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Research article

Adaptation of a freshwater evaluation framework to a coastal system: The case of Kamari, Santorini

Alexandra Ćulibrk [a,*], Ourania Tzoraki [a], Michelle E. Portman [b]

[a] Department of Marine Sciences, School of Environment, University of the Aegean, Greece
[b] Technion – Israel Institute of Technology, Israel

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ABSTRACT

The erosion of sandy beaches creates a significant impact on the local society, the economy and the environment. The present study is an attempt to adapt the innovative DESSIN (Demonstrate Ecosystem Services Enabling Innovation in the Water Sector) framework that specializes in freshwater applications, to urban coastal systems. The framework is applied in the case of Kamari beach, Santorini (Greece), to assess the sustainability of all possible anti-erosion measures. To identify the most vulnerable parts of the coastline, the study used two sensitivity indices: the Coastal Vulnerability Index (CVI), and the Socioeconomic Index (SocCVI). A supply-demand model was applied for the integration of all three aspects that characterize the system: social, economic, and environmental. To project the impact of erosion in the future, the system's state was analyzed in three steps a) the present, b) after the installation of the coastal protection measures and c) a scenario where no protection actions were taken (RCP4.5 scenario). In the current situation the most susceptible part of the coastline due to anthropogenic and environmental pressures is the central one, which does not immediately affect the socio-economic activities of the urban area. In contrast, future changes brought about by climate change will endanger the system's equilibrium and anti-erosion actions are necessary. With the application of the adapted DESSIN framework, the combined installation of submerged breakwaters with sediment replacement is the most sustainable action, promoting socio-economic growth and the protection of essential ecosystem services.

1. Introduction

Greece is one of the most popular countries for summer vacations due to its extensive coastline and the large number of islands. Since 1960, the tourism sector has been steadily growing in the country. High demand has formed a large percentage of small businesses related to tourism. The oversupply of accomodations has reached 420,991 registered rooms, causing Greece to rank 6th in the Europe (APA, 2019). Although the tourism sector is economically highly significant for the country (Velegrakis et al., 2005), the absence of a development plan causes environmental degradation of the Greek islands, especially during the peak touristic months (Buhalis, 2001).

Awareness of anthropogenic and environmental processes, their interconnectivity and conflicts on the coast is the key to its proper management and future exploitation. Beaches are critical and dynamic systems. They regulate coastal ecosystems located within them, they provide protection against possible floods for the human facilities in the backshore, and they are a potential profitable sector for entertainment (Neumann et al., 2015). Tourist beaches in developing cities are systems with multiple pressures. Coastal erosion is a common natural phenomenon worldwide, that is mainly triggered by the human factor, wind and waves (Holgate and Woodworth, 2004), although, it is accelerated mainly due to anthropogenic impact (Pranzini et al., 2015).

The expected rise in sea level and changes in the coastline may endanger coastal ecosystems, populations and infrastructure (McLean et al., 2001) and affect 24% of the world's sandy beaches. According to research that analyzed satellite images from 1984 to 2016, 70% of the worlds sandy beaches experience erosion (Luijendijk et al., 2018), with islands being much more sensitive to global climate change and rising sea levels (Scavia et al., 2002). Large populations living in the coastal zone (Balk et al., 2009; Small and Nicholls, 2003) are directly endangered by ensuing climate change. Without the proper monitoring and management of coastal systems, the potential risks increase. Climate change is recognized as an important factor for public health

* Corresponding author. University Hill, Mytilene, 81100, Greece.
E-mail addresses: aculibrk@aegean.gr (A. Ćulibrk), rania.tzoraki@aegean.gr (O. Tzoraki), MichelleP@ar.technion.ac.il (M.E. Portman).

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(Benevolenza and Derigne, 2018) and the superficial management and monitoring of coastal systems can be crucial in exposing the public to natural hazards. Residential development and overexploitation of the coast are elements that significantly affect the sediment supply. The dynamic and wave activity of the sea, especially in extreme weather scenarios are associated with the reduction of the shore width and the loss of its sediment.

Although, the scale of predicted Sea Level Rise (SLR) is debated (Church and White, 2006; Nicholls et al., 2007; Stocker et al., 2013; Vafeidis et al., 2020), for the above reasons, multiple methods and indicators have been developed for the greatest analysis and monitoring accuracy of these particular systems. One of the biggest pressures that come with SLR, is the increased damage risk of infrastructure in the coastal zone. Underestimating the intensity that SLR scenarios could have on the coast could lead to overlooking significant risks (Ayyub et al., 2012). For this reason, it is extremely important that the SLR management scenarios include all important aspects of society. While transportation infrastructure (Johnston et al., 2014), real estate (Ayyub et al., 2012), and sewerage systems hazards would have a direct impact on the functioning of society (Joyce et al., 2017), changes in coastal ecosystem services are indirectly linked to many sectors of society. Progressing precipitation scenarios due to climate change combined with SLR, will increase the rates of the coastal erosion as well as longer-lasting floods, setting coastal infrastructure at high risk; while, the consequences of salinization will threaten multiple social sectors (Nazarnia et al., 2020). It is especially important in systems where socio-economic and environmental variables interact and are interdependent to conduct analysis of all three to minimize the negative synergistic effects. In order to better understand these interactions, scenarios of possible conflicts and compatibilities of the main variables in the coastal zone are developed, where by selecting appropriate indicators and integrating spatial data form the basis of the analysis (Eurosion, 2002). The sensitivity of the coastal zone to SLR combined with social, economic and ecological pressures, induced by anthropogenic activities have led to a significant number of coastal sensitivity indicators for the specific coastal areas (Alexandrakis et al., 2014; E. Robert Thieler, 1999; G., 1998; Gornitz et al., 1994; Hoozemans et al., 1993; Leggett and Jones, 1996; Mimura, N., Yokoki, 2000; O'Riain, 1996).

The vulnerability framework described by Turner et al. (2003) is widely used for assessing the impact of a change in an area, natural or not, with the use of the theoretical risk-hazard (RH) and pressure-and-release (PAR) models. Variations of this framework have been applied for coastal zone management and have proven that the environment can be co-assessed with the social system in order to provide more sustainable and holistic solutions (Higgins and Dwyer, 2019). Another solution for understanding the relationship between the anthropogenic and the natural environment is the Human-Environment system (HES) model (Scholz and Binder, 2004). This framework can be applied in various cases, including marine and coastal applications, as it emphasizes on the interactions of the human factor and the environment. However it is helpful only in the understanding of the existing problems and their nature and does not provide a decision making mechanism. Also, the Social-Ecological Systems framework (SESF) is used for resource management in various fields such as marine and coastal zone management, fisheries, water resources and forestry (Ostrom, 2007).

One of the most widely applied frameworks is the Driver, Pressure, State, Impact, Response (DPSIR) (Azevedo et al., 2013; Bruno et al., 2020; Dzoga et al., 2020). It is a flexible methodology that focuses on identifying the problems and their origins and evaluating the proper response for each situation. In recent years a new innovative framework has been introduced by the European project DESSIN (Demonstrate Ecosystem Services Enabling Innovations in the Water Sector). The DESSIN evaluation framework is a novel methodology that has been developed with focal points being the management or urban freshwater by operationalizing ecosystem service assessment (Riegels et al., 2020). Integration of the ESS (Ecosystem Services) approach in management frameworks has the unique advantages of being a direct means of communication between researchers and policy makers. It requires deep knowledge of the system from different scientific disciplines and it is easily adjustable for use in other methodologies (Portman, 2013). DESSIN assesses the impact of a change in the ecosystem (natural or anthropogenic) through the changes made to the three components of sustainability: biophysical, economic and social.

