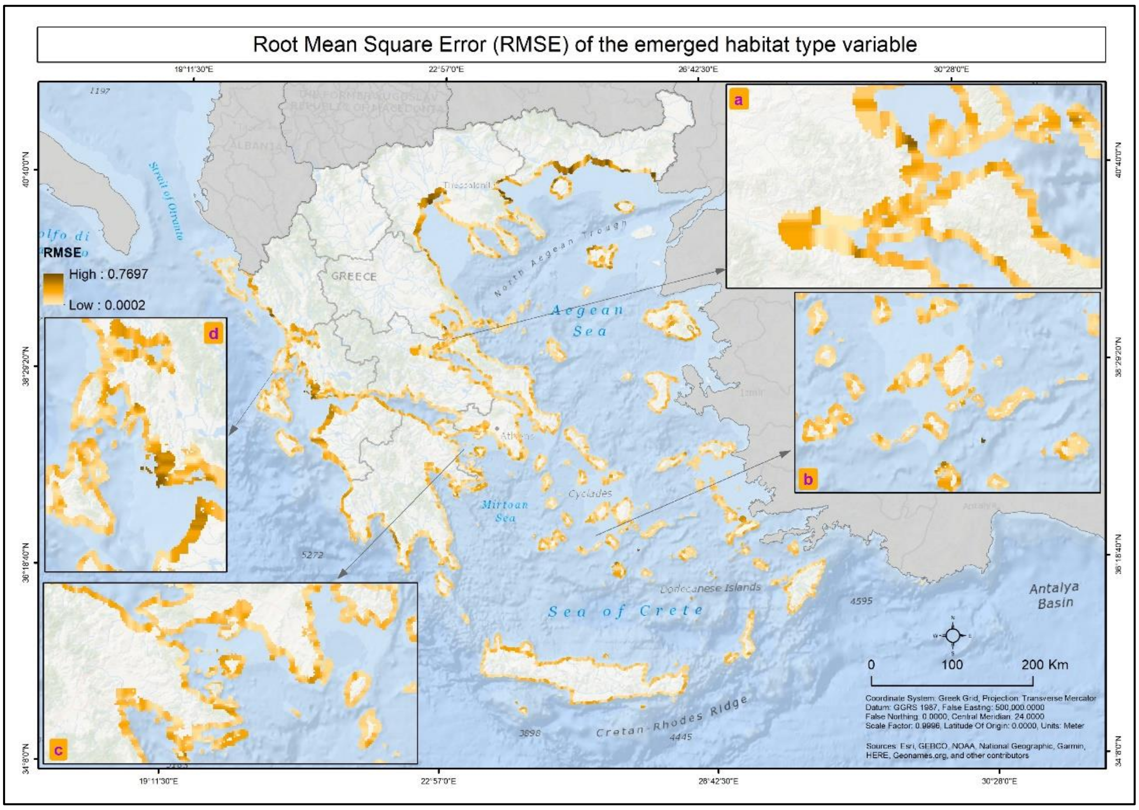


Figure 71: RMSE of emerged habitat variable. Inset maps are the zoomed view of RMSE value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

The values of the variables of the coastal protection exposure indicator have shown less variability than the variables of the coastal protection capacity indicator. The major difference for wave significant height variable is visible with relatively high RMSE value in the coastal zone of the Crete island, Cyclades island, the southeastern coastal zone of Peloponnese, the southern coastal zone of Attica, and both sides of the Gulf of Corinth (Figure 72 and Appendix 6). Strong dissimilarities are seen for the storm surge height variable with relatively high RMSE value in Rhodes, Karpathos, Samos, Ikaria, Lesvos, and Cyclades islands and some coastal areas of Central Macedonia and Eastern Macedonia and Thrace (Figure 73 and Appendix 7). The mean sea level anomaly and tidal amplitude have shown high similarity in both models (Appendix 8 and Appendix 9). A relatively higher RMSE value is seen in the southern coastal zone of Eastern Macedonia and Thrace for the mean sea level variable (Figure 74). For the tidal amplitude variable, a relatively higher RMSE value is seen in the northern coastal zone of Western Greece and Peloponnese and southern coastal zone of Central Greece (Figure 75).

Apart from these, data of the variable of coastal protection demand indicator of both models have a similar pattern (Appendix 10 and Appendix 11). In most of the cases except the population density variable, there is no data of those variables in the calculation unit. If data exists in the calculation unit, it is too low throughout the coastal zone of Greece except for some areas near the capital city Athens and port city Thessaloniki (Figure 76 and Figure 77).

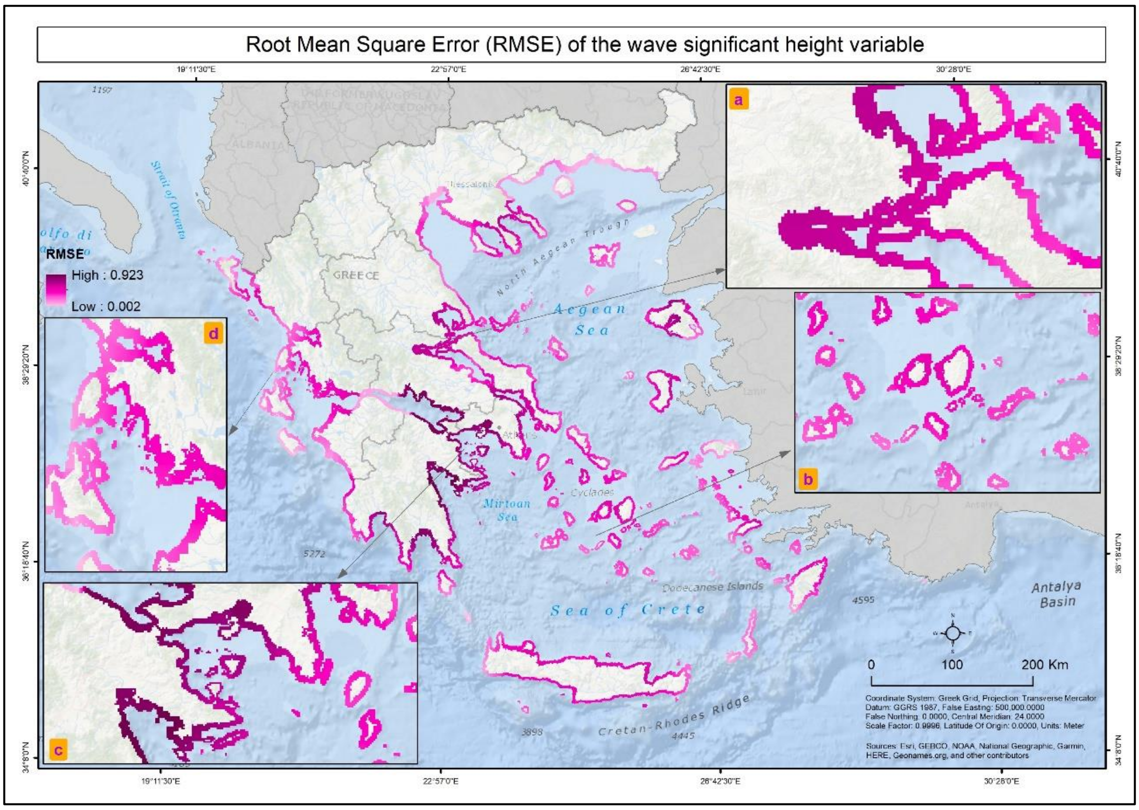


Figure 72: RMSE of wave significant height variable. Inset maps are the zoomed view of RMSE value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands.

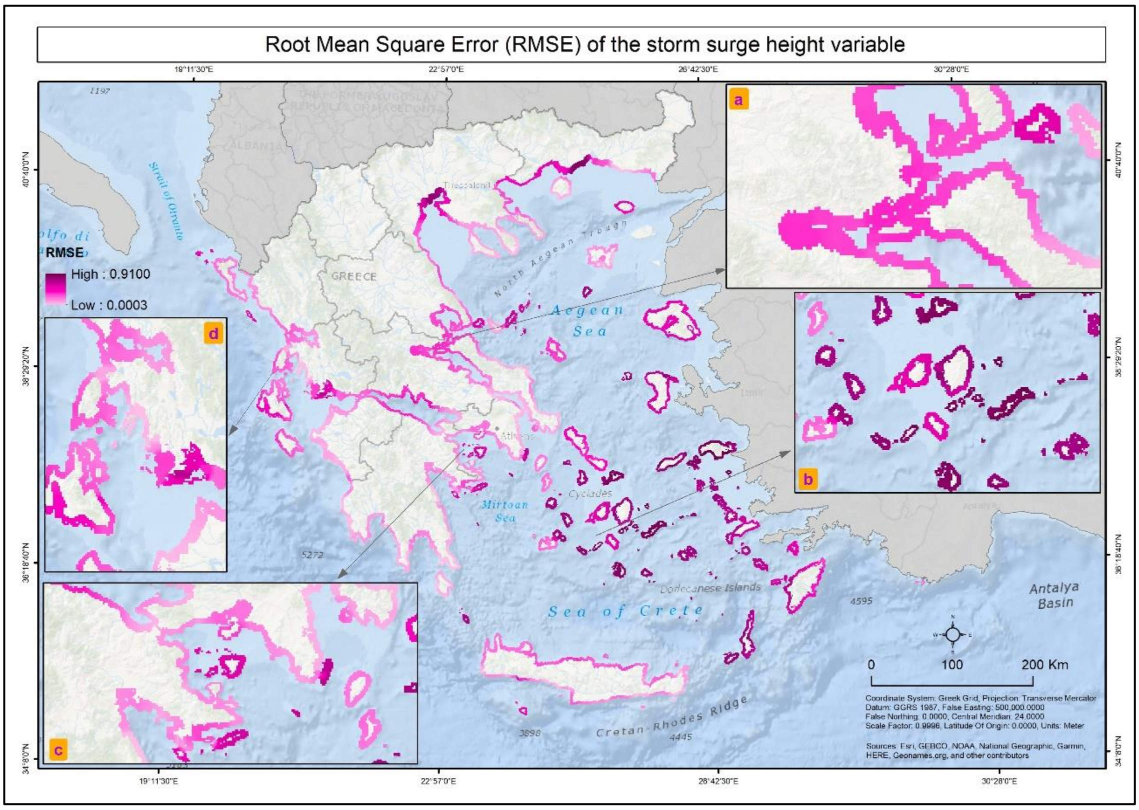


Figure 73: RMSE of storm surge height variable. Inset maps are the zoomed view of RMSE value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

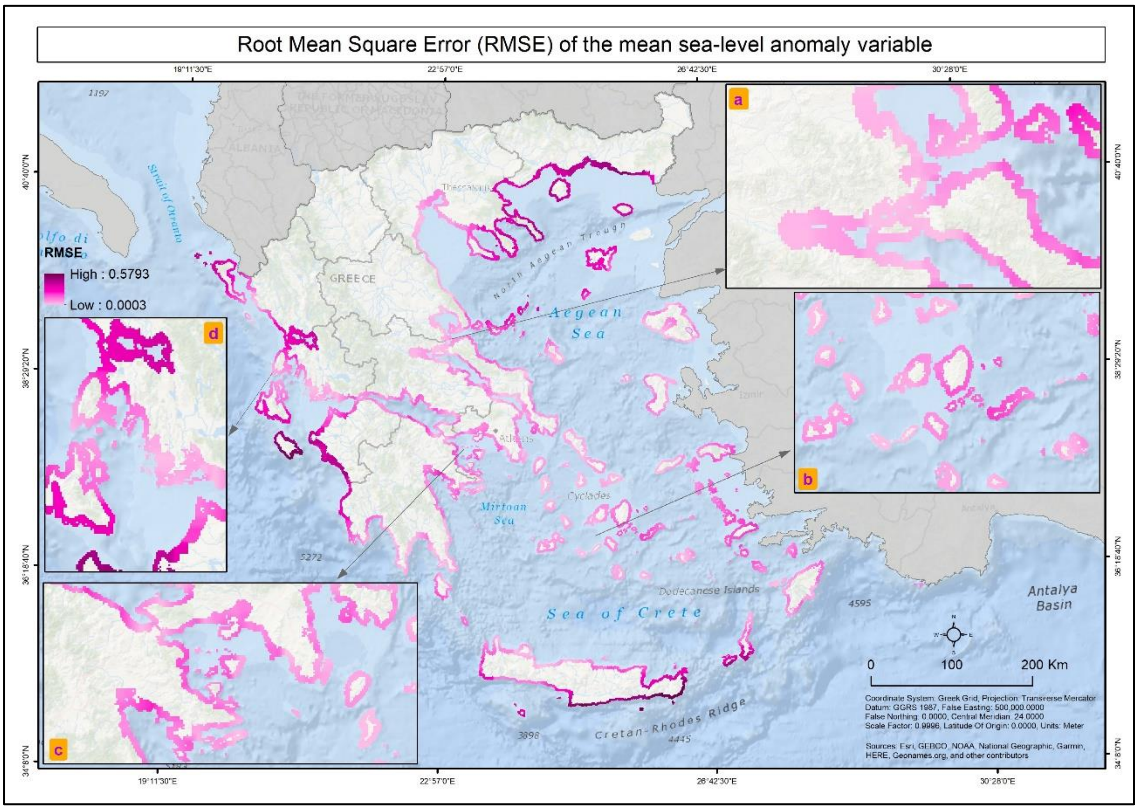


Figure 74: RMSE of mean sea level anomaly variable. Inset maps are the zoomed view of RMSE value variation in the coastal areas of a) Malian Gulf, b) Cyclades islands, c) south of Attica and d) Ionian islands.

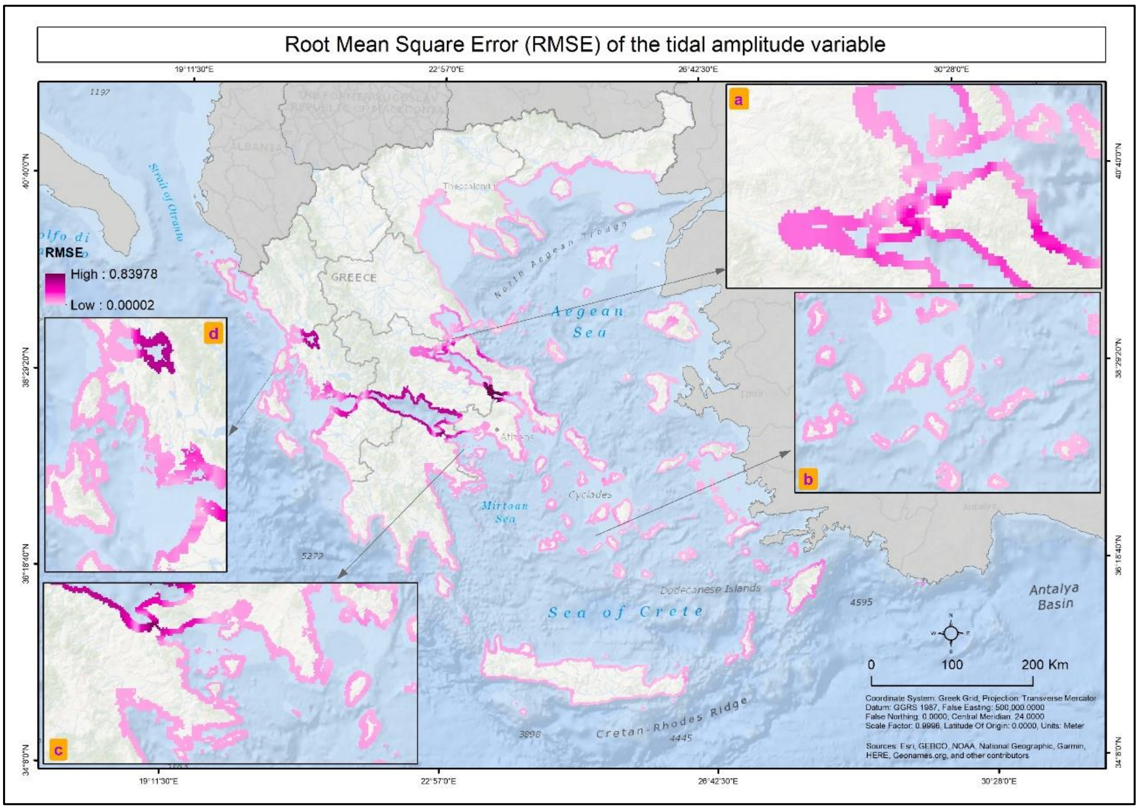


Figure 75: RMSE of tidal amplitude variable. Inset maps are the zoomed view of RMSE value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

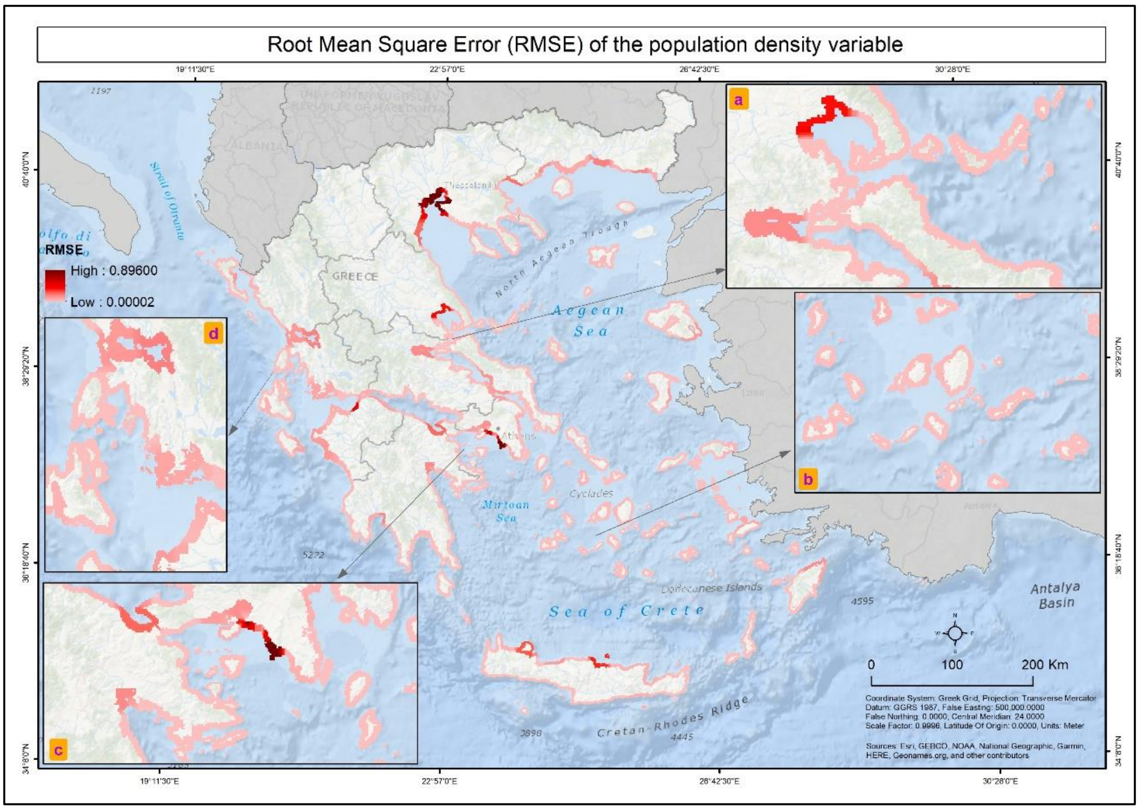


Figure 76: RMSE of population density variable. Inset maps are the zoomed view of RMSE value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