The innovation of the DESSIN's framework lies in that it provides an integrated view of the problem of each different case study. By focusing on ecosystem services, it manages to connect all possible impacts on environment to society's well-being. Furthermore, it allows and assesses different future scenarios depending on each possible response to the problem, thus enabling the evaluation of each action for its feasibility and environmental or economic benefit and from those criteria, distinguish the best possible solution. Finally, one of the greatest advantages of DESSIN is that the whole approach focuses solely on sustainable development. It assesses all actions as part of the ecosystem, all interconnections between natural and artificial environment and all possible conflicts, giving a future projection of the impact that responses will have.

Even though DESSIN manages to provide a spherical viewpoint of the problem and its possible solutions for each study case, it is also affected from some limitations of most management frameworks. Because of its multidisciplinary nature, the amount and the different types of the needed data, indices and methodologies conceal the danger of oversimplifications and assumptions that cumulatively can lead to erroneous conclusions (Anzaldua et al., 2018). More noticeably, due to the flexibility of the framework and because it is case study driven, the available datasets and their appropriate processing methodologies can differ, and as such careful consideration must be taken before the application. Furthermore, it requires multidisciplinary skills and knowledge that can be found in bigger research teams and for that reason it is recommended for the DESSIN framework to be applied to larger scale projects. The first applications of the DESSIN framework, during its development were conducted on three water systems. In Denmark it revolved around the control of the urban water cycle. In Germany the study focused on river restoration for improved water quality and recreation and in Spain the project referred to the impacts of the creation of artificial infiltration ponds (Anzaldua et al., 2018; Termes-Rifé et al., 2016). Other implementation cases involved water shortage issues in urban areas and water quality problems from river supplies (Riegels et al., 2020). The applicability of the framework on inland water bodies has been extensively demonstrated, but there are no case studies on marine or coastal systems.

Marine and coastal areas could benefit greatly from DESSIN application, but as they are more complex systems, certain adjustments must take into account oceanographic and meteorological criteria, as well as anthropogenic processes that are unique for those systems. In this paper, a case study is presented for using a modified version of DESSIN's framework for monitoring the state of a beach and how certain responses would affect it. The area of interest is the Kamari beach in Greece where due to high erosion rates, anti-erosion measures must be taken in order to preserve the coastline and sustain the touristic activities that are the main income of the area. The proposed framework assesses the current state of the beach, analyses the pressures that it receives from anthropogenic and environmental processes and makes future projections of the impact that each possible solution will have on the system based on biophysical, social and economic criteria.

Proving that the DESSIN framework could work for coastal applications, opens new opportunities for sustainable development and blue growth. As the global society's focus turns to the coastal and marine environments (Portman, 2016), there is a need for new and innovated management frameworks that can respond to the complex nature of these systems in order to ensure its protection. DESSIN manages to merge already established and already proven concepts and models such as the ESS framework and DPSIR, in one holistic management model that has immediate practical use. The framework's adaptation for coastal applications would benefit greatly both society and the economy by balancing growth with preservation of natural resources and of course the environment by pinpointing the impact that certain actions would have on the system. The practicality of the DESSIN lies in that its application by definition needs a certain action to be examined and as such it is applicable beyond the scientific community and becomes pertinent to policy makers, managers and practitioners.

For the framework's application, a large spectrum of different types of data and methodologies are used, and each has its own benefits and limitations. Highly accurate in-situ datasets were used for the geomorphological and oceanographical characterization of the coastal area. In contrast, for structuring the beach visitors' opinion on the coast, open-source data were gathered from web traveling advisor portals, which has the advantage of extensive availability but also introduces a level of uncertainty. Furthermore, proxies were created for the area's infrastructure status with the use of satellite data and from information gathered from national databases that may both contain inherent errors. The contrasting nature of the datasets should provide an example of the flexibility of the framework. Careful planning must be made before each application as the data and indices must be reassessed on a case-by-case basis.

Most methods to process and visualize the used data are applied through descriptive statistics and GIS applications. The socio-economic data were briefly gathered through web searches and later spatially visualized through Google Earth. Following, the Methodology section presents the applied framework while all used indices are thoroughly introduced. In the next section the results of all used models and indexes are presents and visualized. The Discussion section interconnects all the results while incorporating them in the applied framework. Finally, the last Chapter concludes the paper while presenting the limits of the research.

2. Methodology

2.1. Study area - Kamari beach

The study area is located on Santorini, Greece one of the most popular tourist islands in Greece, and one of the top choices for visitors worldwide. The large number of visitors throughout the summer created the need to develop tourist accommodation and infrastructure, playing a leading role in changing the employment of the island's inhabitants. With the emergence of the touristic sector as more fruitful, the local industrial sector has deteriorated, resulting in the closure of seven factories; the only one left that operates is in danger (Drosou, 2005). Agriculture is the second largest economic sector of the island, and it is worth noting that out of the total of 22,000 acres in 1970, 15,000 are now cultivated (Freese, 2005). Although the inhabitants of the island are engaged in agriculture, processing, construction and services, the basis of Santorini's economy is coastal tourism. Due to the strong preference of tourists for Santorini, tourism on the island is active almost nine months a year. The number of visitors during the peak tourist months is significantly higher than in other months.

Kamari has an area of about 0.93 km^2 and it is located in the south eastern part of Santorini, with coordinates 36.3770° N, 25.4807° E. The area was the port of Ancient Thira and its ruins are located today in the sea. The village is only 8 km from the island's capital and 6 km from the airport. In the last census in 2011 in Kamari, there were 1344 inhabitants and the population is expected to have an increasing trend in the next, as it has in the last 15 years. The beach of the village with the homonymous name is the largest resort of the island because of the black sand and its length. The exposure of the beach to wave action comes from NE, E, SE and N directions with the largest active wavelength development occurring in the SE sector. The analysis of meteorological data showed that the largest percentage of winds come from directions that are not able to create wind waves that can affect the beach. Long-term wind time series have also revealed south and southeast ranges that can cause severe ripples (Hasiotis et al., 2017).

2.2. Data

Due to the nature of the study a wide variety of datasets for assessing the environmental, economic and social state of the study area which are needed for the implementation of the framework. The repositories vary from website data sourcing, in situ oceanographic and geomorphological data from field studies and manually produced spatial data from satellite images and GIS techniques.

The travel fare platform (www.booking.com) was used to retrieve data on the number of hotels, restaurants/cafes and their spatial distribution. The platform TripAdvisor was also used for collecting a sample of comments from the tourists who visited the village in order to analyze their impressions of the area's infrastructure, entertainment and the beach. These data were used for mapping the establishments and their number and for creating a profile for the main problems or amenities of the touristic aspects of the beach.

Remote sensing data were used for mapping the state and the anthropogenic impact inside the beach area of Kamari. Through the Google Earth Pro software, four images were taken to map the spatial distribution of umbrellas and their temporal change. Furthermore, the shoreline was digitized for each available year in order to determine the areas of the beach that tend to have a loss or deposition of sediment seasonally and yearly and their respective rates.

Statistical data of the populated area around the beach were retrieved from the Greek Statistics Agency (Hellenic Statistical Authority, HELSTAT). These data included the number of beds, rooms and population in the area. They were used to determine the capacity of the area and the capability of the infrastructure to host visitors, as well as the ratio of the population to tourists and the economic dependency on tourism.

Coastal morphology, meteorological and wave activity data were collected from field instrumentation and surveys (Chatzipavlis et al., 2019). The dataset involved sediment size, erosion rates, seasonal wind direction and velocity, maximum wave height etc. These were essential for evaluating the environmental pressures on the shoreline and for determining how the beach would react after the implementation of the proposed anti-erosion measures.

2.3. Methodology

2.3.1. DESSIN framework

The basis of DESSIN is a framework that analyzes the interaction of society and the environment, using the well-known DPSIR model. It also incorporates two methods of classifying ecosystem services, Common International Classification of Ecosystem Services (CICES) (Potschin and Haines-Young, 2011) and Final Ecosystem Goods and Services-Classification System (FEGS) (Landers and Nahlik, 2013). The former is used for the consistent classification of ecosystem services in Europe, while FEGS is used by the US Environmental Protection Agency. The classification is based on the hierarchy of ecosystem services at three levels of services: provisional, regulatory and maintenance, and cultural. By adapting the two methods above, the ecosystem services used in the framework are consolidated and a common classification is achieved.

The frameworks structure is based on 5 key parts (Fig. 1). The first part of DESSIN describes the study area. The second part identifies the problem of the system. At this point, the first two parameters of the DPSIR are being analyzed: 1) the driving forces that define activities in the region, and 2) the subsequent pressures put on the system. The third part is DPSIR's fourth parameter, the response. This outlines the proposed measures and attempts to evaluate their performance. The potential beneficiaries of the changes to the proposed measure will then be

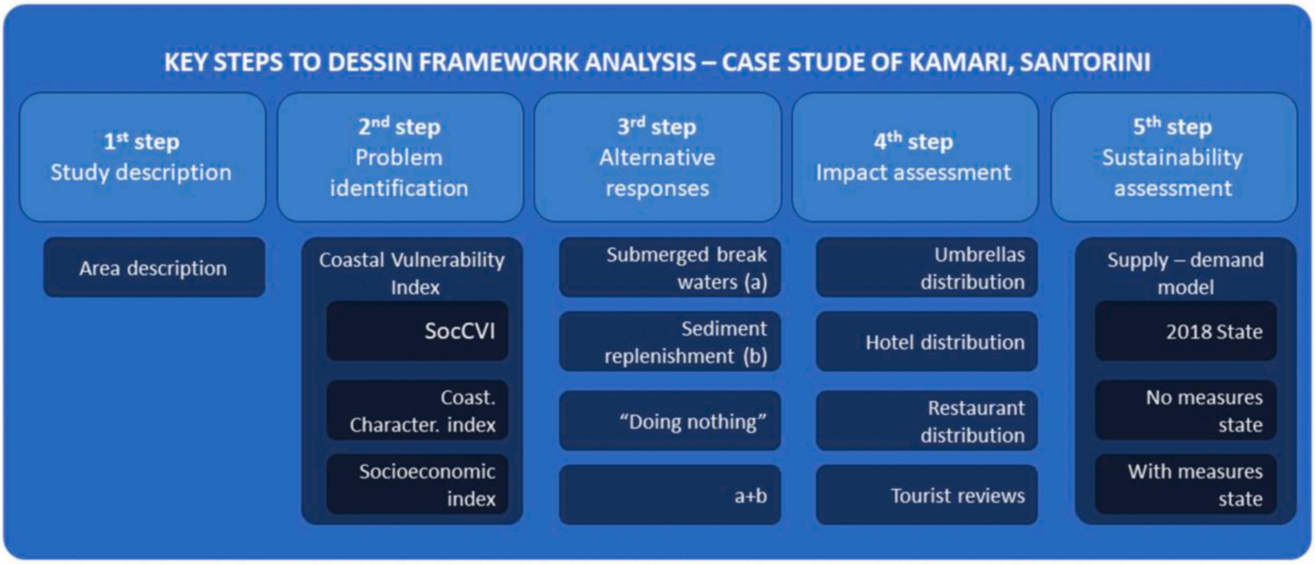

Fig. 1. DESSIN framework key steps and used indices.

identified. The fourth part of the analysis assesses impacts. Therefore, an analysis of the present state of the system and the degree of sensitivity to the proposed measure is involved.

Impacts are divided into Impact I and Impact II. The first one is the selection of indicators that describe the system biophysically and relate to the corresponding ecosystem services. Impact II is linked to the selection of indicators related to human well-being and to the relevant ecosystem services. The procedure is applied twice, the first time before the implementation of the measure and the second after implementation of the measures. The last part of the framework is the evaluation of sustainability. In this step, the appropriate sustainability indicators are selected to evaluate and monitor the proposed measure, along with other possible alternatives.

Due to high erosion rates at Kamari beach (Hasiotis et al., 2017), anti-erosion measures are needed. The possible responses are a) placement of submerged breakwaters, b) sediment replenishment, c) a combination of the former two (Velegrakis, 2017) or d) "do nothing", where no measure is taken (Aaheim and Orlov, 2016). The DESSIN framework is applied for all possible scenarios with the best one distinguished based on the final results. For each step of the implementation framework different models, indexes and data are used (see Fig. 1).

For this application of the framework, the selection of the most appropriate indicators to represent each DESSIN step was made through literature review and correlation with related fieldwork (www.erabeach.aegean.gr). The application of the selected coastal vulnerability indicators allowed identification of the underlying problem. The used indicators account for ecological, social and economic criteria resulting in a comprehensive coverage of the situation in the region. Thereby, each criterion is quantitatively scored and can show if it's a driving force for Kamari's beach. Response alternatives were based on the proposed coastal protection measures from the field study report of Velegrakis et al. (2017). The researchers assessed the impact of different measures, namely the introduction of submerged breakwaters and the beach replenishment with sediment, in order to combat erosion problems that the local authorities faced in their area. Three scenarios of their application on the beach of Kamari were examined, their individual and simultaneous application. However, one scenario that has yet to be included is the minimal human intervention in the current and future condition of the coast.

The fourth part is the impact assessment. Due to the main variable of the study being the beach of Kamari itself, three socio-economic parameters were selected that connect tourists/visitors with the main economic sources of the village. Restaurants, hotels and leisure facilities on the coast (umbrellas and sunbeds) are some of the land uses that are utilized to a greater extent by city visitors and make it touristically attractive. The spatial analysis of the hotels and restaurants shows the preference of the stakeholders to provide the services in proximity to the beach. The beach's leisure facilities are a substantial component for assessing the beach's sensitivity. From the spatial-temporal depiction of the leisure facilities on the beach of Kamari it is shown that they are directly related to the beach's erosion. Looking at these socio-economic parameters in the long run, there is also the risk of flooding that may occur due to SLR and exacerbation of coastal erosion in scenarios without protection. The analysis of the posted tourist comments shows the emphasis of the visitors given to the beach, the hospitality and recreational infrastructure. The analysis of tourists' preferences for services and goods is an important element for the economic development of Kamari but also for their protection and upgrading.

The fifth part assesses the viability of the selected protection measures, based on their costs and benefits, and their impact on the beach and the society. The application of the supply-demand model (Silvestri, 2018) is suitable for this analysis as it incorporates all three parameters of sustainability analysis, economic, social and environmental. The sustainability analysis in this case examines three scenarios: 1) the state of the coast in 2018, 2) with no protection measures will be taken (deterioration of erosion) and 3) following the application of anti-corrosion measures (submerged breakwaters and beach nourishment).