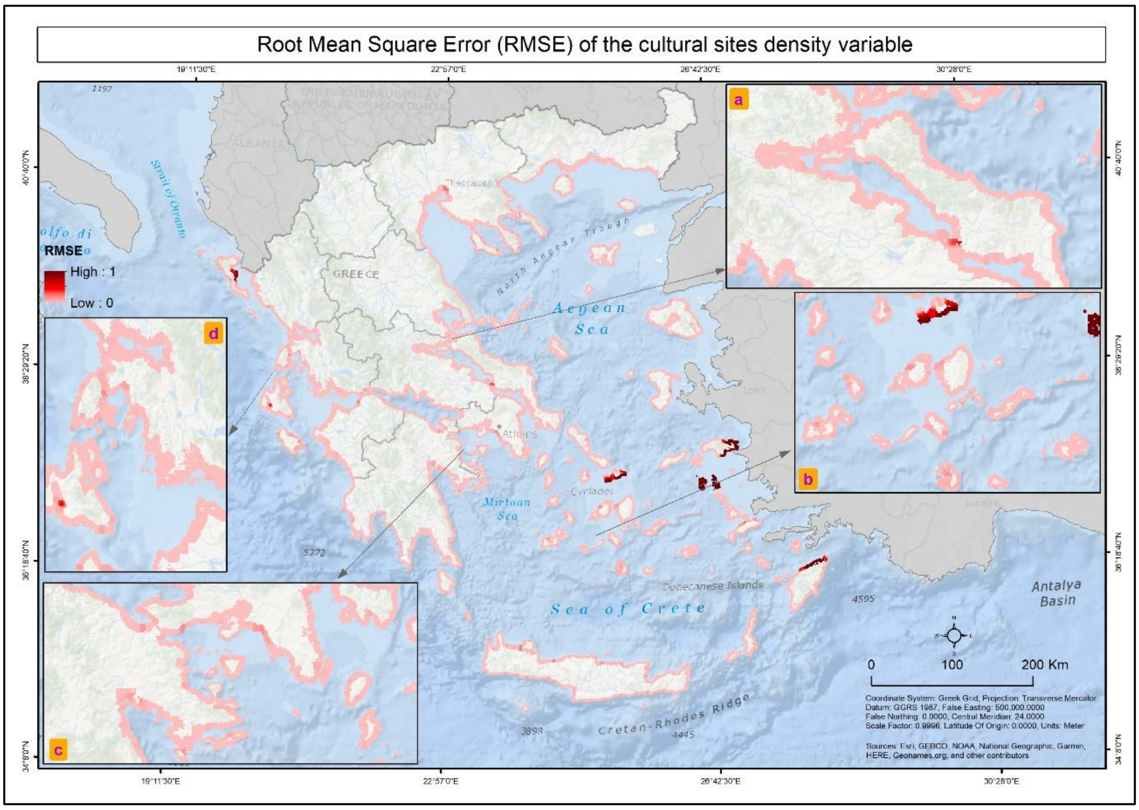


Figure 77: RMSE of cultural sites density variable. Inset maps are the zoomed view of RMSE value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

According to the regional level model, coastal protection capacity is quite high in the northern side of the Gulf of Corinth, near the mount Athos in Central Macedonia, southwestern coastal zone of Crete island, and in Samos and Ikaria island. A medium to high range of coastal protection capacity is visible in the north of Crete island, Rhodes island, Cyclades islands, southeastern coastal zone of Peloponnese, the southern coastal zone of Attica, majority of the coastal area of Chalcis, and in the Ionian islands. Low protection capacity is depicted in the western coastal zone of Western Greece, the northern coastal zone of Peloponnese, the Malian Gulf area, and the southern coastal zone of Central Greece especially near Thessaloniki city (Figure 78).

Medium to high coastal exposure is seen in the coastal zone of the Crete island, Cyclades islands, the southeastern coastal zone of Peloponnese, the southern coastal zone of Attica, and Chalcis. Medium to low coastal exposure is identified in most of the Ionian islands, the western and northern coastal zone of Western Greece and the Peloponnese, the southern and northern coastal zone of Central Greece, the southern and southeastern coastal zone of Thessaly, Central Macedonia and Eastern Macedonia and Thrace area (Figure 79).

Apart from these, throughout the Greek coast low coastal protection demand is observed from the regional level model except high protection demand near Athens and medium to high protection demand in some coastal areas of northern Crete island, northern Peloponnese, and near Thessaloniki city (Figure 80).

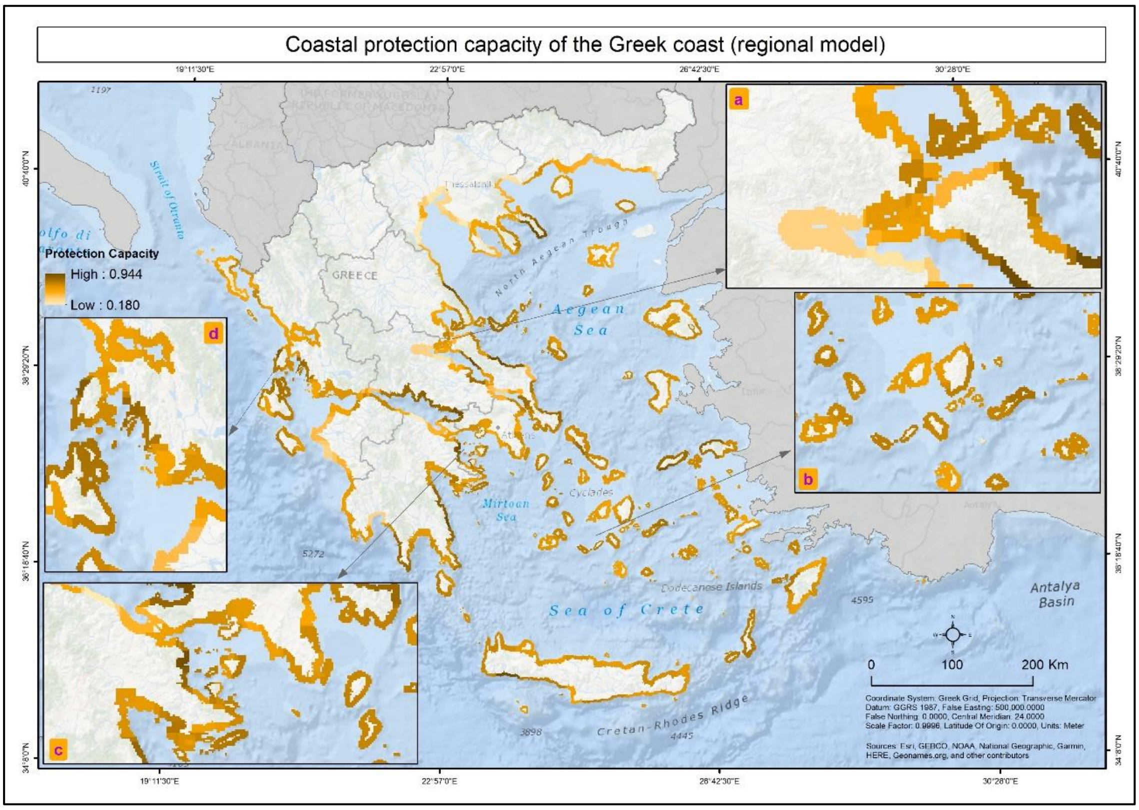


Figure 78: Coastal protection capacity of the Greek coast presented in the regional model. Inset maps are the zoomed view of coastal protection capacity value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and south eastern Peloponnese and d) Ionian islands area.

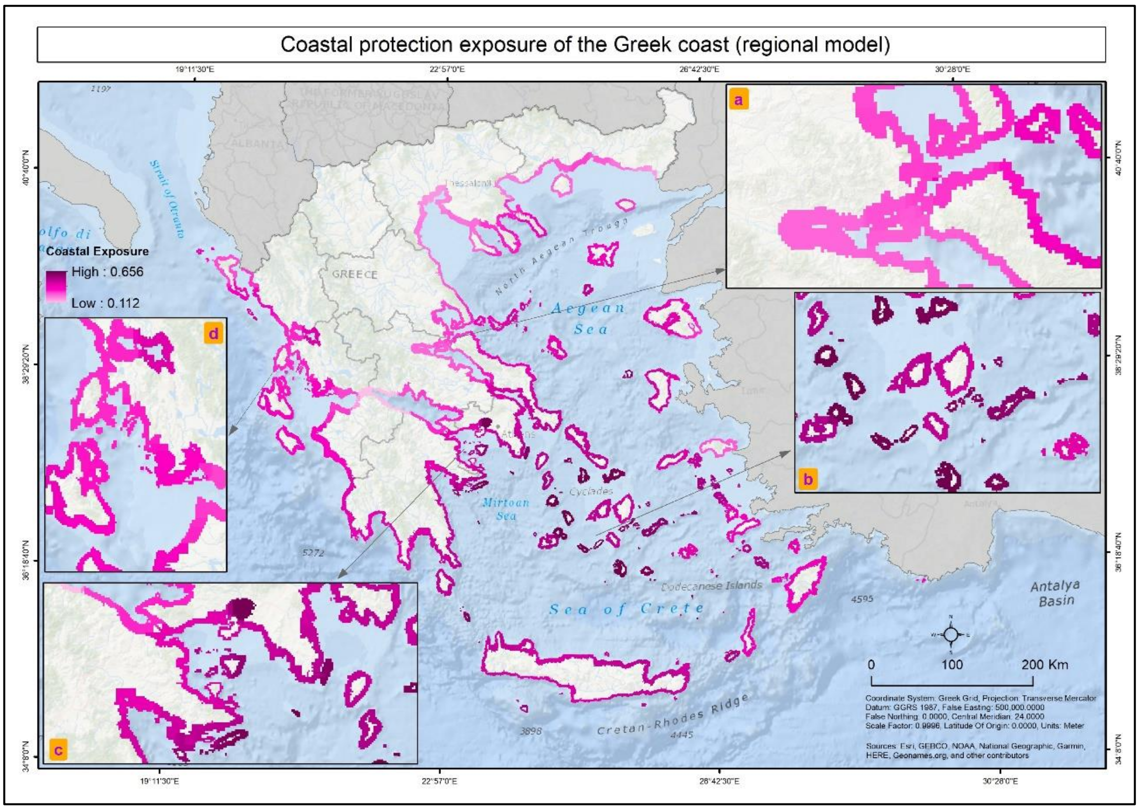


Figure 79: Coastal protection exposure of the Greek coast presented in the regional model. Inset maps are the zoomed view of coastal protection exposure value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and south eastern Peloponnese and d) Ionian islands area.

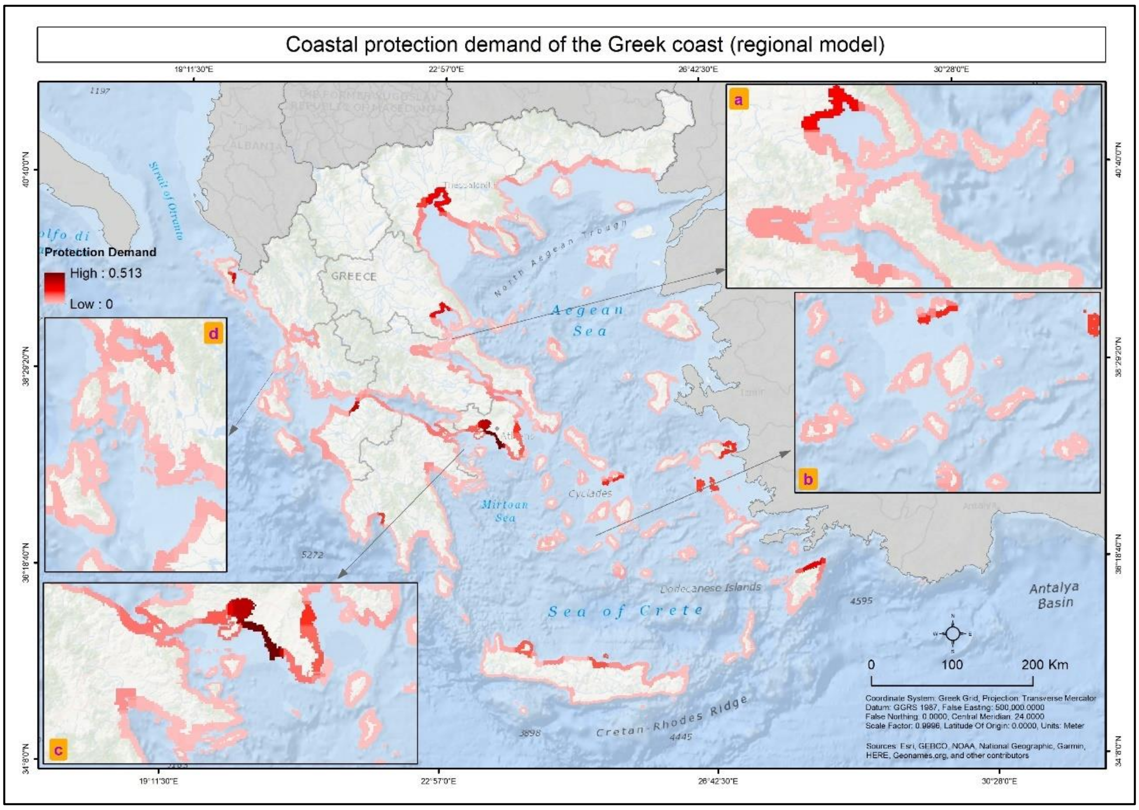
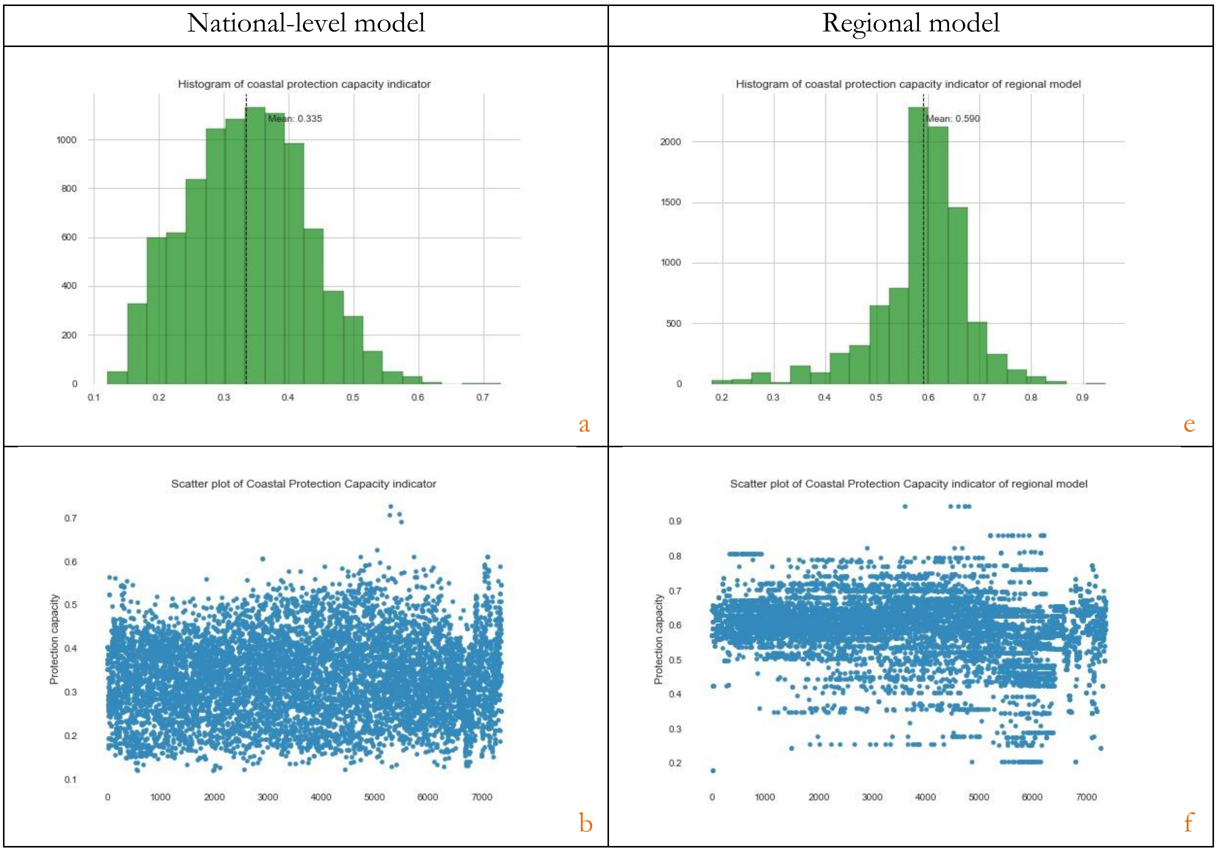


Figure 80: Coastal protection demand of the Greek coast presented in the regional model. Inset maps are the zoomed view of coastal protection demand value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica (near Athens) and d) Ionian islands area.

Data distribution of coastal protection capacity indicator in both the model is quite similar. From Figure 81 it is identifiable that, national-level model data has slight right-skewed distribution whereas in the regional level model a slight left skewness is prominent. The national-level model has less outlier than the regional level model. The mean value in both the models is quite close and also the distribution of data is close to the mean. This distribution pattern indicates that the data of the regional level model has a relatively wider distribution than the national level model.

Histogram of coastal protection exposure indicator of both models suggest that its data has a bimodal distribution, but from the Q-Q plot of regional-level data a right-skewed distribution is identifiable. Q-Q plot of national-level model confirms the bimodal distribution for coastal protection exposure indicator. Both data are free from the outlier, but regional level data is closer to the mean value than the national level data (Figure 82) which also indicates that the data distribution for the national level model is wider than the regional level model.

Due to the lack of value without zero, the distribution of coastal protection demand indicators is not clear. From histogram and scatter plot no concrete decision can be made about its distribution but the Q-Q plot suggest that national-level data has right skewness whereas regional level data has slight left skewness. Both the model data have a very high range of outlier which indicates irregular distribution of data (Figure 83).



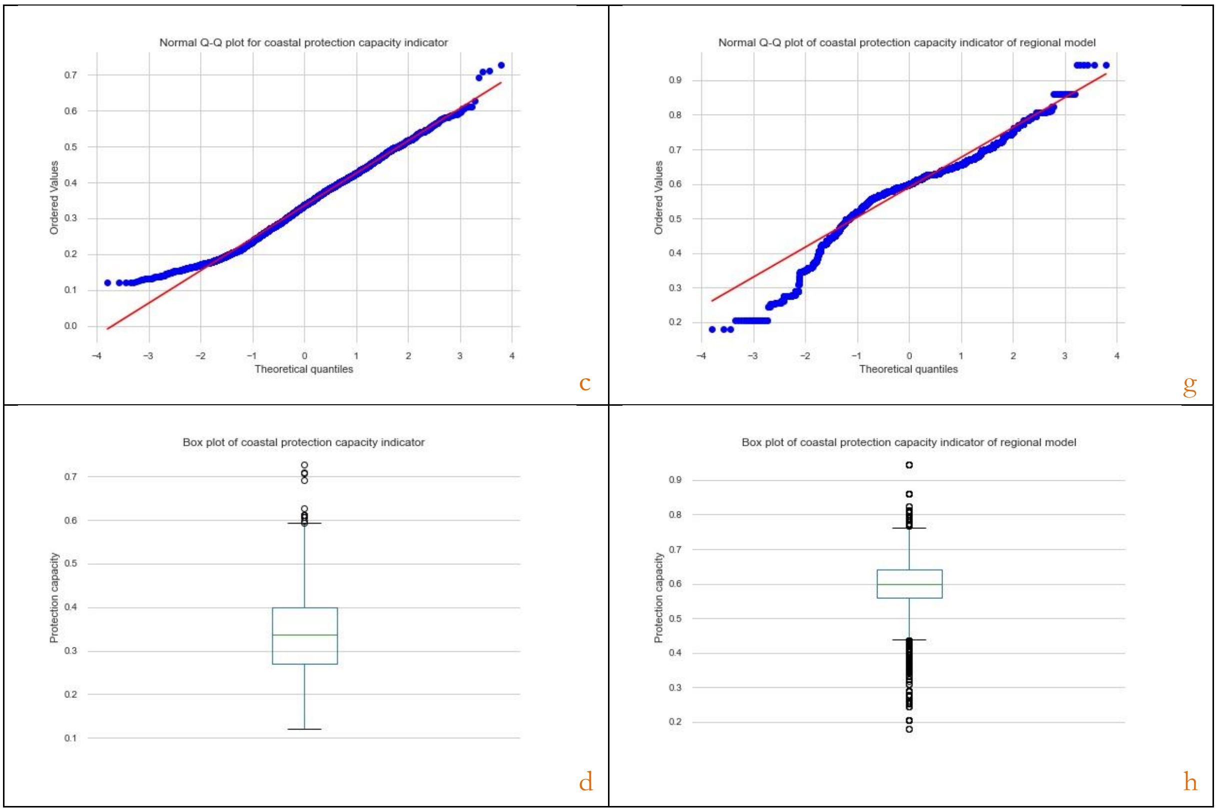


Figure 81: Exploratory data analysis of coastal protection capacity indicator in both models. Histograms (a and e) and Q-Q plots (c and g) of coastal protection capacity indicator of both models suggest that, data variation of this indicator in national level mode has slight right-skewness and in regional level model more left-skewness is visible. No pattern can be identifiable from scatter plots (b, f). Box plots (d, h) suggests that regional level model has more outlier in data than the national level model.

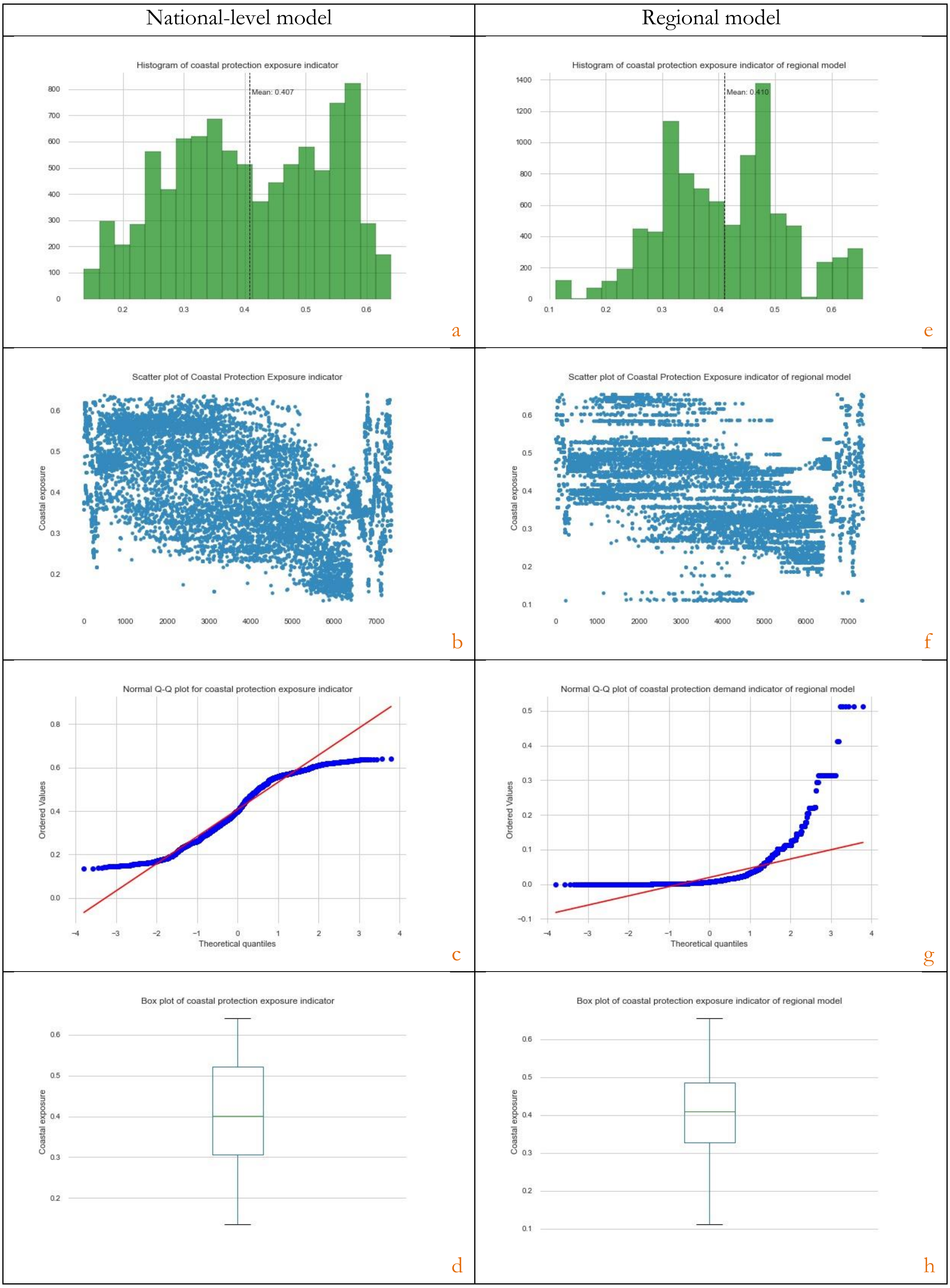


Figure 82: Exploratory data analysis of coastal protection exposure indicator in both models. The bimodal distribution of the data of this indicator is clearly identifiable from histograms (a, e), though Q-Q plots suggest that data of this indicator of regional level model has slight right-skewness (c, g). No clear data distribution pattern is identifiable from scatter plots (b, f). Data of this indicator are outlier free which is visible from the Box plots (d, h).

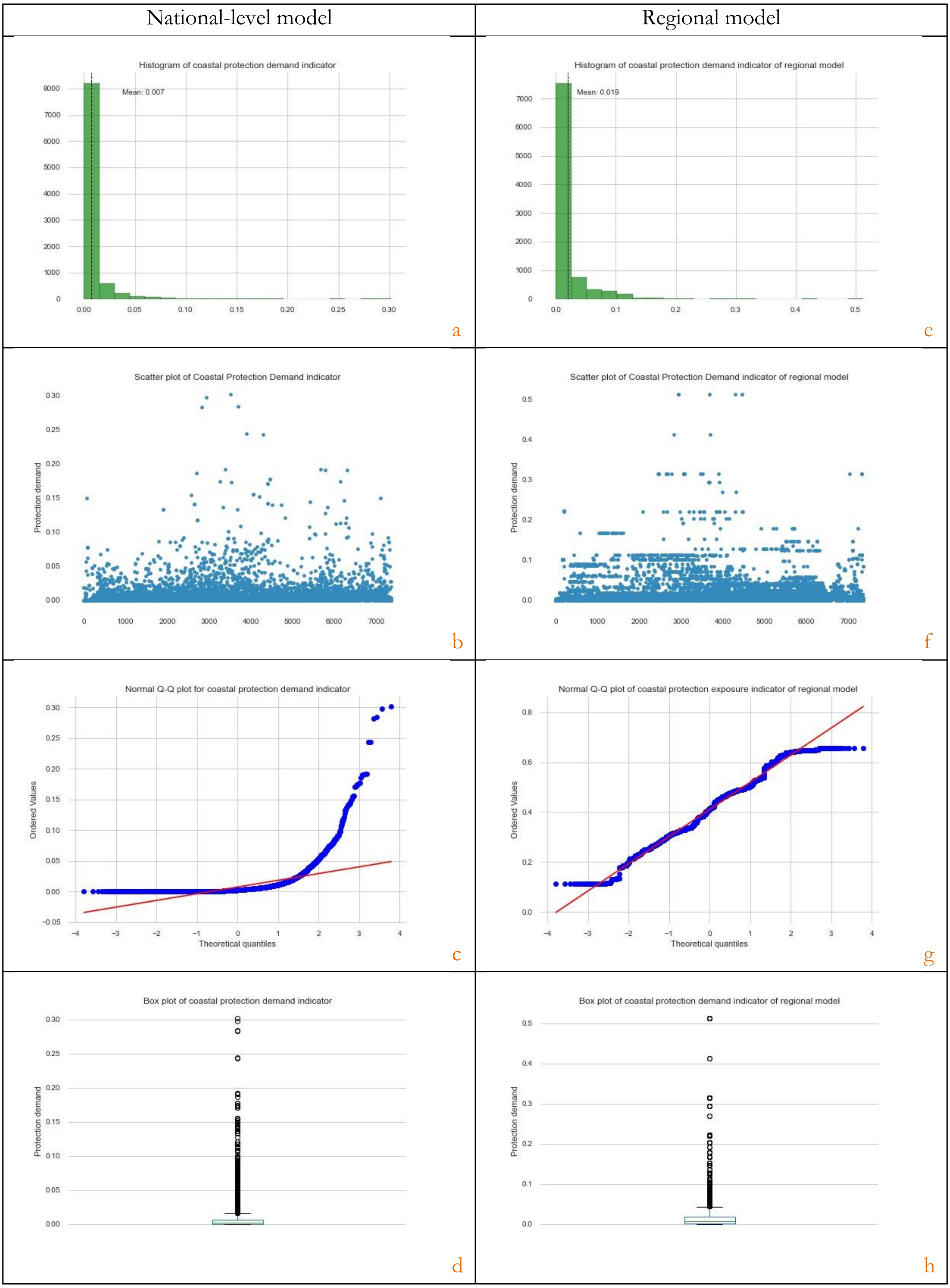


Figure 83: Exploratory data analysis of coastal protection demand indicator in both models. Data distribution of this indicator of both models could not be properly identifiable from histograms (a, e) and scatter plots (b, f). From Q-Q plots a right-skewed distribution of data for national level model and a left-skewed distribution of data for regional level can be identified (c, g). It is also identifiable from boxplots that the data of this indicator is full of outlier (d, h).

In both models, there are some coastal areas where similar coastal protection capacity can be seen, and some areas also depict high discrepancy in terms of coastal protection. High similarity in coastal protection capacity can be seen in the southeastern coastal zone of central Macedonia especially near Thessaloniki city (Figure 84). The high discrepancy with high RMSE value can be seen near the Gulf of Patras, the northern coastal zone of Western Greece, the southern and southeastern coastal zone of Peloponnese, some northern and southern coastal areas of Crete island, the eastern coastal zone of Rhodes, Samos and Ikaria islands, most of the areas of Lesvos island and near mount Athos (Figure 84 and Figure 85). Medium discrepancy or medium similarities in coastal protection can be observed in the coastal areas of Attica, south of Chalcis, Cyclades islands, the southern coastal zone of Eastern Macedonia and Thrace, and in the Ionian islands region (Figure 84 and Figure 85).

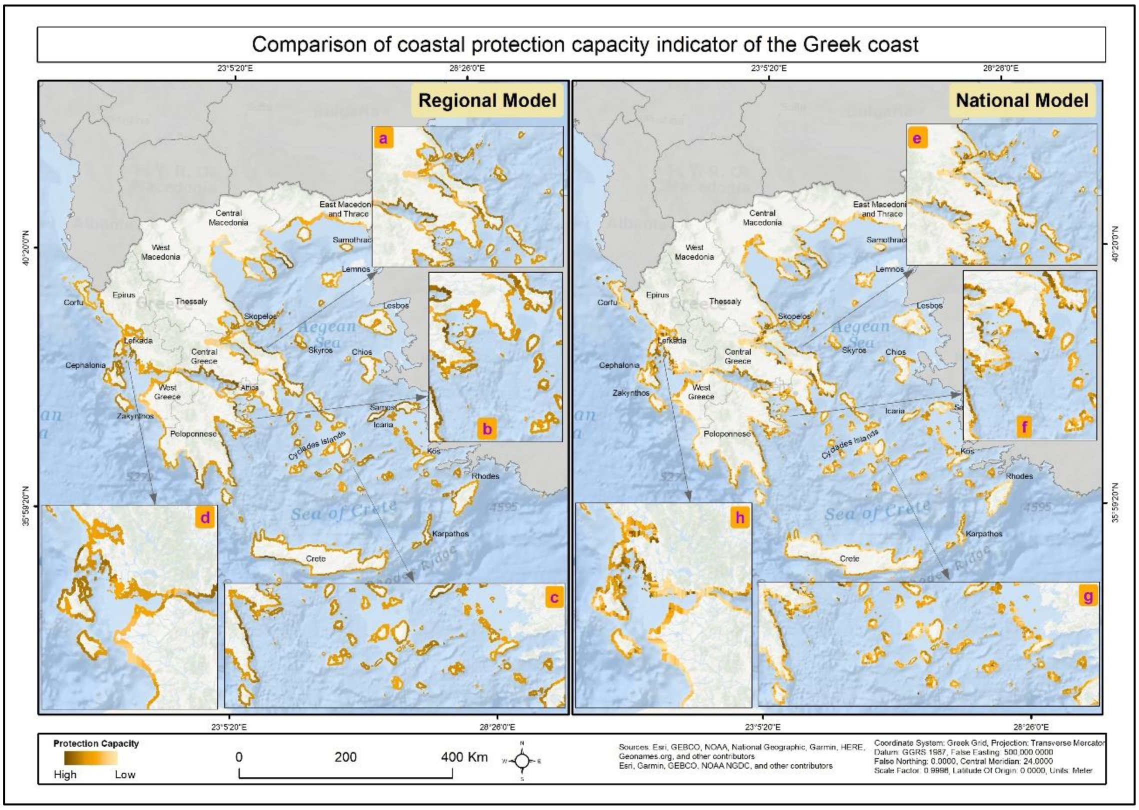


Figure 84: Comparison of coastal protection capacity between regional and national level model. Inset maps are the zoomed view of coastal protection capacity value variation from regional and national model in the coastal areas of Central Greece and Chalcis (a, e), southern Attica and south eastern Peloponnese (b, f), Cyclades islands (c, g), northwestern Western Greece and Ionian islands (d, h).

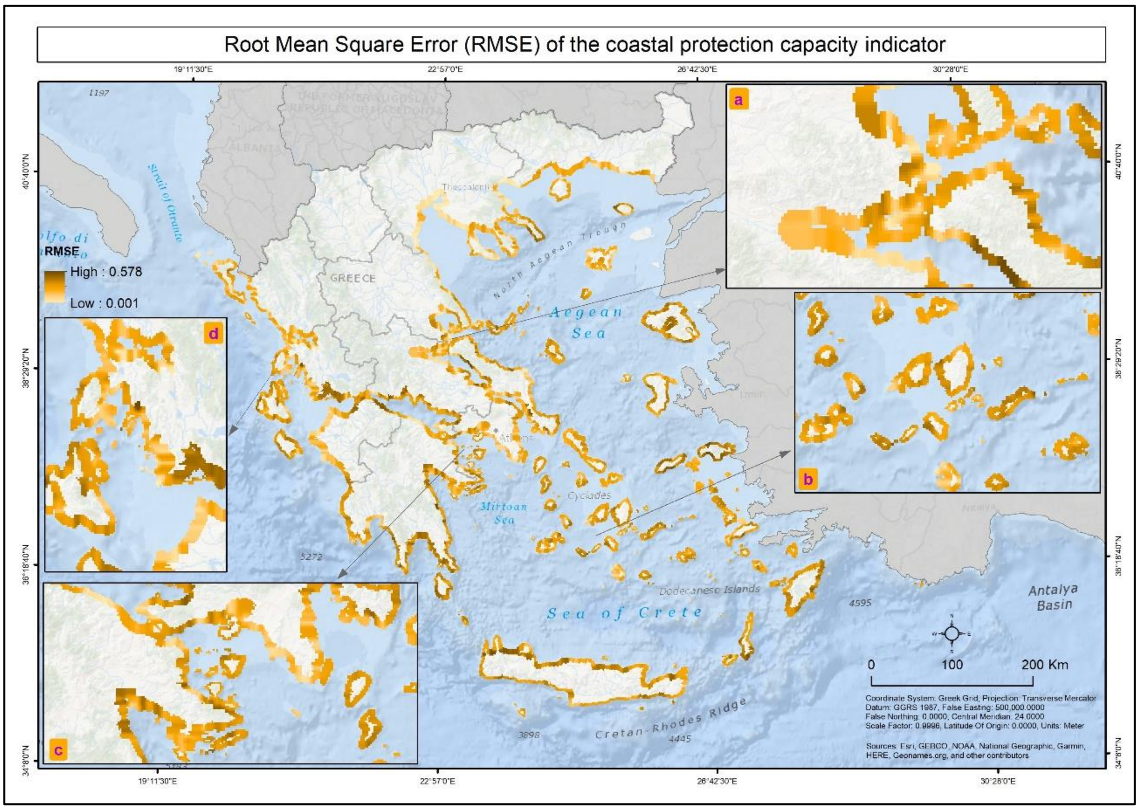


Figure 85: RMSE of coastal protection capacity indicator. Inset maps are the zoomed view of RMSE value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

In the case of the coastal protection exposure indicator, a continuous pattern is visible. The high discrepancy with high RMSE value is seen in the Gulf areas, especially in the Ambracian Gulf, Gulf of Patras, both sides of Gulf of Corinth, near Maliakos and Pagasetic Gulf, and southern part of Central Macedonia and Eastern Macedonia and Thrace (Figure 86 and Figure 87). Some small islands such as Samos and islands situated in the south of Attica, and the southern coastal zone of Rhodes have also a high level of discrepancy in both the model (Figure 86 and Figure 87). High similarity with low RMSE value in coastal exposure can be seen in the northern coastal zone of Crete island, Cyclades islands, the northern coastal zone of Chalcis, and the majority of the Ionian islands (Figure 86 and Figure 87). A medium similarity or discrepancy can be seen in the southern coastal zone of Crete island, the southern and western coastal zone of Peloponnese, the western and northern coastal zone of Western Greece, and the eastern coastal zone of Thessaly (Figure 86 and Figure 87).