The state and impact before and after the construction of the submerged breakwater are estimated from relevant geomorphological studies and an environmental socioeconomic modeling of carrying capacity based on a demand - supply model. The estimating of the hydrodynamic pressures and spatial-temporal variation of the shoreline width before and after the construction of the measures (Velegrakis, 2017) gives a picture of the environmental impact. For socio-economic impacts, the change in beach carrying capacity is used as an indicator. The main economic activities of Kamari are directly based on tourism, so it is necessary to calculate the impact on the beach as a tourist attraction. The visitor carrying capacity was chosen as it combines the dynamic relationship of beach size with the beach visitors and the economic needs of the permanent population.

The main vulnerability of the coastline is due to environmental factors, such as coastal geomorphology, SLR, currents and more. However, socio-economic factors, which are crucial in the shaping and evolving of the coastline are often excluded when studying environmental problems. Examples of socio-economic processes that contribute to the intensity of erosion can be extreme, they may result in environmental pressure due to conflicting land uses, road construction, depletion of sediment etc. (Eurosion, 2002).

2.3.2. Coastal Vulnerability Indexes

Coastal Vulnerability Index (CVI) and Socioeconomic Coastal Vulnerability (SocCVI)) are the used indices for the coastal vulnerability estimation. The CVI expresses the vulnerability of the coastline using environmental parameters such as geomorphology, slope, erosion rate, sea level rise, wave height and tide difference (E. Robert Thieler, 1999). SocCVI adds to the equation the human factor by taking into account adjacent anthropogenic activities. In both indexes the variables are incorporated on a scale of 1–5 depending on their impact, with 1 having the smallest effect and 5 having the greatest (Alexandrakis et al., 2014).

According to equation (1), CVI was calculated using six variables. The outcome was normalized to maximum and minimum and then categorized from 1 to 5, with 5 indicating the highest risk of vulnerability.

$$CVI = \sqrt{\frac{GEO*ERO*CS*RLSR*Hs*T}{6}} \tag{1}$$

GEO is the sediment size of the beach is characterized for the whole coastline as gravel. ERO, the erosion rate was calculated based on two polygons of the coastline that were digitized in detail from satellite imagery, for the years 2016 and 2018. CS, the slope of the beach, extracted from a 12,5 Digital Elevation Model (DEM). RLSR, the mean SLR, calculated based on the IPCC RCP 4.5 (6.1 mm/year). Hs, the average wave height, collected with hydrodynamic experiments from the ERABEACH dataset (Hasiotis et al., 2017) and T the sea level difference between tides, determined based on data provided by the tides4fishing.com for the area of Santorini.

For the calculation of SocCVI the calculation of three sub-indicators was required. These indicators are: (a) Coastal Characteristics (CC) which describes the characteristics of the coastline and the resistance of its corrosion from sea level rise, (b) Coastal Forcing (CF) describes the driving forces and (c) Socio-economic (SE) adds the dimension of the human factor, recognizing the potential impact on existing infrastructure

$$CC = \sqrt{\frac{RLSR*T*Hs}{3}} \tag{2}$$

$$CF = \sqrt{\frac{GEO*CS*ERO}{3}} \tag{3}$$

$$SE = \sqrt{\frac{SET*TN*CH*LU*E}{5}} \tag{4}$$

SET is the populated area near the coastline, TN is the road network rated according to its category and size, CH expresses whether or not archaeological sites or monuments exist near the coastline, LU the land uses of surrounding areas classified according to their economic importance and E the economic value of the coastline according to the activities that depend on it.

The final calculation of the SocCVI is given by the equalization of the three sub-indices.

$$SocCVI = \frac{CC + CF + SE}{3} \tag{5}$$

As with the CVI, the results are normalized to the maximum and minimum values on a scale of 0–1 and the model values are visualized along the coastline in vector polygons. The created polygons were based on the Thiessen method from 1m above the waterline.

2.3.3. Modeling of visitor carrying capacity

Carrying capacity is a multidimensional issue and is directly linked to the sustainability of the area. For holistic assessment of sustainability, both environmental and socio-economic constraints should be considered (Cristiano et al., 2020). For the Kamari beach for instance, an environmental constraint may be how many people can be present on the beach, but this simple approach does not take into account whether tourists are willing to visit the beach when it is in full capacity. Modeling of the carrying capacity should therefore include all the parameters that determine the completeness, traffic and economic viability of the area.

From the above criteria, the theoretical environmental-socioeconomic capacity model based on the supply-demand model, was chosen. This model assesses the constraints posed by the environmental characteristics of the beach, the socio-psychological profile of the visitors to assess their density tolerance against the threshold of the visitors required for economic viability of the area. To construct the model, three curves must be created for each of the dimensions of the problem, namely, the environmental, the economic and the social. The intersection point of the environmental curve with social one, shows the equilibrium point of the system. If the point is below the economic curve, then there is no economic viability, as this will practically mean that tourists visiting the beach will not be enough to support the local market.

From the social point of view, the attractiveness of a beach has two sides. On one hand, individuals need a minimum of a personal space. On the other hand, if the beach does not have enough people, a visitor looking for social interaction may see this as an indicator that the area is not interesting enough. So, there is a balance between the number of visitors that determines the arrival of new ones. The equilibrium is quantified according to equation (6) which shows the demand of the coastline (social index).

$$N = (x - s)*\left(1 - \frac{x}{e}\right) \tag{6}$$

Where N is the dependent variable indicating the number of visitors, x the personal space available to each visitor, and s and e the minimum and maximum thresholds beyond which visitors stop coming or begin leaving. This equation is in the form of a parabola that intersects the xx axis at the points s and e.

The provision of the coastline (environmental restriction) is directly related to the characteristics of the beach as they determine the number of visitors that can theoretically be accommodated. Demand modeling is given in equation (7).

$$N = \frac{D}{x} \tag{7}$$

Where D is the beach area in m^2 and x, as above, the space available for each visitor in m^2/person. The model is in the form of an exaggeration, showing the social carrying capacity of the coastline. Economic viability is defined as the minimum traffic, below which the region's tourist activities cease to be profitable. This limit is to cover 30% of the total accommodation, which can be represented as a straight line parallel to the xx axis.

$$N = 0.3*PL \tag{8}$$

Where PL the number of all the beds of each type of accommodation in the area of Kamari.

Another advantage of this model is that the viability of the site in a future alternative scenario can be estimated, which could be an erosion event for this particular project. This parameterization can be achieved by varying the input data of the coastline flow curve, and in particular the beach area.

The model is repeated twice to verify the response of the Kamari carrying capacity to a scenario where the coastline is eroded. In the first case as input data it accepts the current condition in the region and in the second case the method is repeated but with estimates of the coastline change based on the Intergovernmental Panel on Climate Change RCP4.5 sea rise scenario. A comparison of the two models shows the change in the spatial equilibrium and whether Kamari will be able to withstand the initial "shock" of the change and remain financially viable.