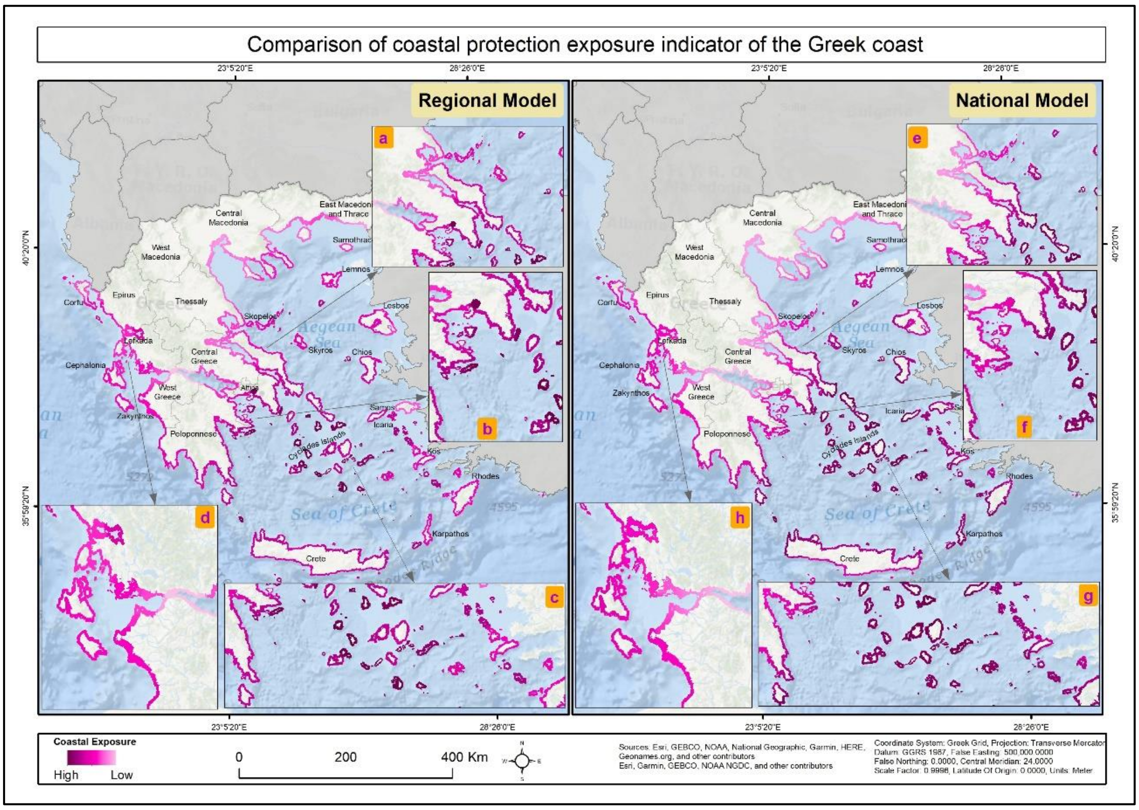


Figure 86: Comparison of coastal exposure between regional and national level model. Inset maps are the zoomed view of coastal protection exposure value variation from regional and national model in the coastal areas of Central Greece and Chalcis (a, e), southern Attica and south eastern Peloponnese (b, f), Cyclades islands (c, g), northwestern Western Greece and Ionian islands (d, h).

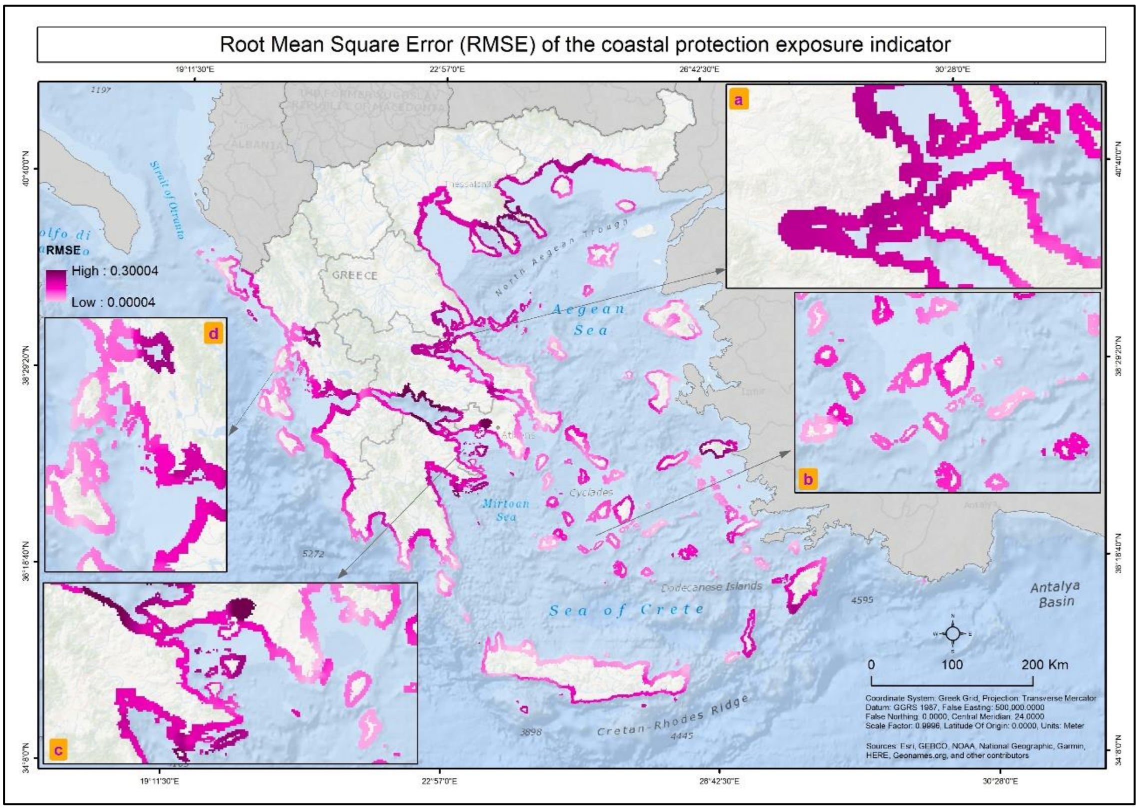


Figure 87: RMSE of coastal protection exposure indicator. Inset maps are the zoomed view of RMSE value

variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

Both the models showed high similarity for coastal protection demand indicator throughout the Greek coast (Figure 88 and Figure 89). Some dissimilarities can be identified in the southern coastal zone of Attica and Central Greece, the northern coastal zone of Rhodes island, and the eastern coastal zone of Samos island (Figure 88 and Figure 89). This discrepancy occurred due to the difference in the extent of the calculation units in both models. In the regional level model, the size of the calculation units was larger than the national level model, which showed a high demand over a large area, whereas that demand is actually for a smaller area which is more accurately represented in the national level model. (Figure 88).

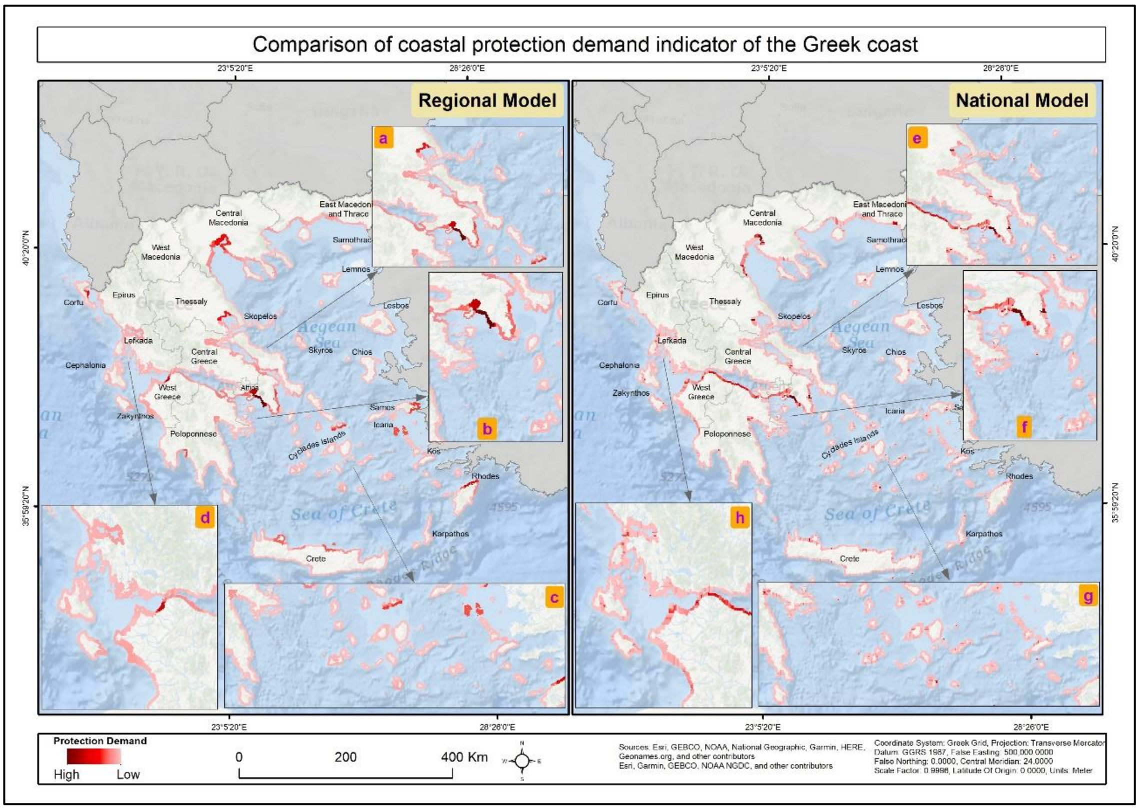


Figure 88: Comparison of coastal protection demand between regional and national level model. Inset maps are the zoomed view of coastal protection demand value variation from regional and national model in the coastal areas of Central Greece and Chalcis (a, e), southern Attica and south eastern Peloponnese (b, f), Cyclades islands (c, g), northwestern Western Greece and Ionian islands (d, h).

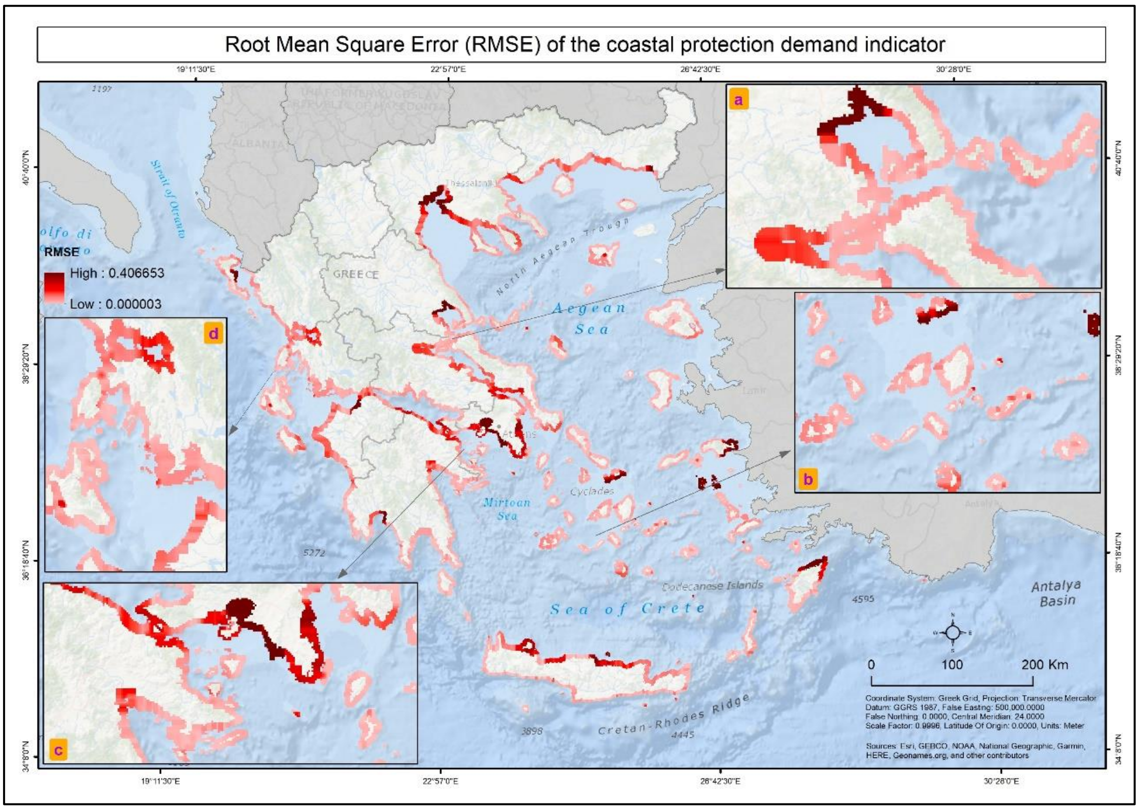


Figure 89: RMSE of coastal protection demand indicator. Inset maps are the zoomed view of RMSE value variation in the coastal areas of a) Malian Gulf and north of Chalcis, b) Cyclades islands, c) south of Attica and d) Ionian islands area.

5. DISCUSSION

5.1. Indicators, variables and expert opinion

In this study, coastal protection of the Greek coast has been assessed through coastal protection capacity, coastal protection exposure, and coastal protection demand indicators. 20 variables have been selected to assess these indicators among which slope, geomorphology, emerged habitat, seabed habitat and sediment accretion rate have been selected for coastal protection capacity indicator. These selected variables have shown variation in terms of values along the Greek coast. Moreover, a variation is also observed in terms of their protection capacity which has been expressed through the associated weightage of the variables assigned by the experts. A high weighted geomorphology value has been seen in the southern part of Crete island, the southeastern part of Peloponnese, and the northeastern part of Chalcis as this area is either dominated by 'Rock/hard cliffs' or 'Rock/hard cliffs (few erosion)' geomorphology types. According to experts, this type of geomorphology has higher protection capacity which is also evident by the work of Tragaki et al., (2018), where they identified that the southern part of Peloponnese is comprised of Rock or cliff which caused less vulnerability of that area. On the other hand, the northwestern part of Western Greece and Peloponnese has a relatively low weighted value of geomorphology as the main geomorphology types of these areas are 'developed beaches' or 'soft strands' which have been identified with relatively low protection capacity by the experts. According to the work of Tragaki et al., (2018) these areas of Peloponnese and Western Greece are more vulnerable in terms of coastal erosion. Similarly, the research work of Karymbalis et al., (2012) in the northern Peloponnese area shows that the presence of Cliff resulted in low sensitivity to vulnerability.

In this study higher slope value contributed to higher coastal protection. In the southern coastal zone of Central Greece, a higher slope value is visible which resulted in comparatively higher coastal protection of that area (Figure 43 and Figure 63). A similar pattern is also seen for the northern coastal zone of Peloponnese where most of the area has a relatively low slope value with some exception. Those exceptional areas of the northern coastal zone of Peloponnese with relatively high slope value resulted in medium to high coastal protection. These finding matches with the findings of Karymbalis et al., (2012) where they identified that area between Psathopyrgos and Lampiri of northern Peloponnese has relatively higher steepness which resulted in less sensitivity to vulnerability in terms of sea-level rise.

Greek coast has a very diversified natural landscape. Most of the areas which have a higher weighted value of emerged habitat such as the eastern part of Cephalonia, the southeastern part of Central Greece, the southern part of Attica, and the area near Mount Athos are covered with Forest and/or Scrub and Herbaceous vegetation which has relatively higher protection capacity according to the experts. Whereas the low weighted value of emerged habitat is seen in Corfu island and western part of Pagasetic Gulf which are either covered by agricultural land and/or arable land and/or fruit trees.

Throughout the Greek coast, very low weighted values of seabed habitat have been observed. According to experts, 'Seagrass meadows' has a higher protection capacity, but its quantity within the coastal zone is very minimal which is one of the reasons to have a very low weighted value of seabed habitat along the coast. Those areas which have a relatively high density of 'Seagrass meadows' such as the western part of Western Greece, the southern part of Attica, Sporades islands have a higher weighted value of seabed habitat (Figure 45) and a relatively high to medium coastal protection capacity is seen in those areas (Figure 63).

Sedimentation has a positive impact on coastal protection capacity, but the overall rate of sediment accretion in the Greek coast is less than the erosion rate (Xeidakis & Delimani, 2002, Synolakis, Kalligeris, Foteinis, & Voukouvalas, 2008). Moreover, the data used for the sediment accretion rate variable in this study is not continuous and does not resemble the situation of the entire coast. Due to lack of proper data, the real scenario of sedimentation could not be incorporated properly in this study which ultimately hindered proper assessment and mapping of coastal protection. Having said that, higher sedimentation is seen in southern part of Central Greece especially near Thessaloniki city where overall medium protection capacity has been observed (Figure 47 and Figure 63).

Due to the lack of relevant work related to the influence of coastal vegetation, seabed habitat or sediment accretion rate on coastal protection of Greece, findings of this research work could not be validated properly.

The values of the variables of the coastal protection exposure indicator have shown quite a similar pattern in terms of their distribution. In most cases, the high or low values of these variables have been seen in the same locations of the Greek coast. For instance, wind speed is relatively higher in the southern coastal areas of Greece than in the northern areas of coastal Greece (Figure 52) which is also evident from the study of Vagenas, Anagnostopoulou, & Tolika, (2017). Similarly, the values of the storm surge height, sea level rise and wave height have also been seen higher in the southern coastal areas than the northern coastal areas of Greece (Figure 48, Figure 49 and Figure 50) which support the study of Krestenitis, Makris, & Galiatsatou, (2018). The findings related to wave significant height by Tragaki et al., (2018) matches with the findings of this research work, where relatively low wave significant height has been identified in the northern coastal zone of Peloponnese which caused low vulnerability or exposure of that area in both studies. Following a similar pattern, a relatively strong current and high seawater temperature have been observed in the southern coastal areas than the northern coastal area of Greece (Figure 53, Figure 54, and Figure 55). Only the tidal amplitude variable showed a different pattern where relatively low tidal amplitude has been seen in the southern coastal areas than the northern coastal areas of Greece. Due to having a similar pattern for most of the variables, the outcome of the coastal protection exposure indicator was continuous with gradual changes of exposure from south to north of coastal Greece (Figure 64).

The coastal protection demand indicator has been assessed through the population, settlement, transport network, port, cultural sites, ecologically important sites, and mineral extraction sites density. Though population density is relatively higher in the coastal areas of Greece (Mourmouris et al., 2006), the distribution of density is not necessarily the same throughout the coastal zone (Figure 56). Polyzos & Tsiotas, (2012) suggest that the greatest concentration of population is visible in those coastal areas where the coastline is relatively less open to the sea and attributed with physical protection. This statement is quite similar to the findings of this research. Though the population density is high near the coast, Figure 19 and Figure 56 suggests that the main concentration of population density is visible near big cities such as Athens and Thessaloniki which have both physical as well as man-made protection capacity and the rest of the coast has a very low population density. The same statement is valid for settlement density pattern where higher density is visible in southern Attica and near Thessaloniki city (Figure 57). On the other hand, throughout Greece, a well-developed transport network can be seen which is also visible in the coastal zone. Despite having a good transport network in most of the coastal areas, a wide variation in transport network density pattern has been seen throughout the Greek coast. As in this study, the density of any variable has been calculated with respect to the calculation units, the variation of transport network density has been occurred due to the size differences of calculation units. From Figure 59 it can be seen that the northern side of Peloponnese has a higher transport network density than the southern Attica especially Athens, which is caused by the relatively large size of calculation units in the southern Attica than the northern Peloponnese. Moreover, most of the cultural sites that have been incorporated in this study such as 'archaeological site', 'camp site' 'museum', and 'monument' etc. are situated in inland. Cultural sites which are situated in the sea or very close to the sea could not be incorporated in this study due to lack of data, which caused an incompleteness in protection demand from the cultural site perspective. The same situation has been observed for the ecological sites also. Furthermore, most of the mineral extraction sites of Greece are situated in Western Macedonia and very few sites can be seen in the coastal zone (Melfos & Voudouris, 2012). Therefore, very low mineral extraction site density has been observed in the coastal zone. On the other hand, though the major ports are situated in the coastal areas, the port area density throughout the coastal zone is very low as the distribution of these ports are confined within some selected areas. Very low density of cultural sites, ecologically important sites, mineral extraction sites and port area density have influenced to generate low protection demand to the Greek coast. Overall, population density along with settlement and transportation network density variables have played the main role in generating coastal protection demand in the Greek coast.

5.2. Modelling coastal protection at the national level

Throughout the Greek coastal zone, variation can be seen in coastal protection capacity, coastal protection exposure, and coastal protection demand due to the variation of the values of the associated variables and their assigned weights. In terms of coastal protection capacity, relatively high protection capacity is present in the coastal areas of southeastern Peloponnese, the southern portion of Central Greece, northeastern and southwestern part of Chalcis, and the southwestern portion of Crete island due to the combination of high weighted values of geomorphology, emerged habitat variables and high mean values of slope variable. Tragaki et al., (2018) in their study also found that southeastern Peloponnese is less vulnerable due to the influence of Geomorphology and slope variable. The high protection capacity in the eastern portion of Thessaly has been observed because of high mean values of sediment accretion rate variable along with high mean values of slope and high weighted values geomorphology, and emerged habitat variables. Despite having low weighted values of seabed habitat variable, high to medium coastal protection capacity has been observed in most of the islands of Cyclades islands, some islands of Ionian islands, the northeastern part of Chalcis, the southern part of Attica, and the southeastern part of Crete island due to the high to medium range of values of the slope, geomorphology and emerged habitat variables. Even though having high to medium range of values of sediment accretion rate variable, medium to low protection capacity has been observed in Central Macedonia and Eastern Macedonia, and Thrace due to medium to low values of geomorphology, emerged habitat, seabed habitat and slope variables. On the other hand, the northern and western part of Western Greece and Peloponnese have low to medium protection capacity due to the low values of the slope, geomorphology, and seabed habitat variables which is also evident from the work of Tragaki et al., (2018). From the above discussion, it can be said that the geomorphology variable has a relatively higher influence on the overall pattern of coastal protection capacity of the Greek coast but unfortunately which could not be validated due to a lack of relevant research work.

High coastal exposure has been observed in the southern and southeastern part of Attica, southeastern and southwestern part of Chalcis, the northern part of Crete island, all the small islands of the Sea of Crete, Mirtoan Sea and Aegean sea such as Cyclades islands, Karpathos, Rhodes, Samos, Icaria and Chios islands due to the quite high values of mean wind speed, wave significant height, sea level height, storm surge height and medium range of mean values of seawater temperature and eastward and northward ocean current. These findings match partially with the works of Kontogianni et al., (2014) where medium to high coastal vulnerability has been identified in the northwestern coastal zone of Western Greece, the northern coastal zone of Crete islands, and some islands of Cyclades islands in terms of sea-level rise only. In the western part of Pagasetic and north Euboean Gulf, and both sides of the Gulf of Corinth and Gulf of Patras low coastal exposure has been seen due to the low values of wave height, sea level height, wind speed, eastward and northward ocean current and medium to low values of storm surge height and seawater temperature. A medium to low values of storm surge height, sea level height, ocean current, wind speed, and wave height, and medium values of seawater temperature is responsible for medium to low coastal exposure in the Ionian islands, the western part of Western Greece and Peloponnese, and Sporades islands.

The entire Greek coast has very low protection demand which is also evident from the regional level study by Liquete et al., (2013b). High protection demand is seen in the densely populated or built-up areas such as in Attica especially near Athens, in Central Macedonia especially near Thessaloniki city. Demand from these areas is generated due to their high population density, high settlement density, and medium to high transport network density. Medium protection demand has been seen in the northern part of Peloponnese and Western Greece due to high transport network density and medium population and settlement density.

Though some areas such as some islands of Ionian islands, some areas of the western part of Western Greece, some areas in northern Crete island, some Dodecanese islands such as Kos, and some southern areas of Eastern Macedonia and Thrace have relatively higher population density than the rest of the coastal areas of Greece except Attica and Thessaloniki, the overall protection demand on those areas are within medium to low range due to medium to low values of the transport network and settlement density and very low values or no values of cultural, port or mineral extraction site density.

Relatively higher coastal protection service flow is observed in those areas where relatively high protection capacity and low exposure is present. Most of the benefit has been received to those areas where service flow is high. Despite having high protection demand, the southern part of Attica has very low benefits due to the very low service flow in that area. Whereas in Thessaloniki medium to high benefit has been seen due to medium to high flow of service.

Due to lack of relevant research works, the overall pattern of coastal protection exposure, coastal protection demand, coastal protection service flow and benefit that has been found in this study could not be validated.

5.3. Comparison of regional and national level model

In the regional level model, high protection capacity is influenced by higher geomorphology and slope value (Liquete et al., 2013b). On the other hand, low coastal exposure in the Greek coast in the regional level model is influenced by low values of storm surge height and wave height, and similar to the national level model high coastal protection demand is influenced by high population density (Liquete et al., 2013b). The pattern of coastal protection exposure and protection demand throughout the Greek coast is quite similar in both models. On the contrary, the pattern of coastal protection capacity indicator in the national-level model differs highly than the regional model. The main reason behind this difference might be attributed to the difference in the size of the calculation unit and the nature of the data. In the national-level model, a more detailed assessment has been conducted by generating the calculation unit with a length 30 times smaller than the length of the calculation unit of regional level model. Due to smaller size of calculation unit, variation of the variables is well captured in national level model. Moreover, the data of the geomorphology, seabed habitat and emerged habitat variables of coastal protection capacity indicator are discrete in nature and frequent change of values within the coastal zone for those data is clearly observable from Figure 44, Figure 45 and Figure 46. In regional level model those changes of values of those variables has been neutralized due to the presence of heterogeneity in values within large sized calculation unit. Whereas in national level model those changes have been well represented. On the other hand, variables of coastal protection exposure indicator are continuous in nature. Relatively less sudden change of values within coastal zone can be seen for those variables in both models (Appendix 6, Appendix 7, Appendix 8 and Appendix 9). Therefore, the coastal exposure pattern is similar for both the models as the size of the calculation unit does not show any direct influence in overall coastal exposure pattern. Though the data of the variables of coastal protection demand is discrete in nature, the variation in data set was quite minimal in both models. Most of the cases values were agglomerated to a particular area which means that demand for protection is coming only from some particular areas. But variation of demand in those areas in both models is still observed due to the size difference of calculation unit and a more detailed demand is seen in national level model than the regional level model.

Based on the comparative analysis of the two models it can be said that the national-level model has been more successful in incorporating all the minor variation of variables to calculate the three indicators than the regional level model. Therefore more accurate and precise coastal protection scenario has been generated through national level assessment. The coastal protection pattern of the regional level model for a country was too generalized which may mislead the policy decision at the national level. On the contrary, national-level assessment is more representative of the national level biophysical and socio-economic conditions which can provide better insights for national level policy, planning and management issues.

6. CONCLUSION

6.1. Conclusion and outcome of the research

Coastal protection as an ecosystem service at the national level of Greece has been assessed and mapped using three indicators namely, coastal protection capacity, coastal protection exposure, and coastal protection demand for which 13 biophysical and seven socio-economic variables have been selected. Expert opinion played a significant role in assessing the contribution of each variable in coastal protection.

The coastal protection capacity of the Greek coast did not resemble any continuous pattern, but low protection capacity has been observed prominently in the western and northern part of Western Greece and Peloponnese, the northern part of Central Greece, the southern part of Eastern Macedonia and Thrace and some area of northern Crete island. In contrast, relatively high protection capacity has been observed in the eastern coastal part of Thessaly, the northern part of Chalcis and the southern part of Central Greece. A more continuous pattern is seen for coastal protection exposure indicator and it has been identified that small islands such as Cyclades islands, Rhodes, Karpathos, Icaria, Samos islands including the northern part of Crete island and southern part of Attica and Chalcis are the most exposed areas of the Greek coast. The northern coastal areas of Greece such as Central Greece, Central Macedonia, Eastern Macedonia and Thrace and the northern part of Peloponnese and Western Greece are relatively less exposed. On the other hand, the high demand for coastal protection has been seen to be agglomerated only near the major cities such as Athens and Thessaloniki. Due to high protection capacity and low exposure higher service flow has been seen in the southern coastal part of Central Greece, Central Macedonia and Eastern Macedonia and Thrace. A high benefit has also been seen in those areas due to the high service flow. Despite having high demand, southern coastal Attica has very low benefit due to low service flow.

After modelling coastal protection at the national level, a comparison has been made with the regional level model by calculating RMSE. The national-level model showed a more detailed assessment than the regional one and a significant difference has been observed for the coastal protection capacity indicator in both models than the coastal protection exposure and coastal protection demand indicators. This difference occurred due to the size difference of calculation units and the nature of the data.

Comparative analyses of national and regional level models indicate that the national level assessment and mapping process has presented all the minor variations of the biophysical and socio-economic condition of the coastal zone. On the other hand, the regional level model was too simplified to explain a national level condition as it could not incorporate many important variables of the national context in its modelling process. Therefore it can be concluded from the analysis and discussion that the national level assessment can provide better insight into the national policy and planning process than the regional level model.

6.2. Limitations of the research

To map and model coastal protection at the national level, various challenges have been encountered. A brief description of the limitations of this research work is given below:

i. One of the major challenges of this research work was to delineate the coastal zone based on the hydrodynamic and socio-economic conditions of Greece. Due to the intricated coastline of Greece, the presence of different landmasses including islands, and variation of the size of landmasses, a uniform coastal zone could not be drawn throughout the coast of Greece. A set of rules has been developed to delineate the coastal zone by considering the size of landmasses. The criteria that have been followed to delineate the coastal zone could not manage to extract information properly from the coast of very small islands such as islands situated between Samos and Kos as the delineated coastal zone covers the entire landmass of those small islands.

ii. After delineating the coastal zone next challenge was to divide it into suitable calculation units. Though it has been tried to maintain the same length of calculation unit throughout the coastal zone, uniformed calculation unit with the same size could not be managed to draw due to the difference in bathymetry and elevation within the delineated coastal zone. Moreover, the coastline of Greece is not straight rather curved in some areas. The size of the calculation unit on those curved areas was needed to be drawn bigger so that the calculation unit remains perpendicular to the coastline.

iii. Most of the data of selected variables have a very coarse resolution therefore the minor variations of values within the coastal zone could not be captured properly. Moreover, there was some missing data for each variable which has been filled by the data of the adjacent area which may not be representative. This might have impacted the modelling process of the overall coastal protection.

iv. There were a lot of missing data for the socio-economic variables. The population density that has been used for each calculation unit does not necessarily represent the population density of that calculation unit as it has been calculated from the population density of the corresponding municipality. Besides data for settlements, cultural sites, ecologically important sites, transport network density variables were not sufficient which has influenced the assessment of coastal protection demand indicator.

v. Moreover, as this study was conducted at a national scale many local phenomena should have been incorporated for better assessment. Due to the lack of data, some important aspects such as coastal subsidence information, wave action direction, climate change issues, and natural adaptation capacity of the coast could not be included in this study.

vi. The coastal protection that has been assessed and mapped in this study partially represent the actual protection capacity of the coast as this assessment only focused on the natural protection capacity without considering the artificial protection capacity of the coast. Moreover, this study could not incorporate human activity (sand mining, poor design of artificial structure etc.) induced exposure.

vii. Visualizing the detailed outcome was also challenging using a single colour or even multi-colour ramp, as the outcome has been visualized in a single small-scale map for the entire coastal zone. To overcome this, inset zoomed map of some specific location have been included.

viii. RMSE has been calculated to compare the regional and national model, yet the overall comparison was mainly observation-based. A spatial pattern analysis might be able to give more clear evidence on the difference between the two models in the future, but it was beyond the scope and the time frame of this thesis.

ix. Lastly, the outcome of this thesis work could not be validated properly due to the lack of relevant research work which is one of the major limitations of this study.

6.3. Recommendation for the future work

By addressing the limitations of this study including the knowledge and data gaps some aspects have been highlighted below which can improve future works.

i. To properly assess and map the coastal protection at the national level, finer resolution data set should be used. If possible, data from national sources such as national cadastre or oceanographic and meteorological institutes should be incorporated.

ii. The inclusion of more variables and climate change issues can improve the quality of the assessment of coastal protection.

iii. The non-linear response of each variable for coastal protection can be addressed in future work.

iv. To assess the coastal protection demand, detailed information on selected variables should be collected within the delineated coastal zone. More specifically, population density, settlement density, artificial infrastructure, cultural, and ecologically important site information needs to be in higher resolution.

v. A separate study can be conducted by using higher-level statistics to compare the outcomes of the regional and national level model.

vi. Another research initiative can be taken to validate the protection capacity by applying statistical or other modelling approaches.

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APPENDIXES

Appendix 1: Questionnaire for taking expert opinion

Questionnaire for Expert Opinion

Dear Experts,

Thank you for participating in this survey, which is a part of my MSc thesis research on 'Mapping and Modelling Coastal Protection at National Level: A Study on Greece's Coastline' carried out at the faculty of Geoinformation Science and Earth Observation (ITC), University of Twente.

Within this thesis work, coastal protection is calculated through three different indicators namely:

- Coastal protection capacity: the natural potential of the coastal ecosystems to protect the coast against inundation or erosion.
- Coastal exposure: vulnerability of the coast due to climatic and oceanographic conditions; and
- Coastal protection demand: the necessity of protecting the coast to save human lives and resources.

These indicators are assessed by a set of biophysical and socio-economic variables. To fully quantify the indicators (mentioned in the questions of this survey), this survey is being conducted to know the relative contribution of those variables to the indicators of coastal protection, exposure, and protection demand. This comes to validate and complement the work already conducted to quantify those relations through the literature. In this survey you are asked to give weights (on a scale of 1 to 4 where 1 means very low and 4 means very high) to different variables according to their importance in coastal protection, exposure, and protection demand.

Beside this, you are also requested to give weight to different sub-types of geomorphology, seabed habitat and emerged habitat in the same scale (1 to 4) for their contribution in coastal protection capacity indicator.

If you think that, any of these variables is not suitable or is not properly placed under the indicators you can indicate that in the comment section and mention under which indicator it should be placed. In addition to this, if any important variable for these three indicators is missing here you can name it with a proper weight in the comment section.

It should be mentioned that the purpose of this questionnaire survey is purely for research purposes and no personal information of the participants will be circulated or further published.

* Required

1. Name *

2. Affiliation *

3. Email address *

Assigning weight to variables under the indicators

On a scale of 1 to 4, provide weight to the variables where 1 is very low and 4 is very high.

4. **Coastal Protection Capacity Indicator** *

Coastal protection capacity is the natural potential of the coastal ecosystems to protect the coast against inundation or erosion. Following variables have been identified as contributors of coastal protection capacity indicator based on literature review.

Mark only one oval per row.

	1	2	3	4
Geomorphology	⬭	⬭	⬭	⬭
Slope	⬭	⬭	⬭	⬭
Emerged Habitat	⬭	⬭	⬭	⬭
Bathymetry	⬭	⬭	⬭	⬭
Seabed Habitat	⬭	⬭	⬭	⬭
Sediment Accumulation Rate	⬭	⬭	⬭	⬭

5. Comments

6. **Coastal Exposure Indicator** *

Coastal exposure is the vulnerability of the coast due to climatic and oceanographic conditions. Following variables have been identified as contributors of coastal exposure indicator based on literature review.

Mark only one oval per row.

	1	2	3	4
Sea level rise				
Storm surge height				
Wave height				
Tidal range				
Wind Speed				
Eastward Ocean Current				
Northward Ocean Current				
Sea Water Potential Temperature				

7. Comments

8. **Coastal Protection Demand Indicator** *

Coastal protection demand is the necessity of protecting the coast to save human lives and resources. Following variables have been identified as contributors of coastal protection demand indicator based on literature review.

Mark only one oval per row.

	1	2	3	4
Population Density				
Settlements (residential, industrial, commercial)				
Cultural site				
Transportation network (roads, railway)				
Ports (airports, ports)				
Areas of high ecological values				
Mineral extraction site				

9. Comments

Assigning weight to the subtypes of individual variables

On a scale of 1 to 4, provide weight to the subtypes of the variables where 1 is very low and 4 is very high.

10. **Geomorphology subtypes** *

The geomorphology of Greece is broadly composed of the following types. Please provide weight to these types based on their capacity to coastal protection.

Mark only one oval per row.

	1	2	3	4
Rocks and/or cliffs made of hard rocks (little subject to erosion)	⬭	⬭	⬭	⬭
Rocks and/or cliffs with small beaches	⬭	⬭	⬭	⬭
Conglomerates and/or cliffs made of material subject to erosion: presence of rock waste and sediments (sand pebbles on the strand)	⬭	⬭	⬭	⬭
Small beaches separated by rocky capes	⬭	⬭	⬭	⬭
Developed beaches (length of the beach > 1 km) with strands made of coarse sediments: gravels or pebbles	⬭	⬭	⬭	⬭
Developed beaches with sandy strands: fine to coarse sand	⬭	⬭	⬭	⬭
Coastlines made of soft non-cohesive sediments	⬭	⬭	⬭	⬭
Strands made of muddy sediments: "waddens" and intertidal marshes with "slikkes and schorres"	⬭	⬭	⬭	⬭
Harbour areas	⬭	⬭	⬭	⬭
Coastal embankments for construction purposes (e.g. by emplacement of rocks earth etc.)	⬭	⬭	⬭	⬭
Soft strands with "beach rock" on intertidal strands	⬭	⬭	⬭	⬭
Soft strands of heterogeneous category grain size	⬭	⬭	⬭	⬭
Soft strands of unknown category grain size	⬭	⬭	⬭	⬭

11. **Emerged Habitat subtypes** *

The following are the major subtypes of emerged habitat of Greece. Please provide weight to these subtypes based on their contribution to coastal protection.

Mark only one oval per row.

	1	2	3	4
Arable land				
Beaches, dunes, sands				
Coastal lagoons				
Estuaries				
Forests				
Fruit trees				
Heterogeneous agricultural areas				
Open spaces with little or no vegetation				
Pastures				
Permanent crops				
Scrub or herbaceous vegetation				
Water courses				
Wetlands				

12. **Seabed Habitat subtypes** *

Following are the generalized sub-types of seabed habitat of Greece. Please provide weight to these subtypes based on their contribution to coastal protection.

Mark only one oval per row.

	1	2	3	4
Coarse & mixed sediment	⬭	⬭	⬭	⬭
Seagrass meadows	⬭	⬭	⬭	⬭
Shallow muds	⬭	⬭	⬭	⬭
Shallow sands	⬭	⬭	⬭	⬭

Thank you for your cooperation and time!