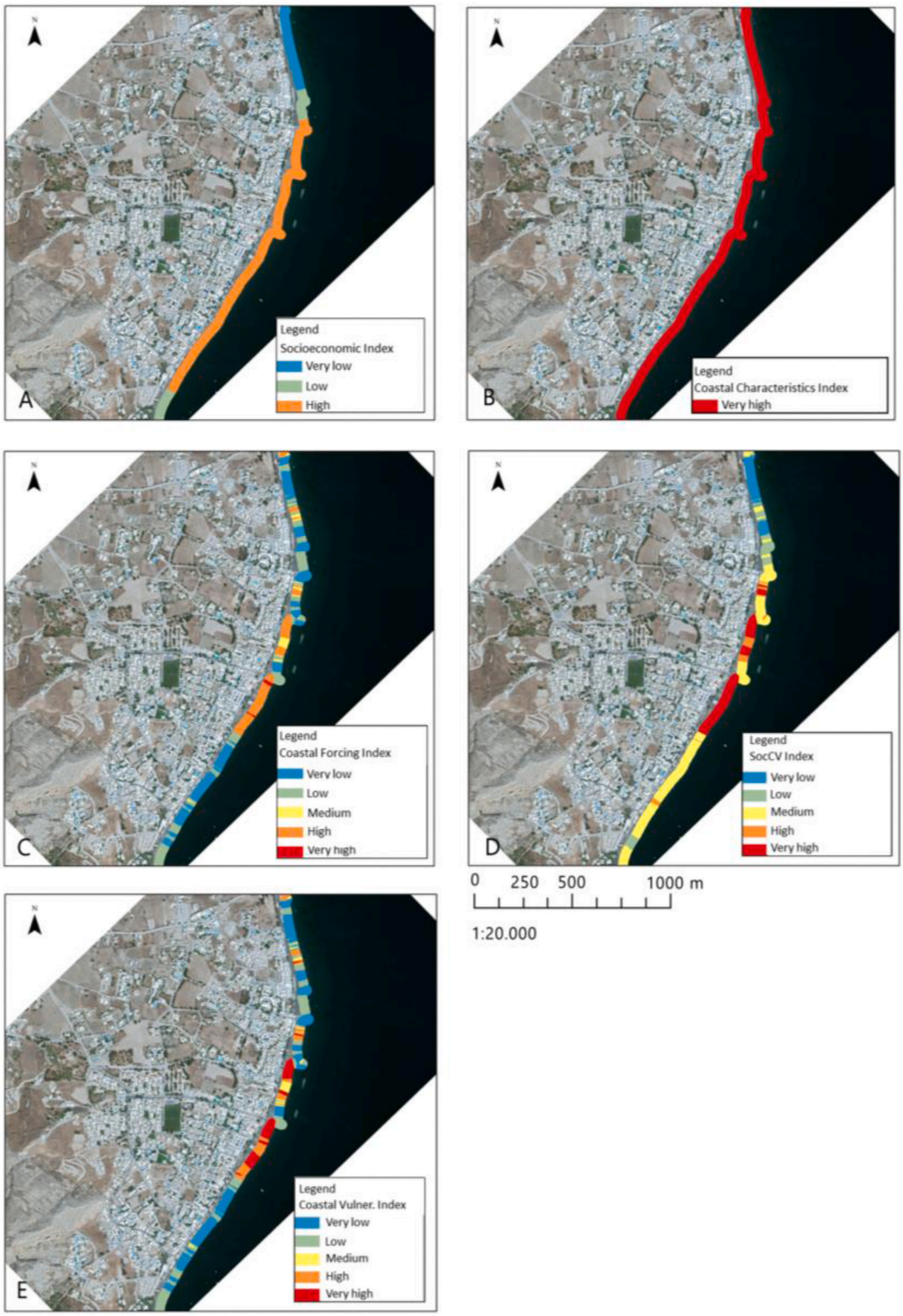

Fig. 2. (A) visualization of socioeconomic index (B) visualization of coastal characteristics index (C) visualization of coastal forcing index (D) visualization of social CVI (E) visualization of coastal vulnerability index.

2.3.4. Socio-economic analysis

Of the 285 hotels operating in Santorini, 122 hotels are in Kamari as are 120 restaurants and entertainment venues. To analyze the spatial distribution of socio-economic parameters, the number of hotels, restaurants/cafes and umbrellas in the coastal environment were used. The data collection was achieved through tourist websites, like booking.com. The multitude of restaurants and hotels were processed through ArcMap software. Areas of interest were marked at 100, 200, 400, 600, 800 and 1500 m from the coastline for easier observation of the spatial layout of the infrastructure.

To monitor the coastal clusters of the umbrellas, aerial photos were taken from the Google Earth Pro service for four years. The selected images were taken during the peak tourist months and they cover the years 2003, 2012, 2016 and 2018 (06/2003, 08/2012, 07/2016, 09/2018). ArcMap software was used to count umbrellas, group polygons and create polygon shorelines for each for the four years in order to compare the results for the four time periods. Note that the shoreline was captured based on the visual change of the water and land at the time the satellite was taken and therefore is not an accurate measurement of the waterline since the tide is not taken into account. To further analyze the dispersal of the umbrella population, the shoreline length was divided into four equal spatial segments. The segmentation of the zones is shown in Fig. 3, with the numbering being from north to south.

A large percentage of tourists visiting Kamari used an online travel agency to book their accommodation and choose to share their views and experiences about the place by leaving a comment on the same site they used to reserve the hotel rooms. For the analysis of the user's experience, 150 comments were randomly selected. The comments were manually analyzed to determine users' reference to the beach, the entertainment, and the infrastructure of Kamari.

3. Results

3.1. Results of coastal vulnerability indicators

The results of the CVI are presented in Fig. 2. The index was constructed using the parameters of geomorphology, soil slope, erosion rate, mean wave height, SLR rate and tidal ratio difference. Of the above variables, the highest variability is the slope of the soil with a σ=4.58° and $\bar{x}$=8.31° . The erosion along the coastline had a standard deviation of 5.71m and an average of −1.37m. The other variables have a constant value for the entire length of the coast. The significance of this event is that the vulnerability rotation can be directly identified due to these two variables, while the others determine the range of the vulnerability, offsetting the overall environmental status in the region.

The results of the CVI, show that generally the south and north sides of the beach are characterized by very low to low vulnerability. The most vulnerable areas are located in the central part, where the index values are throughout its range, with the value of very high vulnerability prevailing. Looking further into the central part, the most vulnerable areas appear to the south of the projections. The results of the index are also confirmed by the findings of ERABEACH (Monioudi et al., 2017).

The results of the SocCVI change the degree of vulnerability of the beach by establishing three characteristic zones. The three zones created are the South, North and Central zones, where the vulnerability is characterized as very low, moderate and very high respectively. This