Code for data downloading

Code snippet 1: Downloading and converting sea-level data and calculating mean

```
import requests
import numpy as np
import patoolib
import os
import ftplib
import zipfile
import netCDF4
from glob import glob
from tqdm import tqdm
from datetime import datetime
import pytz
import itertools
import subprocess
from osgeo import gdal

username = 'm.u.hasan@student.utwente.nl'
password = '******'

# Setting up connection with ftp server and downloading data
ftp_host = 'ftp-access.aviso.altimetry.fr'
FTP = ftplib.FTP()
FTP.connect(ftp_host)
FTP.login(username, password)
cwd = FTP.cwd('climatology/global/delayed-time/monthly_mean')
local_path = 'D:\ITC-UT\Thesis\Mid-term Phase\Data\Code\pythonCode'

retrlines = FTP.retrlines('LIST')


for i in FTP.nlst():
    local_file = open(i, "wb")
    FTP.retrbinary("RETR " + i, local_file.write)
    local_file.close()

print("respective files got downloaded")

FTP.close()

for zipflies in os.listdir(r'D:\ITC-UT\Thesis\Mid-term
Phase\Data\Code\pythonCode'):
    if zipflies[-3:] == '.gz':
        patoolib.extract_archive(
            zipflies, outdir=r'D:\ITC-UT\Thesis\Mid-term
Phase\Data\Code\pythonCode\Extracted_nc')


# calling data from saved directory and reading the NetCD file
filename_list = glob(r'D:\ITC-
UT\Thesis\MidTermPhase\Data\Code\pythonCode\Extracted_nc/*.nc')

grids = []
for filename in filename_list[:]:
    # print(filename)
```

```
ds = netCDF4.Dataset(filename)
    # print(ds)
    times = netCDF4.num2date(ds.variables['time'][:],
ds.variables['time'].units, calendar='julian')
    # print(times)
    local = pytz.timezone("Europe/Athens")
    times = [datetime.strptime(t.isoformat(), "%Y-%m-
%dT%H:%M:%S").replace(tzinfo=pytz.utc) for t in times]
    # print(times)
    arrs = []
    z = ds.variables['sla'][:]
    x = ds.variables['lon'][:]
    y = ds.variables['lat'][:]

    a = ds.variables['crs']

    grids.append({
        "url": filename,
        "x": x,
        "y": y,
        "z": z,
        "times": times
    })
    ds.close()
def run(cmd, shell=False):
    # print(cmd)
    subprocess.call(cmd,shell=shell)

# Converting NetCD to tiff
start_index = 0
jj=0
for g in tqdm(grids):
    # print(g)
    ncols = len(g['x'])
    # print(ncols)
    nrows = len(g['y'])
    # print(nrows)
    cellsize = g['x'][1] - g['x'][0]
    # print(cellsize)
    xllcorner = np.min(g['x'])
    # print(xllcorner)
    yllcorner = np.min(g['y'])
    # print(yllcorner)
    nodata_value = -32767
    z = g['z']
    # print(z)
    for i, t in enumerate(g['times']):
        if i < start_index:
            i = i + 1
            continue

        jj = jj+1
        print('counter', jj)
```

```
filename = 'msl_' + str(g['url'][91:97])
        filepath = r'D:\ITC-UT\Thesis\MidTermPhase\Data\Code\nc2tif\msl/' +
filename
        print(filename)
        filepath_asc = filepath + '.asc'
        filepath_tif = filepath + '.tif'
        filename_tif = filename + '.tif'

        zi = z[i]

        with open(filepath_asc, 'w') as f:
            f.write('ncols {0}\n'.format(ncols))
            f.write('nrows {0}\n'.format(nrows))
            f.write('cellsize {0}\n'.format(cellsize))
            f.write('xllcorner {0}\n'.format(xllcorner))
            f.write('yllcorner {0}\n'.format(yllcorner))
            f.write('nodata_value {0}\n'.format(nodata_value))
            for row in range(nrows-1,-1,-1):
                s = ' '.join([str(v) for v in zi[row,]]).replace('--',
str(nodata_value))
                f.write(s)
                f.write('\n')

        cmd = 'gdal_translate -ot Float32 -a_srs EPSG:4326 -co
COMPRESS=DEFLATE -co PREDICTOR=2 -co ZLEVEL=6 -of GTiff {0} {1}' \
            .format(filepath_asc, filepath_tif)
        run(cmd)

# Calling tiff fill to calcualte mean value
file_paths = glob(r'D:\ITC-
UT\Thesis\MidTermPhase\Data\Code\nc2tif\msl/*.tif')

res = []
for f in file_paths:
    print(f)
    ds = gdal.Open(f)
    res.append(ds.GetRasterBand(1).ReadAsArray())

stacked = np.dstack(res)
mean = np.mean(stacked, axis=-1)
# Sainng the mean tiff file
driver = gdal.GetDriverByName('GTiff')
result = driver.CreateCopy('MSL00_m.tif', gdal.Open(file_paths[0]))
result.GetRasterBand(1).WriteArray(mean)
result = None
```

Code snippet 2: Downloading and converting storm surge data and calculating mean

```
import pandas as pd
import requests
import numpy as np
import patoolib
import os
import ftplib
import zipfile
import netCDF4
from glob import glob
from tqdm import tqdm
from datetime import datetime
import pytz
import itertools
import subprocess
from osgeo import gdal
import csv
import cdsapi

# Downloading storm surge data using API

year = list(range(1993,2003))
month = ['01', '02', '03', '04', '05', '06', '07', '08', '09','10', '11',
'12']

c = cdsapi.Client()
for y in year:
    for m in month:
        c.retrieve(
            'sis-water-level-change-timeseries',
            {
                'variable': 'storm_surge_residual',
                'experiment': 'historical',
                'year': str (y),
                'month': str(m),
                'format': 'zip',
            },
            'download' + str(y)+str(m)+'.zip')

c = cdsapi.Client()

c.retrieve(
    'sis-water-level-change-indicators',
    {
        'variable': 'surge_level',
        'experiment': 'historical',
        'return_period': '100',
        'percentile': '50',
        'format': 'zip',
    },
    'download.zip')
# Getting all the NetCDF file of this directory
filename_list = glob(r'D:\ITC-
UT\Thesis\MidTermPhase\Data\Code\pythonCode/*.nc')
```

```
grids = []
for filename in filename_list[:]:
    # print(filename[62:80])
    ds = netCDF4.Dataset(filename)
    # print(ds)
    times = netCDF4.num2date(ds.variables['time'][:],
ds.variables['time'].units, calendar='julian')
    # print(times)
    local = pytz.timezone("Europe/Athens")
    times = [datetime.strptime(t.isoformat(), "%Y-%m-
%dT%H:%M:%S").replace(tzinfo=pytz.utc) for t in times]
    # print(times)
    arrs = []
    z = ds.variables['surge'][:]
    x = ds.variables['station_x_coordinate'][:]
    y = ds.variables['station_y_coordinate'][:]
    X = x[np.logical_and(np.logical_and(x < 31, x > 17), np.logical_and(y <
42, y > 20))]
    Y = y[np.logical_and(np.logical_and(x < 31, x > 17), np.logical_and(y <
42, y > 20))]
    stations_ids = np.logical_and(np.logical_and(x < 31, x > 17),
np.logical_and(y < 42, y > 20))
    Z = z[:, stations_ids]
    # print('z', z)
    # print(Z)

    grids.append({
        "url": filename,
        "x": X,
        "y": Y,
        "z": Z,
        "times": times
    })
    ds.close()
def run(cmd, shell=False):
    # print(cmd)
    subprocess.call(cmd,shell=shell)


start_index = 0

c=0
for g in tqdm(grids):
    surge = np.array(g['z'])
    latData = np.array(g['x'])
    lonData = np.array(g['y'])
    c = c +1
    filename = str(g['url'][62:80])
    # print(filename)
    with open(filename+'.csv', 'w') as file:
        writer = csv.writer(file, delimiter=',')
        for x, y, z in np.nditer([latData.T, lonData.T, surge], order='C'):
            writer.writerow([x, y, z])
```

```python
### cleaning surge data and initial groupping within each file

filename_list = glob(r'D:\ITC-
UT\Thesis\MidTermPhase\Data\Code\pythonCode\SurgeHeight/*.csv')


c = 0
grp_list = []
for file in filename_list:
    c = c+1

    list = []
    with open(file, 'r') as fin:
        # define reader and writer objects
        reader = csv.reader(fin, skipinitialspace=False)
        # iterate and write rows based on condition

        for i in reader:
            if i[2:3] != ['-999'] and i != []:
                list.append(i)
    df = pd.DataFrame(list, columns=['X', 'Y', 'Surge'], dtype=float)
    grp = df.groupby(['X', 'Y'])['Surge'].mean().reset_index()
    grp.to_csv(str(file[63:77])+'.csv', header=False, index=False)
    print('counter', c)


##### Grouped surge data to a single surge file
path = r'D:\ITC-
UT\Thesis\MidTermPhase\Data\Code\pythonCode\Grouped_SurgeHeight'
all_files = glob(path + "/*.csv")
list = []
for file in all_files:
    with open(file, 'r') as f:
        reader = csv.reader(f, skipinitialspace=False)
        for i in reader:
            list.append(i)

# print(list)
df = pd.DataFrame(list, columns=['X', 'Y', 'Surge'], dtype=float)
# print(df)
res = df.groupby(['X', 'Y'])['Surge'].mean().reset_index()
# print(res)
res.to_csv('Storm_Surge_1977_2005.csv', index=False)
```

Code snippet 3: Downloading and converting ocean current data

```
import requests
import numpy as np
import patoolib
import os
import ftplib
import zipfile
import netCDF4
from glob import glob
from tqdm import tqdm
from datetime import datetime
import pytz
import itertools
import subprocess
import gdal
from osgeo import osr


# Connecting to server to download the data and save it to local drive
username = 'mhasan1'
password = '***********'
year = [2018, 2019, 2020]
month = ['01', '02', '03', '04', '05', '06', '07', '08', '09', '10', '11',
'12']


c = 0
for i in year:
    ftp_host = 'nrt.cmems-du.eu'
    FTP = ftplib.FTP()
    # print(FTP)
    FTP.connect(ftp_host)
    FTP.login(username, password)
    url = 'Core/MEDSEA_ANALYSIS_FORECAST_PHY_006_013/med00-cmcc-cur-an-fc-m/'
+ str(i) + '/'
    cwd = FTP.cwd(url)
    # print(cwd)

    local_path = r'D:\ITC-
UT\Thesis\MidTermPhase\Data\Code\pythonCode\OceanCurrent'
    #
    retrlines = FTP.retrlines('LIST')
    # print(retrlines)
    # print(FTP.nlst())
    c = c + 1
    print(c)
    for k in FTP.nlst():
        local_file = open(k, "wb")
        FTP.retrbinary("RETR " + k, local_file.write)
        local_file.close()

        print("respective files got downloaded")

    FTP.close()
```

```
# calling data from local drive and converting NetCDF to tiff
filename_list = glob(r'D:\ITC-
UT\Thesis\MidTermPhase\Data\Code\pythonCode\OceanCurrent/*.nc')

grids = []
for filename in filename_list[:1]:
    # print(filename)
    ds = netCDF4.Dataset(filename)
    # print(ds)
    times = netCDF4.num2date(ds.variables['time'][:],
ds.variables['time'].units, calendar='julian')
    # print(times)
    local = pytz.timezone("Europe/Athens")
    times = [datetime.strptime(t.isoformat(), "%Y-%m-
%dT%H:%M:%S").replace(tzinfo=pytz.utc) for t in times]
    # print(times)
    # arrs = []
    z = ds.variables['uo'][:]
    # print(z)
    x = ds.variables['lon'][:]
    y = ds.variables['lat'][:]
    # print(x)
    grids.append({
        "url": filename,
        "x": x,
        "y": y,
        "z": z,
        "times": times
    })
    ds.close()
# print(grids)
def run(cmd, shell=False):
    # print(cmd)
    subprocess.call(cmd,shell=shell)

start_index = 0
jj = 0
for g in tqdm(grids):
    # print(g)
    ncols = len(g['x'])
    # print(ncols)
    nrows = len(g['y'])
    # print(nrows)
    cellsize = g['x'][1] - g['x'][0]
    # print(cellsize)
    xllcorner = np.min(g['x'])
    # print(xllcorner)
    yllcorner = np.min(g['y'])
    # print(yllcorner)
    nodata_value = -32767
    z = g['z']
    # print(z)
    # print(g['url'])
```

```
for i, t in enumerate(g['times']):
        if i < start_index:
            i = i + 1
            continue

        jj = jj+1
        print('counter', jj)
        filename = 'oceanCurrent_' + str(g['url'][64:72])
        # print(filename)
        filepath = r'D:\ITC-
UT\Thesis\MidTermPhase\Data\Code\nc2tif\OceanCurrent/' + filename
        # print((g['url']))
        filepath_asc = filepath + '.asc'
        filepath_tif = filepath + '.tif'
        filename_tif = filename + '.tif'

        zi = z[i]
        for row in range(nrows,):
            print('row',row)
            for v in zi[row,]:
                for kk in v:
                    print(kk)
        with open(filepath_asc, 'w') as f:
            f.write('ncols {0}\n'.format(ncols))
            f.write('nrows {0}\n'.format(nrows))
            f.write('cellsize {0}\n'.format(cellsize))
            f.write('xllcorner {0}\n'.format(xllcorner))
            f.write('yllcorner {0}\n'.format(yllcorner))
            f.write('nodata_value {0}\n'.format(nodata_value))
            for row in range(nrows-1,-1,-1):
                s = ' '.join([str(v) for v in zi[row,]]).replace('--',
str(nodata_value))
                f.write(s)
                f.write('\n')

        cmd = 'gdal_translate -ot Float32 -a_srs EPSG:4326 -co
COMPRESS=DEFLATE -co PREDICTOR=2 -co ZLEVEL=6 -of GTiff {0} {1}' \
            .format(filepath_asc, filepath_tif)
        run(cmd)
```

Code snippet 4: Downloading Tidal Amplitude Data and converting NetCDF to tiff

```
import subprocess
import itertools

import numpy as np
import requests
import pytz
import datetime
import netCDF4
from osgeo import gdal
from os import path
from osgeo.gdalconst import *
from tqdm import tqdm
from bs4 import BeautifulSoup
from netCDF4 import Dataset
from datetime import datetime, timedelta

path = r'D:\ITC-UT\Thesis\Mid-term
Phase\aviso\ocean_tide_extrapolated\ocean_tide_extrapolated\m2.nc'

grids = []
# for url in tqdm(urls[:-1]):
ds = netCDF4.Dataset(path)

print(ds.variables.keys())
# print(ds)
# times = netCDF4.num2date(ds.variables['time'][:],
ds.variables['time'].units, calendar='julian')
# local = pytz.timezone("Europe/Amsterdam")
# times = [local.localize(t, is_dst=None).astimezone(pytz.utc) for t in
times]
# times = [datetime.strptime(t.isoformat(), "%Y-%m-
%dT%H:%M:%S").replace(tzinfo=pytz.utc) for t in times]
# print(times)
arrs = []
amplitude = ds.variables['amplitude'][:]
phase = ds.variables['phase'][:]
lat = ds.variables['lat_bnds'][:]
lon = ds.variables['lon_bnds'][:]
print(lat)

grids.append({
        "amplitude": amplitude,
        "x": lat,
        "y": lon,
        "phase": phase
})
ds.close()

def run(cmd, shell=False):
    print(cmd)
    subprocess.call(cmd,shell=shell)
```

```python
start_index = 0
for g in tqdm(grids):
    ncols = len(g['x'])
    print(ncols)
    nrows = len(g['y'])
    print(nrows)
    cellsize = g['x'][1] - g['x'][0]
    print(cellsize)
    xllcorner = np.min(g['x'])
    print(xllcorner)
    yllcorner = np.min(g['y'])
    print(yllcorner)
    nodata_value = -32767
    z = g['amplitude']
    print(z)

    # for i, t in enumerate(g['times']):
    #     if i < start_index:
    #         i = i + 1
    #         continue
    #
    filename = 'tide_'
    filepath = r'D:\ITC-UT\Thesis\Mid-term Phase\Data\Code/' + filename
    filepath_asc = filepath + '.asc'
    filepath_tif = filepath + '.tif'
    filename_tif = filename + '.tif'
    #
    #     zi = z[i]

    with open(filepath_asc, 'w') as f:
        f.write('ncols {0}\n'.format(ncols))
        f.write('nrows {0}\n'.format(nrows))
        f.write('cellsize {0}\n'.format(cellsize))
        f.write('xllcorner {0}\n'.format(xllcorner))
        f.write('yllcorner {0}\n'.format(yllcorner))
        f.write('nodata_value {0}\n'.format(nodata_value))
        for row in range(nrows):
            s = ' '.join([str(v) for v in z[row,]]).replace('--',
str(nodata_value))
            f.write(s)
            f.write('\n')

    cmd = 'gdal_translate -ot Float32 -a_srs EPSG:2100 -co COMPRESS=DEFLATE -
co PREDICTOR=2 -co ZLEVEL=6 -of GTiff {0} {1}' \
        .format(filepath_asc, filepath_tif)
    run(cmd)
```

Code snippet 5: Downloading Wave Height Data and converting NetCDF to tiff

```
import requests
import numpy as np
import patoolib
import os
import ftplib
import zipfile
import netCDF4
from glob import glob
from tqdm import tqdm
from datetime import datetime
import pytz
import itertools
import subprocess
import gdal
from osgeo import osr


username = 'mhasan1'
password = '*******'
year = [2019, 2020]
month = ['01', '02', '03', '04', '05', '06', '07', '08', '09', '10', '11',
'12']


c = 0
for i in year:
    for j in month:
        ftp_host = 'nrt.cmems-du.eu'
        FTP = ftplib.FTP()
        # print(FTP)
        FTP.connect(ftp_host)
        FTP.login(username, password)
        url = 'Core/MEDSEA_ANALYSIS_FORECAST_WAV_006_017/med00-hcmr-wav-an-
fc-h/' + str(i) + '/' + str(j)
        cwd = FTP.cwd(url)
        # print(cwd)

        local_path = 'D:\ITC-
UT\Thesis\MidTermPhase\Data\Code\pythonCode\wave'
        #
        retrlines = FTP.retrlines('LIST')
        # print(retrlines)
        # print(FTP.nlst())
        c = c + 1
        print(c)
        for k in FTP.nlst():
            local_file = open(k, "wb")
            FTP.retrbinary("RETR " + k, local_file.write)
            local_file.close()

            print("respective files got downloaded")

        FTP.close()
```

```
filename_list = glob(r'D:\ITC-
UT\Thesis\MidTermPhase\Data\Code\pythonCode\wave/*.nc')

grids = []
for filename in filename_list[:]:
    # print(filename)
    ds = netCDF4.Dataset(filename)
    # print(ds)
    times = netCDF4.num2date(ds.variables['time'][:],
ds.variables['time'].units, calendar='julian')
    # print(times)
    local = pytz.timezone("Europe/Athens")
    times = [datetime.strptime(t.isoformat(), "%Y-%m-
%dT%H:%M:%S").replace(tzinfo=pytz.utc) for t in times]
    # print(times)
    arrs = []
    z = ds.variables['VHM0'][:]
    # print(z)
    x = ds.variables['longitude'][:]
    y = ds.variables['latitude'][:]
    # print(y)
    grids.append({
        "url": filename,
        "x": x,
        "y": y,
        "z": z,
        "times": times
    })
    ds.close()
# print(grids)
def run(cmd, shell=False):
    # print(cmd)
    subprocess.call(cmd,shell=shell)

start_index = 0
jj = 0
for g in tqdm(grids):
    # print(g)
    ncols = len(g['x'])
    # print(ncols)
    nrows = len(g['y'])
    # print(nrows)
    cellsize = g['x'][1] - g['x'][0]
    # print(cellsize)
    xllcorner = np.min(g['x'])
    # print(xllcorner)
    yllcorner = np.min(g['y'])
    # print(yllcorner)
    nodata_value = -32767
    z = g['z']
    # print(z)
    for i, t in enumerate(g['times']):
        if i < start_index:
```

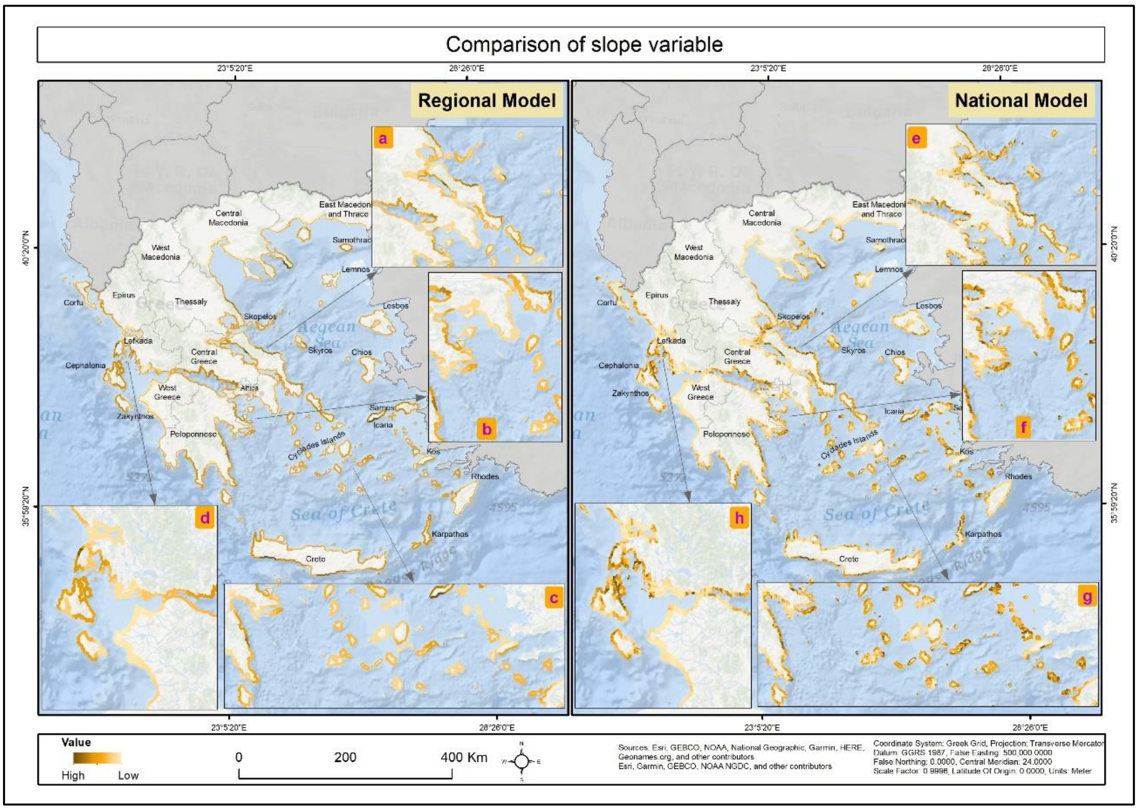
```
i = i + 1
                continue

        jj = jj+1
        print('counter', jj)
        filename = 'wave_' + str(g['url'][94:102])+"_"+str(jj).rjust(5, '0')
        filepath = r'D:\ITC-UT\Thesis\MidTermPhase\Data\Code\nc2tif\wave/' +
filename
        # print((g['url']))
        filepath_asc = filepath + '.asc'
        filepath_tif = filepath + '.tif'
        filename_tif = filename + '.tif'

        zi = z[i]

        with open(filepath_asc, 'w') as f:
            f.write('ncols {0}\n'.format(ncols))
            f.write('nrows {0}\n'.format(nrows))
            f.write('cellsize {0}\n'.format(cellsize))
            f.write('xllcorner {0}\n'.format(xllcorner))
            f.write('yllcorner {0}\n'.format(yllcorner))
            f.write('nodata_value {0}\n'.format(nodata_value))
            for row in range(nrows-1,-1,-1):
                s = ' '.join([str(v) for v in zi[row,]]).replace('--',
str(nodata_value))
                f.write(s)
                f.write('\n')

        cmd = 'gdal_translate -ot Float32 -a_srs EPSG:4326 -co
COMPRESS=DEFLATE -co PREDICTOR=2 -co ZLEVEL=6 -of GTiff {0} {1}' \
            .format(filepath_asc, filepath_tif)
        run(cmd)
```

Code snippet 6: Downloading Wind Speed Data and converting NetCDF to tiff

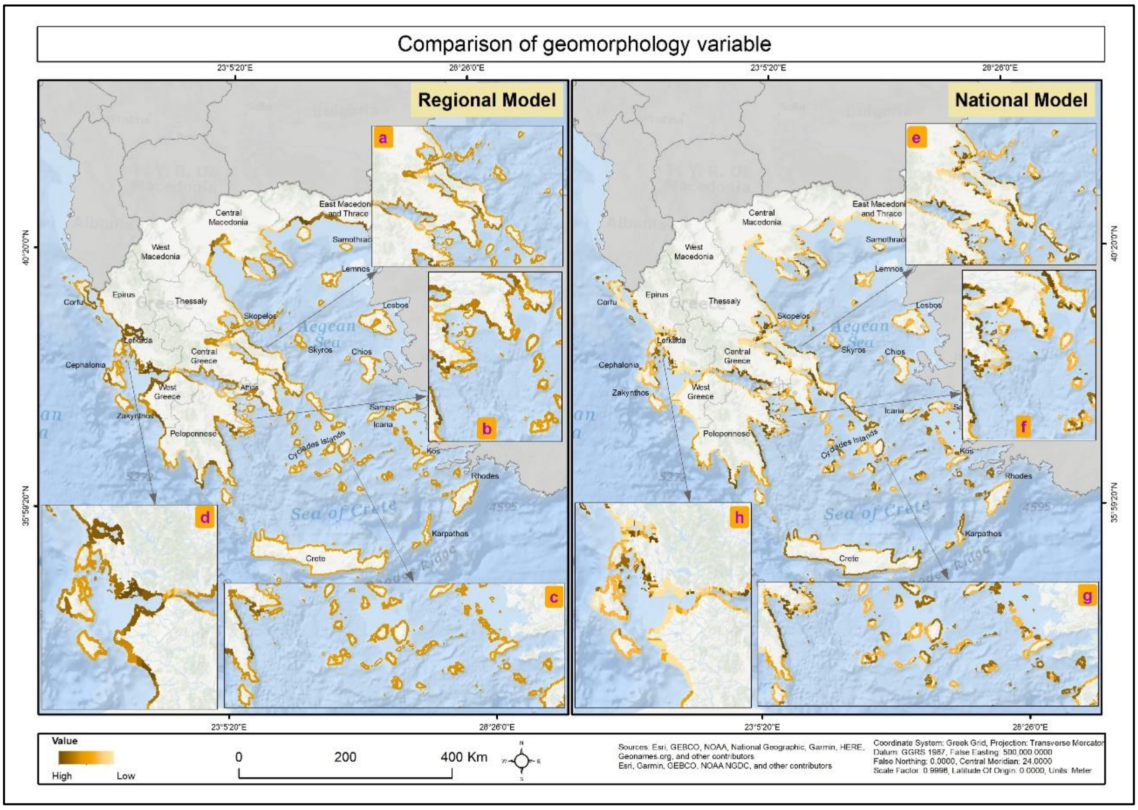
```
import requests
import numpy as np
import patoolib
import os
import ftplib
import zipfile
import netCDF4
from glob import glob
from tqdm import tqdm
from datetime import datetime
import pytz
import itertools
import subprocess
import gdal
from osgeo import osr



username = 'mhasan1'
password = '********'
year = list(range(2007,2020))


c = 0
for i in year:
    ftp_host = 'my.cmems-du.eu'
    FTP = ftplib.FTP()
    # print(FTP)
    FTP.connect(ftp_host)
    FTP.login(username, password)
    url = 'Core/WIND_GLO_PHY_CLIMATE_L4_REP_012_003/CERSAT-GLO-REP_WIND_L4-
OBS_FULL_TIME_SERIE/' + str(i) + '/'
    cwd = FTP.cwd(url)
    print(cwd)
    local_path = 'D:\ITC-
UT\Thesis\MidTermPhase\Data\Code\pythonCode\WindSpeed'
    #
    retrlines = FTP.retrlines('LIST')
    # print(retrlines)
    # print(FTP.nlst())
    c = c + 1
    print(c)
    for k in FTP.nlst():
        local_file = open(k, "wb")
        FTP.retrbinary("RETR " + k, local_file.write)
        local_file.close()

        print("respective files got downloaded")

    FTP.close()
```

```
filename_list = glob(r'D:\ITC-
UT\Thesis\MidTermPhase\Data\Code\pythonCode\WindSpeed/*.nc')

grids = []
for filename in filename_list[:1]:
    # print(filename)
    ds = netCDF4.Dataset(filename)
    print(ds)
    times = netCDF4.num2date(ds.variables['time'][:],
ds.variables['time'].units, calendar='julian')
    # print(times)
    local = pytz.timezone("Europe/Athens")
    times = [datetime.strptime(t.isoformat(), "%Y-%m-
%dT%H:%M:%S").replace(tzinfo=pytz.utc) for t in times]
    # print(times)
    arrs = []
    z = ds.variables['wind_speed']
    print(z)
    x = ds.variables['latitude'][:]
    y = ds.variables['longitude'][:]
    d = ds.variables['depth'][:]
    # print(y)
    grids.append({
        "url": filename,
        "x": x,
        "y": y,
        "z": z,
        "d": d,
        "times": times
    })
    ds.close()
print(grids)
def run(cmd, shell=False):
    # print(cmd)
    subprocess.call(cmd,shell=shell)
#
start_index = 0
jj = 0
for g in tqdm(grids):
    # print(g)
    ncols = len(g['x'])
    # print(ncols)
    nrows = len(g['y'])
    # print(nrows)
    cellsize = g['x'][1] - g['x'][0]
    # print(cellsize)
    xllcorner = np.min(g['x'])
    # print(xllcorner)
    yllcorner = np.min(g['y'])
    # print(yllcorner)
    nodata_value = -32767
    z = g['z']
    # print(z)
```

```
for t in enumerate(g['times']):
        for i, dd in enumerate(g['d']):
            if i < start_index:
                i = i + 1
                continue

            jj = jj+1
            print('counter', jj)
            filename = 'windspeed_' + str(g['url'][61:71])
            # print(filename)
            filepath = r'D:\ITC-
UT\Thesis\MidTermPhase\Data\Code\nc2tif\WindSpeed/' + filename
            # print((g['url']))
            filepath_asc = filepath + '.asc'
            filepath_tif = filepath + '.tif'
            filename_tif = filename + '.tif'
            #
            zi = z[i]
            #
            with open(filepath_asc, 'w') as f:
                f.write('ncols {0}\n'.format(ncols))
                f.write('nrows {0}\n'.format(nrows))
                f.write('cellsize {0}\n'.format(cellsize))
                f.write('xllcorner {0}\n'.format(xllcorner))
                f.write('yllcorner {0}\n'.format(yllcorner))
                f.write('nodata_value {0}\n'.format(nodata_value))

                for row in range(nrows-1,-1,-1):
                    # print(row)
                    for v in zi:
                        # print(v)
                        for vv in v:
                            for vvv in vv:
                                s = ' '.join([str(vvv)]).replace('--',
str(nodata_value))
                                f.write(s)
                                f.write('\n')


            cmd = 'gdal_translate -ot Float32 -a_srs EPSG:4326 -co
COMPRESS=DEFLATE -co PREDICTOR=2 -co ZLEVEL=6 -of GTiff {0} {1}' \
                .format(filepath_asc, filepath_tif)
            run(cmd)
```

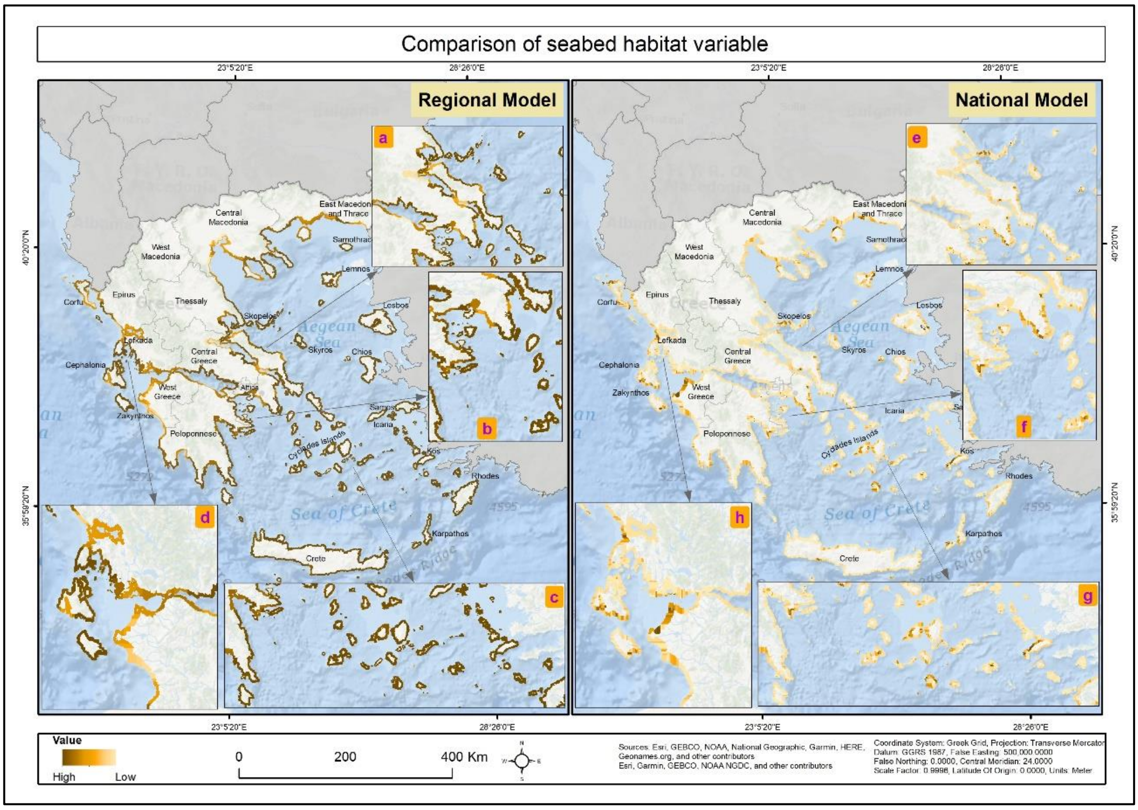


Appendix 2: Comparison of slope variable between regional and national level model. Inset maps are the zoomed view of slope value variation from regional and national model in the coastal areas of Central Greece and Chalcis (a, e), southern Attica and south eastern Peloponnese (b, f), Cyclades islands (c, g), north western Western Greece and Ionian islands (d, h).

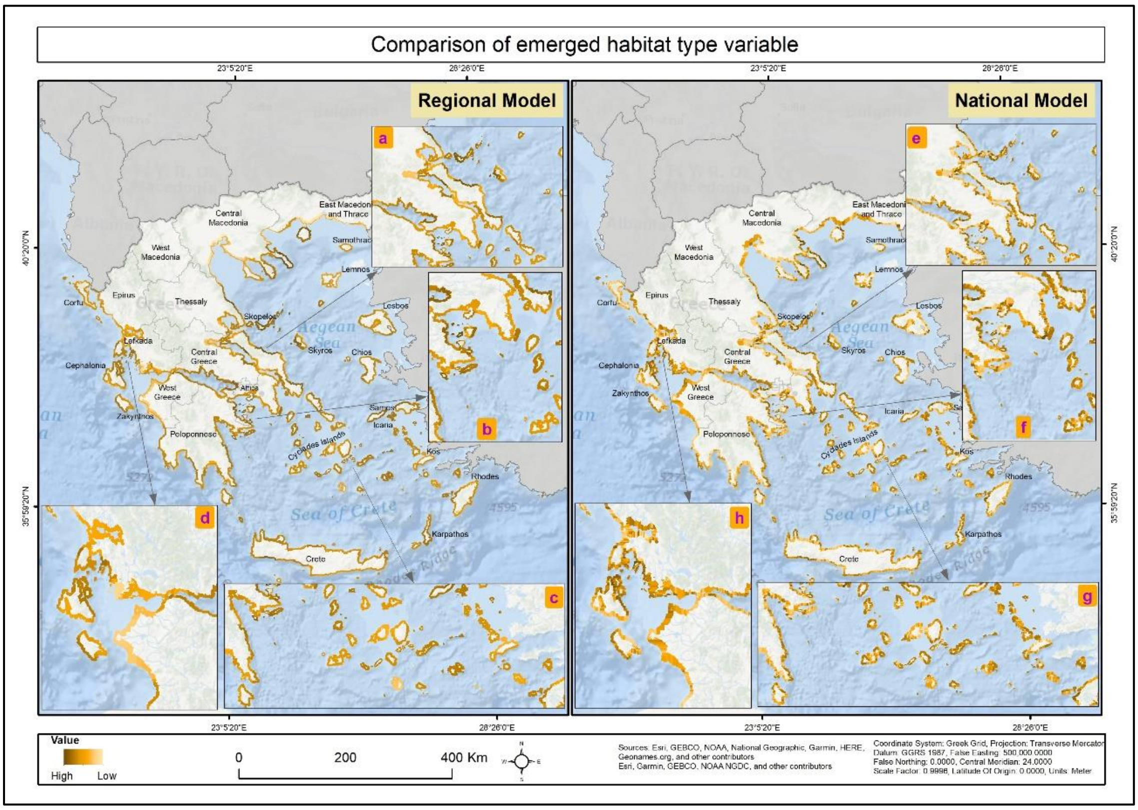


Appendix 3: Comparison of geomorphology variable between regional and national level model. Inset maps are the zoomed view of geomorphology value variation from regional and national model in the coastal areas of Central

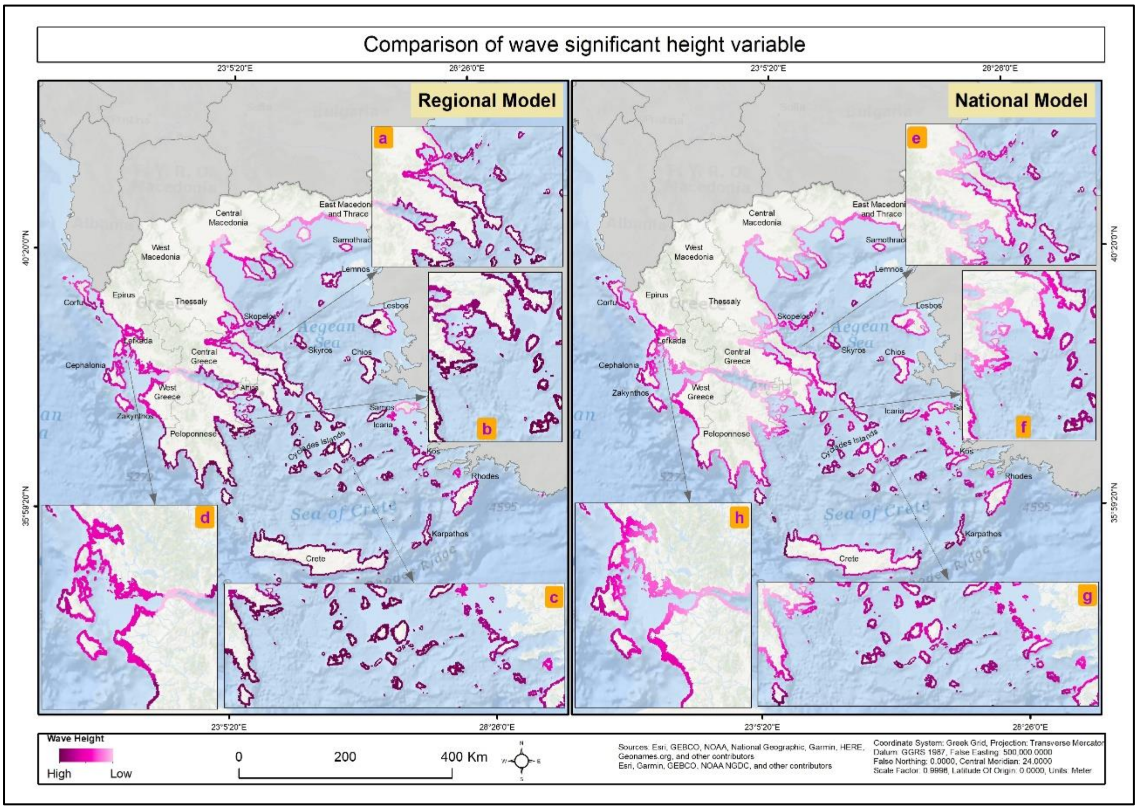
Greece and Chalcis (a, e), southern Attica and south eastern Peloponnese (b, f), Cyclades islands (c, g), northwestern Western Greece and Ionian islands (d, h).