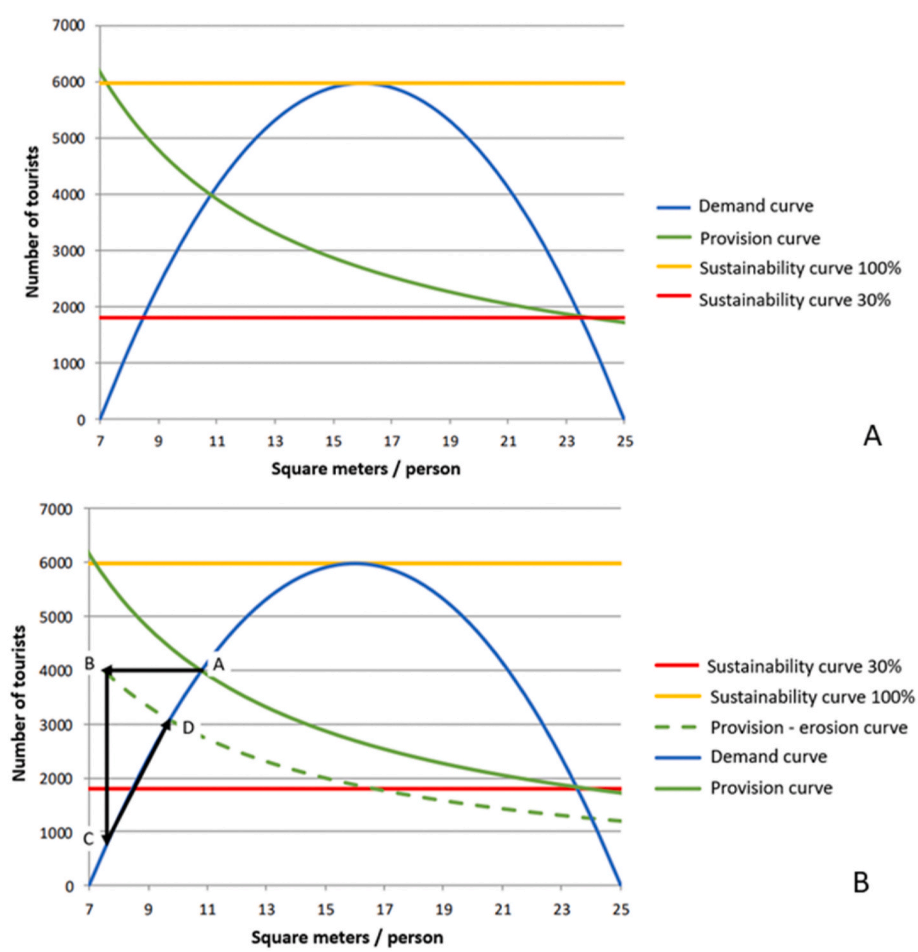

Fig. 3. (A) Demand - Supply model of the current state (2018) of Kamari. (B) Demand - supply model after the erosion (scenario of "doing nothing") and presentation of the initial systems "shock".

time, the central zone has an even higher index, as the values are between moderate and very high. The latter class even has a larger area, especially in the lower part where it appears to extend near the upper edge of the South Zone.

It is recalled that the SocCVI also takes into account parameters describing human activities, namely, population (settlement), road network, cultural heritage, land use and economic variables. These variables are represented by the sub-indicator SE, which is visualized in Fig. 2A. The other two CC and CF sub-indicators are shown in Fig. 2B and C respectively. These indicators are analyzed to identify the factors that affect vulnerability variability as they each represent different sources of pressure.

The CC index (Fig. 2B) includes the variables of SLR, tide and average wave height. All three variables are typical of the oceanographic pressures that the beach receives, but because they have only one value for their entire length, they do not differ. However, it seems that Kamari is under very strong pressure from the wave variable, as the CC indicator maintains the maximum value of the vulnerability.

The CF index characterizes the pressures the coast receives from its morphology, namely its geomorphology, its slope and the rate of erosion or sediment deposition. The results of the indicator are shown in Fig. 2C. This indicator shows values of vulnerability - pressure strength across the range, from low to very high. However, it seems that very low to low prices dominate in the north and south of the coastline, while the high prices dominate the central one. A very small part of the beach is characterized by very high index values in the southern part of the first pier. In general, the results show that Kamari beach receives the most pressures due to its morphology in its central part.

The socio-economic pressures the region receives are described by the SE index (Fig. 2A). The indicator shows three values of pressure range very low, low and high. The first two are in the northern part of the coastline, the latter in the central and southern parts. This difference between the regions is mainly due to the location of the city and the economic activities. The population is located entirely in the central and southern part of the beach and there is also a parallel road that follows the coastline. In addition, at the city and beach boundaries, the market consists of restaurants, cafes and tourist shops, with economic activity dominated by tourism, in contrast to the north, where land uses are exclusively crops.

3.2. Results of the coastline carrying capacity model

For the construction of the demand parabola (Equation (6)), the definition of the minimum and maximum space per visitor, "*s*" and "*e*" respectively, is required. Although bibliographical references pertaining to the to the personal space boundaries that each tourist or vistor seeks, we adapted the results of the field study by Cabezas-Rabadan et al. (2019). In this study, the researchers distributed questionnaires and measured the density of tourists. They found that the beaches that were preferred by guests who demanded more social interactivity had a maximum density of 2.3 m^2/person, whereas the minimum density found on beaches where guests preferred calm conditions was at 24.5 m^2/person. Assuming these numbers are close to the edges *s* and *e* to be defined, *s* took the value of 25 m^2/person. However, since the tourist coasts of Greece are on average more narrow than other areas, *e* is set at 7 m^2/person.

The coastline supply curve was made based on the size of the coastline as it was formed in 2018 (Fig. 3A). The total area of the coastline at that time was 43100 m^2 and it seems that the hyperbola (Demand Curve) reaches a maximum of 6157 people if they have 7 m^2 for themselves.

The threshold for the region's economic viability was calculated on the basis of 30% of the accommodation multiplied by the days of the tourist season. The number of all beds in the Kamari area was 5977 and so the viability threshold takes the price of 1793 active visitors to the beach. The graphs also show the maximum number of visitors according to the capacity of the village, specifically 5977 people.Based on the model results, it is concluded that the equilibrium point of the curve is close to 4000 people according to the intersection point of the demand curve with the supply curve. This means that 4000 visitors to the beach are the ideal number considering its size. At the same time, it seems that the cut-off point is well above the threshold of 1793 people needed to ensure the region's economic viability.

In order to calculate the carrying capacity of the coastline where no measures are taken to limit or reduce erosion, a new supply curve reflecting the evolution of the beach is constructed. In this case, based on the IPCC RCP4.5 sea rise scenario, it is predicted that in the long run the Kamari coastline will be reduced by 8 m along its entire length (Monioudi et al., 2017). Considering that the length of the coastline in 2018 was 1650 m, then the area to be lost is estimated at 13,200 m^2, specifically over 30% of the existing surface. The reconstruction of the model with the new data is shown in Fig. 3B, where the new supply curve is plotted with the green dotted line. According to the new model, the new capacity balance point is located close to 3100 people, which is again above the economic viability threshold. However, the balance point change according to Silvestri (2018), is not smooth and the dynamics of the system receive an initial shock before it returns, as potential visitors are unaware of the shoreline's decline. Thus, the next tourist season will come with the same number of tourists, problematic because demand will exceed supply (Point B). At the same time, the large crowd of visitors causes discomfort and therefore in the second consecutive year the traffic will collapse to a lower point below equilibrium (Point C). In the coming years, however, there will be room for new visitors and the system will rebound to its new equilibrium (Point D). The problem, however, is the alternation between points B and C, and because if point C falls below the economic viability threshold, then the local market will collapse, growth in the region will be frozen or possibly reversed and the system will not be able to recover.

This phenomenon is also observed in the new model. While the new equilibrium is at 3100 people, after the initial shock, density drops to 900 people, well below economic viability. However, it is not safe to conclude that the local market will collapse, as the RCP4.5 sea-rise scenario refers to decades of deep changes and thus the 'shock' of the system will be much smoother than presented in this paper.