Appendix 4: Comparison of seabed habitat variable between regional and national level model. Inset maps are the zoomed view of seabed habitat value variation from regional and national model in the coastal areas of Central Greece and Chalcis (a, e), southern Attica and south eastern Peloponnese (b, f), Cyclades islands (c, g), northwestern Western Greece and Ionian islands (d, h).

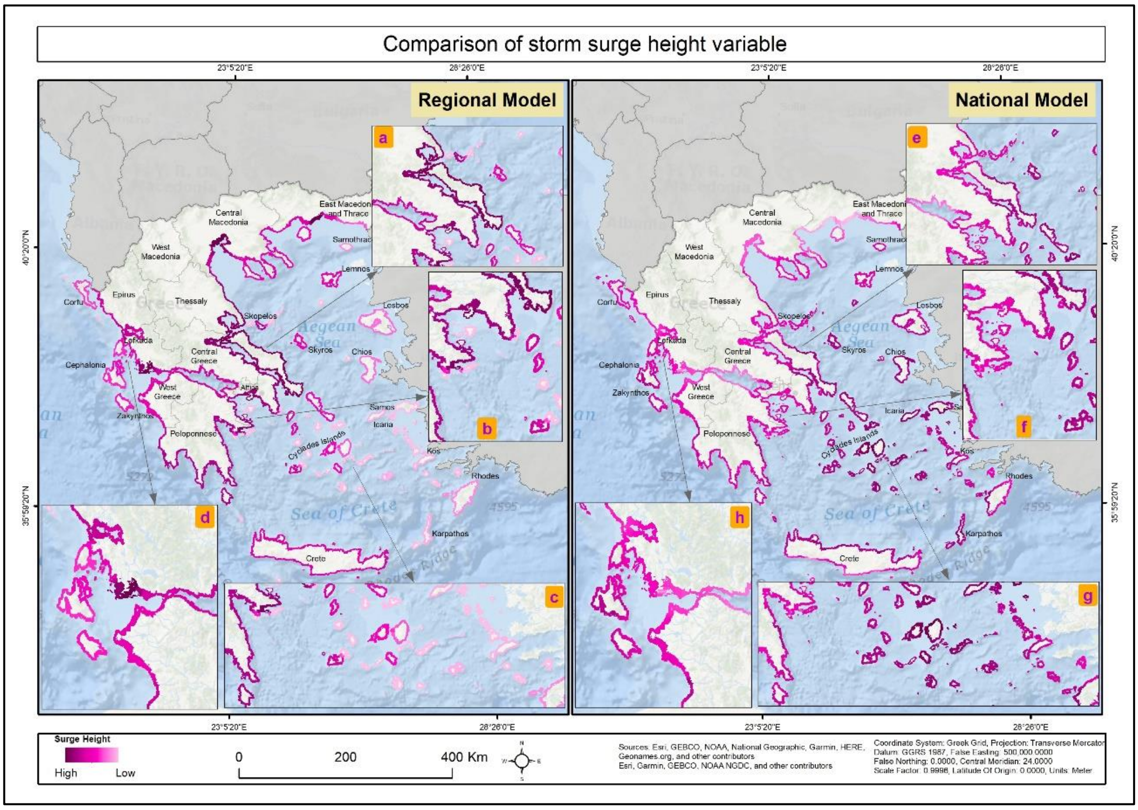


Appendix 5: Comparison of emerged habitat variable between regional and national level model. Inset maps are the zoomed view of emerged habitat value variation from regional and national model in the coastal areas of Central Greece and Chalcis (a, e), southern Attica and south eastern Peloponnese (b, f), Cyclades islands (c, g), northwestern Western Greece and Ionian islands (d, h).

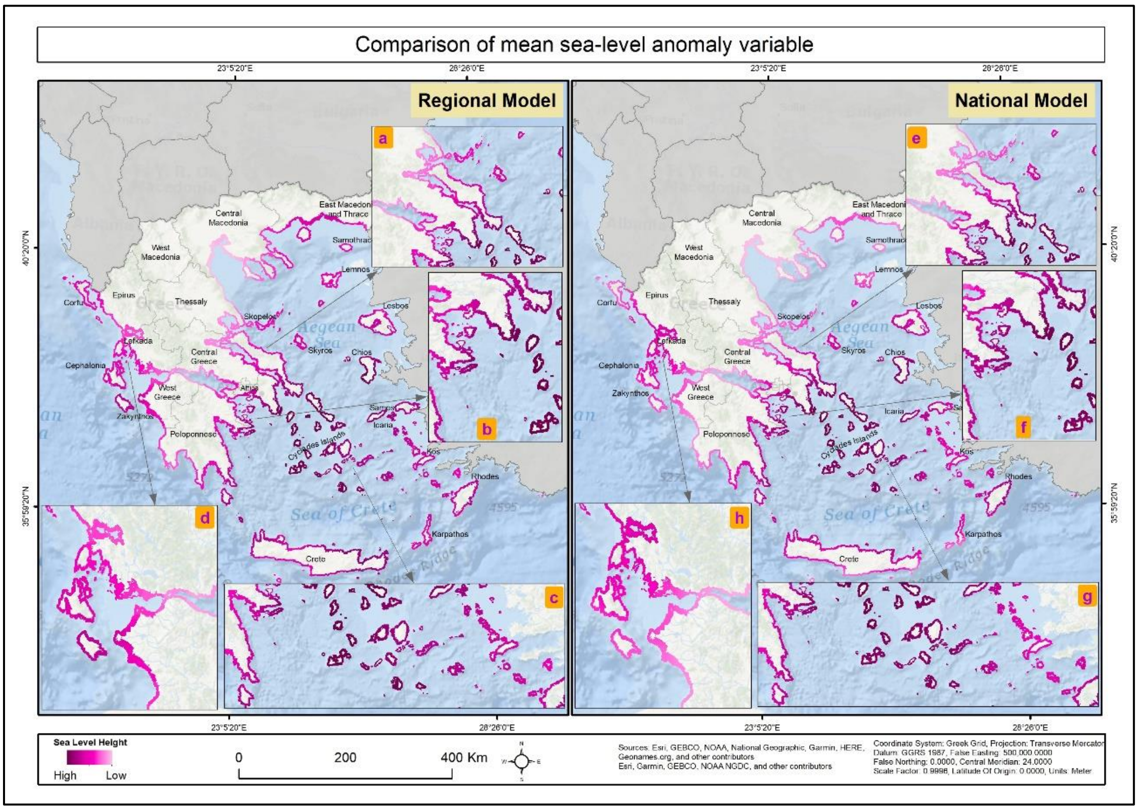


Appendix 6: Comparison of wave significant height variable between regional and national level model. Inset maps are the zoomed view of wave significant height value variation from regional and national model in the coastal areas

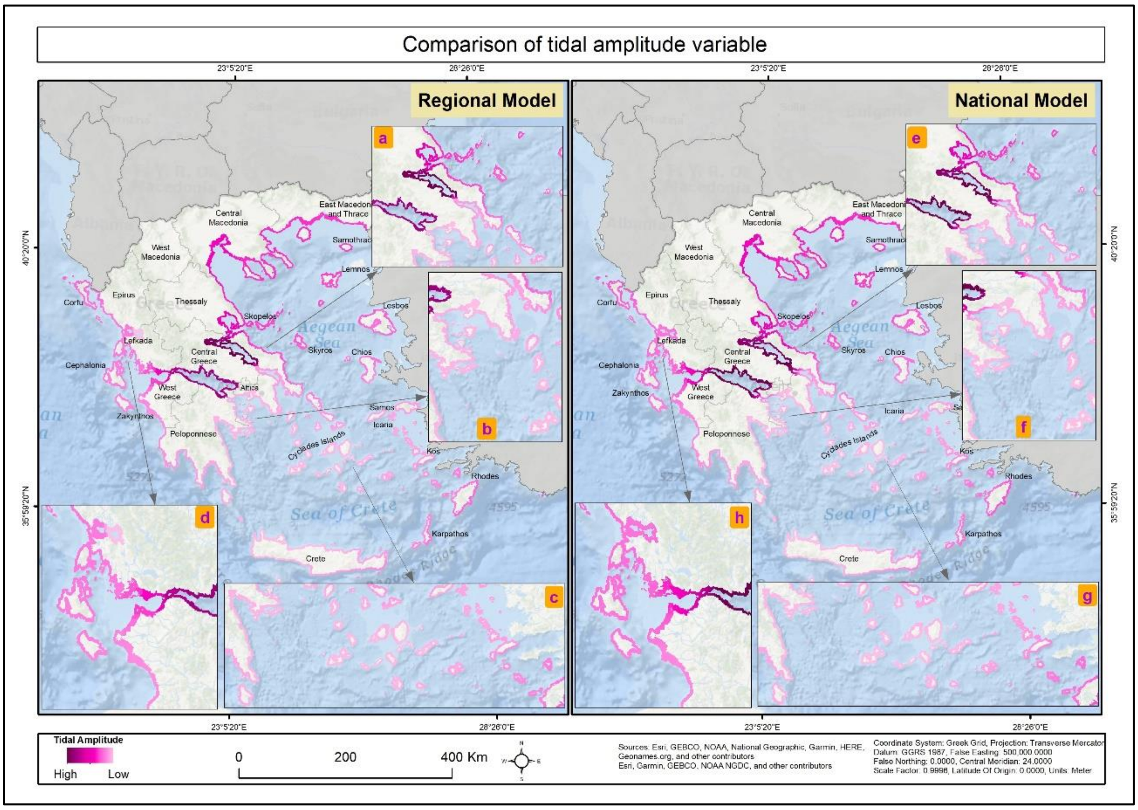
of Central Greece and Chalcis (a, e), southern Attica and south eastern Peloponnese (b, f), Cyclades islands (c, g), northwestern Western Greece and Ionian islands (d, h).



Appendix 7: Comparison of storm surge height variable between regional and national level model. Inset maps are the zoomed view of storm surge height value variation from regional and national model in the coastal areas of Central Greece and Chalcis (a, e), southern Attica and south eastern Peloponnese (b, f), Cyclades islands (c, g), northwestern Western Greece and Ionian islands (d, h).

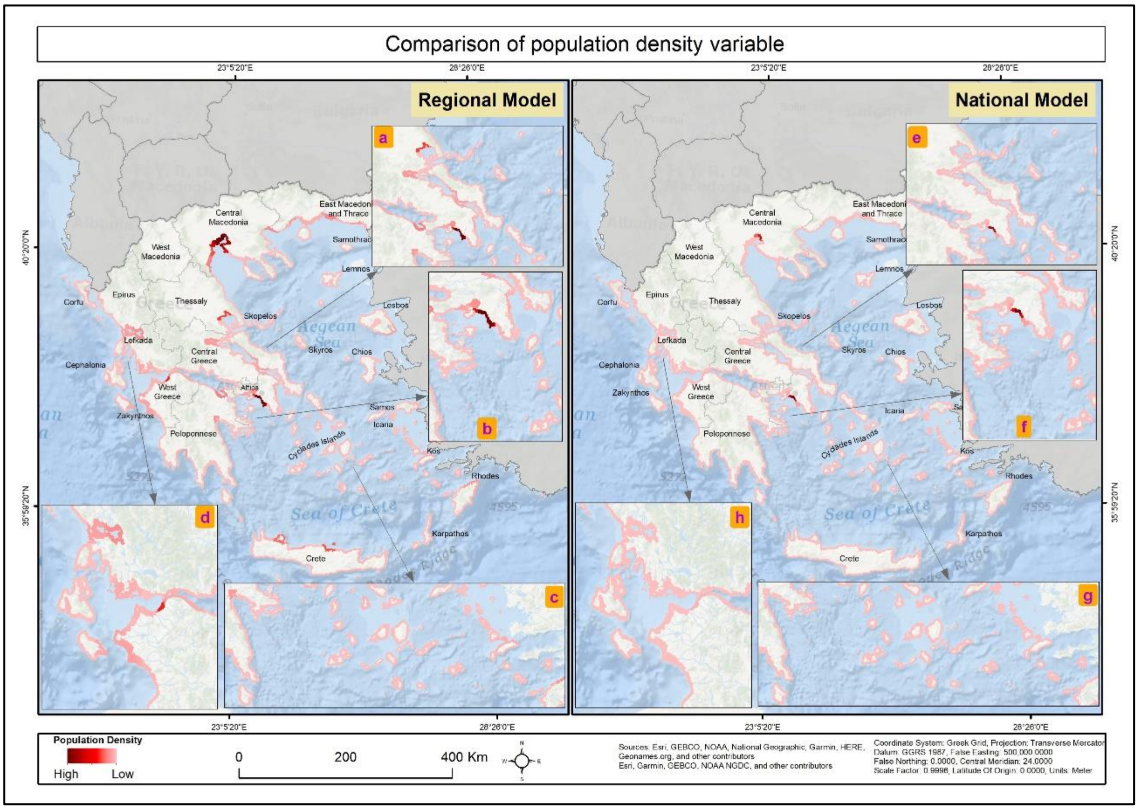


Appendix 8: Comparison of sea level anomaly variable between regional and national level model. Inset maps are the zoomed view of mean sea level value variation from regional and national model in the coastal areas of Central Greece and Chalcis (a, e), southern Attica and south eastern Peloponnese (b, f), Cyclades islands (c, g), northwestern Western Greece and Ionian islands (d, h).

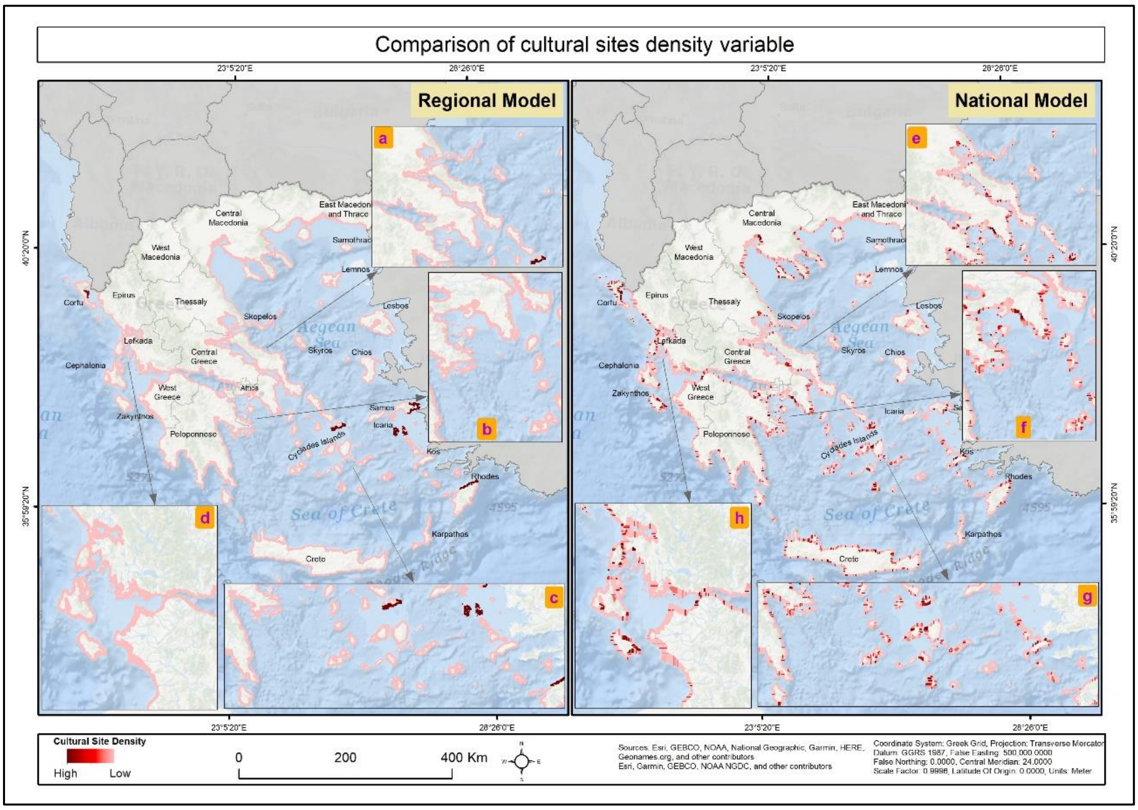


Appendix 9: Comparison of tidal amplitude variable between regional and national level model. Inset maps are the zoomed view of tidal apmplitude value variation from regional and national model in the coastal areas of Central

Greece and Chalcis (a, e), southern Attica and south eastern Peloponnese (b, f), Cyclades islands (c, g), northwestern Western Greece and Ionian islands (d, h).



Appendix 10: Comparison of population density variable between regional and national level model. Inset maps are the zoomed view of population density value variation from regional and national model in the coastal areas of Central Greece and Chalcis (a, e), southern Attica and south eastern Peloponnese (b, f), Cyclades islands (c, g), northwestern Western Greece and Ionian islands (d, h).



Appendix 11: Comparison of cultural sites density variable between regional and national level model. Inset maps are the zoomed view of cultural site density value variation from regional and national model in the coastal areas of Central Greece and Chalcis (a, e), southern Attica and south eastern Peloponnese (b, f), Cyclades islands (c, g), northwestern Western Greece and Ionian islands (d, h).