3.3. Results of spatial quantification of socio-economic parameters

The large number of hotels and leisure venues indicate the significant tourism. The 122 hotels in the village cover approximately 5977 beds, raising the population by 4.4 times the peak tourist months. The 122 hotels in the village are shown in Fig. 4A. As shown in the figure, the majority of hotels are located in the coastal zone and declining over land-sea distance from the sea increases. Of the total facilities the percentage of hotels in each zone are, from the first zone to the sixth, respectively: 36.9%, 23%, 29.5%, 5.7%, 4.1% and 0.8%. The largest percentage of the touristic facilities density (hotels, restaurants, etc.) in the third zone is due to the larger area of the band (twice) than the first two. What is shown in the picture is a spatial pattern of hotels in tourist areas with a main natural sea resort. The closer the hotel is to the coastline, the greater the demand is for rooms and the greater the profit for the owner.

A similar distribution seems to be followed by restaurants and cafés in the area (Fig. 4B). The entertainment infrastructure (bars, restaurants, etc.), reaches 120, almost equal to the number of hotels. Their spatial distribution is similar to that of the hotels, thus decreasing from beach to countryside. The first two zones, with 100-m radius, are the densest in entertainment infrastructure. The first zone has 62% of restaurants and cafes followed by the second zone with 18%. The third zone is similar to 18% but is twice the size of the first two. In the fourth zone there are only 2 shops, while in the last two zones there are none.

The tourist development of Santorini in recent decades has affected all the villages of the island. Kamari beach is the largest natural resort in

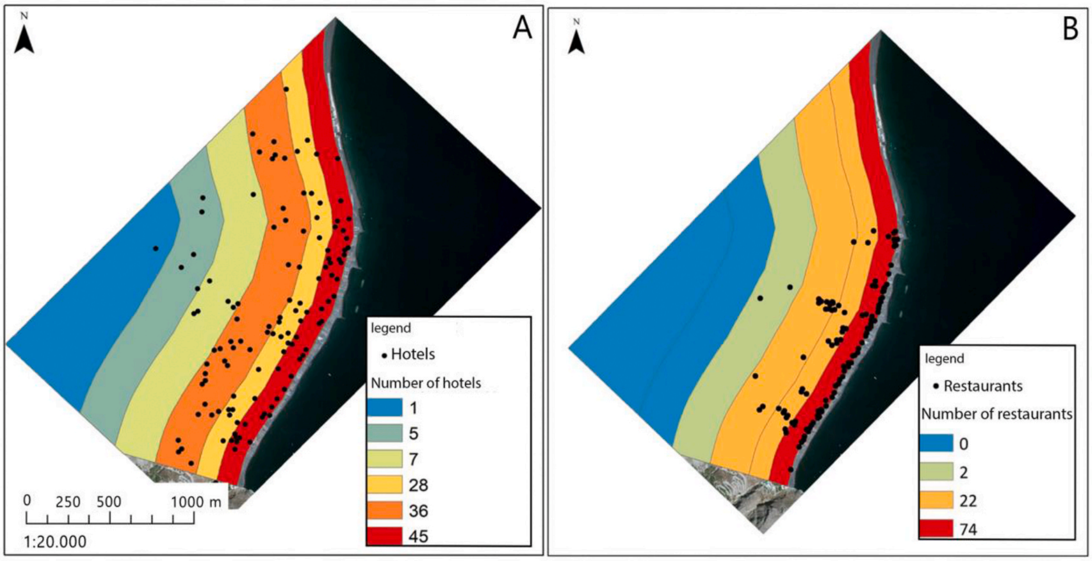

Fig. 4. Visual representation of the spatial distribution of hotels (Image A) and restaurants (Image B) in Kamari.

the village and for this reason an increase is expected in the number of tourist infrastructures, whether related to the entertainment shops or the comfort of the bathers. In addition to seaside cafes and restaurants, umbrellas and sun loungers to show this change over time.

In 2003, there were 756 umbrellas observed along the coast of the beach. The total area of the grouped umbrellas is 0.01358 km^2 (13.58 acres), covering 24.4% of the coast. Although the beachfront appears to have declining from 2003 to 2018, the number of umbrellas is 2.3 times higher than the first year. The biggest difference in the density appears in 2003–2012, but it should be noted that the time span is 9 years. Then, in the next 3 images with 4 and 2 years difference, the umbrellas increase significantly. From the first timeline to the last, the increase in umbrella shore coverage is from 24.4% in 2003 to 43.2% in 2018. The table below shows information on the number of umbrellas, the extent of their grouping and their size of coastline for the examined years.

Table 1 shows the number of umbrellas calculated in each of the four zones for the four years. As shown, beyond 2003 where the largest number of umbrellas is in the first zone, the remaining years show most of them in the second zone. It is noteworthy that, for four years, the second densest umbrella zone is the second. The third and fourth zones by density of umbrellas do not seem to follow any pattern. The two years that have a similar crowd pattern are 2016 and 2018. This can be justified by their short temporal difference. It is worth noting that the largest number of umbrellas in 2003 is almost twice the maximum of 2018.

Table 1
Umbrellas density per beach zone.

Umbrellas				
	2003	**2012**	**2016**	**2018**
Zone 1	239	348	293	383
Zone 2	171	384	445	459
Zone 3	182	348	432	446
Zone 4	157	292	431	418
Total	749	1372	1601	1706

Kamari is one of the most important tourist areas on the island of Santorini. A sample of Kamari visitors' views, from TripAdvisor's website (www.tripadvisor.com), were analyzed to identify key points of reference for the site. RAOSOFT sample size calculator (www.raosoft.com) was used to determine the size of the representative sample. Existing tourists comments are approximately 6000 in the examined period, so the requisite sample size was 150 with 90% confidence level, 5% margin error and 15% response distribution. The sample of 150 comments, from 2018 to 2019, was selected at random and constitutes a small percentage of the total. The overall rating of Kamari and the beach is rated 4/5 (very good) in 6000 posts from visitors from all over the world. 95.7% of the ratings are from 3/5 stars and above, with the small remaining 4.3% marking frustrated visitors (see Fig. 5). From the analysis of the 150 posts, specific features of the site were identified that give the visitors more emphasis. Analyzes were made based on beach quality (cleanliness, water quality, sedimentology, wave dynamics), infrastructure (restaurants, cafes, sun loungers, umbrellas) and entertainment/community (nature of the area, tourists, shops). Each variable was analyzed in a further three, good opinion, bad opinion, and neutral opinion or additional "no comment" (Fig. 5).

Observing the figure below, three peaks stand out. The majority (92%) of visitors commented favorably on the area's infrastructure, either on the beach (sunbeds and parasols) or on the coastal road (restaurants). The second highest percentage is that of good quality of beach (69%) and third in good quality of entertainment/social environment (38%). Regarding the quality of the beach, 21% found it mediocre and 12% found it bad. The cleanliness of the beach and the characteristic black pebbles that cover it have left a positive impression. The poor quality of the beach, with 12% has the highest negative rate compared to the other two characteristics. The main negative features noted are: a) the size of the pebbles on the beach (instead of sand), b) their high temperature especially at noon and c) great wave activity and intense sea currents. Only one comment was related to the morphology of the beach, pointing out the small width of the beach in relation to the length, while there were very few visitors who reported trash on the beach.

Tourists were most attentive to the infrastructures available. The organized beach and the wide variety of restaurants are the main positive points expressed. However, 5.3% of visitors said they were dissatisfied with the lack of toilets on the beach and the relatively high prices.

The least amount of comments addressed entertainment. The 38% of visitors who posted a positive review said the area was ideal for couples

Fig. 5. Tourists comments analysis of the Kamari beach, regarding three variables, Beach, Facilities and Entertainment quality.

and families as it was significantly quieter on the northwest side of the island. The polite shopkeepers and the calm climate on the beach were the key elements. The negative comments, had to do with nudism on the beach, tourists exhibiting inappropriate behavior and the plethora of beach retailers.

4. Discussion

The pressures on Kamari's coastline come from environmental, social and economic sources. Environmental pressures consist of the morphology of the coastline and the oceanographic regime of the area. From the results of the CVI and SocCVI vulnerability indices, it was shown that the greatest pressures come from the SLR, the waves and the high tide, while the CC index gets the highest possible values along the entire length of the coastline. From a morphological point of view, pressures on the beach are lighter. The CF index which takes into account the geomorphology, the slope and the erosion rate proves that the northern and southern part of the beach receive quite weaker pressures as the index is characterized as very low, in contrast to the central part where high values prevail. In other words, it seems that from the environmental point of view, Kamari is more endangered by the hydrodynamics than by the land uses. In particular, comparing the CF and CC indices, the central part is the one that receives the most pressure and especially the areas under the cantilevers.

With to the the Socioeconomic Index, the coastline is under the greatest pressure in the southern and central part. In these areas, the index was characterized strong and in the north low. The difference between these areas lies in the location of the village of Kamari and the economic activities located in the area. The population is entirely in the southern and central part, so land uses and economic activities are mostly made up of tourism, which gets the highest score on the vulnerability scale. In contrast, no houses or roads are located in the northern part, while land uses are limited to arable land. As a result, the northern part has less economic value for the region and thus is not prioritized protection and preservation of the coastline.

Comparing the environmental pressures with the socio-economic ones, Kamari is at the greatest risk due to its morphology and hydrodynamics. The CVI index, which calculates vulnerability using only the physical characteristics of the coastline, showed that the beach is endangered mainly in its central part. Taking into account the socio-economic variables, the field does not change significantly except for the degree of the vulnerability risk. In other words, Kamari is mainly endangered by ripples and geomorphology and at lower degree by human activities. This may indicate that the measures to be taken should focus on the conservation and protection of the coastline from the sea and not directly on land use control. Particular emphasis should be placed on shielding the beach from weather phenomena such as wind generated waves and storms, as in the current situation the coastline is extremely vulnerable.

The long-term erosion of the beach is highlighted in the study and its possible deterioration due to climate change, shows the need to build a technical anti-erosion measure to reduce the erosion. In the study of Velegrakis (2017), various numerical simulations were performed with scenarios of the current sea level and the future with the effect of hard and soft anti-erosion measures. Emphasis was placed on the artificial replenishment of the coast and the construction of submarine breakwaters. The four underwater breakwaters are proposed to be placed in the southern part of the beach at a depth of 4–5m, with a length of 80m each and a distance of 50m between them. Regarding the method of artificial replenishment of the coast, various replenishment sediments and characteristics of sediment granules were examined. For the extension of the width of the coast by 33 m to the sea with a sediment size of 0.6 mm (d50), with an optimal slope of 0.25, it was estimated that 136 m^3/m are required (Velegrakis, 2017).

Through the ERABEACH project (www.erabeach.aegean.gr), with the monitoring and analysis of erosion of the beach of Kamari, it was found that the most vulnerable parts of the coast are the middle and possibly the northern part (Hasiotis et al., 2017). Although anti-erosion protection measures were installed on the beach, results show that the high variability of the coastline is evident even in this area with local erosion >20 m (in the period 2013–2016). Through the study of the results of the coast monitoring system in the period June 2016 and December 2016 it was noted that on the coast are reflected reverse patterns of loss and supply of sediment, while there is a great variability, with maximum and minimum positions being between 13 m and 28 m. The highest coastline stability is noted in the southern part of the coast, while the northern part is characterized by significant erosion. In addition, greater coastline stability was observed during summer observations (Hasiotis et al., 2017). With the further analysis of satellite images of a four-year monitoring period, coastal erosion is ensured especially with large sediment losses mainly during energy episodes.

The condition of the beach before and after the construction of the project is examined with the results of the supply and demand model. For this purpose, three models were constructed, two of which were described in the results chapter. The first of these three models, is the reference point as it shows the carrying capacity of Kamari in 2018, the second model based on the characteristics of the beach if no measures are taken against erosion, and the third model calculates the carrying capacity, once the protection measurements are implemented. The comparison of these models shows what the condition the future evolution of the beach depending on the decision that will be taken to solve the problem.

In 2018 it was found that considering the environmental characteristics of the beach, and the social perception of visitors, the carrying capacity of Kamari is about 4000 people. This number exceeds the limit of economic viability, which is set at 1793 people, and thus the local market can be supported. In the current situation, Kamari can support the economy of the region and grow its tourism sector, as the equilibrium point is almost three times higher than the threshold of sustainability.

In the scenario where no measures will be taken to protect the coast, it was found from the literature that the new area of the beach will be 29900 m^2 which means less space for visitors and thus changing the dynamics of the system. The new model showed that the equilibrium point shifts to 3100 people. This point is again above the sustainability limit, but it has been shown that the initial "shock" of change will throw it below the threshold in the first phase. However, because the change is gradual and over a long period of time this "shock" will probably be smaller. This does not mean, however, that the effects of erosion will be favorable or even acceptable, as the reduction of the point does not give the market the opportunity to grow.

For the construction of the model for the condition of the beach after the implementation of the project, a new coastline width was calculated (Fig. 6). The part of the beach that will be protected by breakwaters and will be replenished with new sediment will add to the shore approximately 11055 m^2 and with the erosion assumed to occur on the rest of the beach the area will likely encompass 46315 m^2. This size is very close to the data of 2018 and shows that the coastline will mostly be maintained with limited gains. The model for this case is shown in Fig. 6. It becomes apparent that the equilibrium point takes a larger position even if it does not have such a significant difference. This point is again above the threshold of economic viability, thus the project will have positive consequences for the region for both the environmental and the socio-economic dimension.

Athough the strategy of sediment replenishing of the beach is cited as the most cost-effective solution (Aaheim and Orlov, 2016), the weakness of the weather protection measure reduces efficiency. On the other hand, underwater breakwaters are a much safer investment due to their weather resistance. The combination of the two coast protection measures seems to be the most effective. Breakwaters are great protection against the hydrodynamics while they nourish the coast in sediment. The conservation of the coast and the equivalent sediment from the sea will help the immediate increase of the width of the beach.

In summary, the options available for the protection of the area and their implications are as follows:

With the scenario of "do nothing", the configuration of the coastline is left as it is without any human intervention to protect it. It is the most economical and short-term economic solution as it turned out that the market is not in danger of collapsing. However, economic activities will decline and there is also the possibility of different effects per region. In particular, the fact that each part of the beach receives different pressures, resulting in different erosion rates, can cause different problems along the coastline. Nevertheless, looking at the beach as a whole, the destruction in one location can affect the others through social perception. In other words, in the long run, this tactic is not sustainable enough.

The construction of underwater breakwaters in combination with sediment replenishment will keep the coast at today's standards. This is confirmed by the adjustment of the supply-demand model of the coastline with its profile in case of implementation of these projects. It turned out that in this case the carrying capacity of the beach is maintained at the levels of 2018 and so it can be said that socio-economic activities will not be affected as well as that there will be the same opportunities for development. The shielding of the beach with artificial means is confirmed as the most economical long-term solution by the utilitarian approach (Aaheim and Orlov, 2016).

Based on the results of this study, the proposed optimal solution for the beach of Kamari is the construction of breakwaters in combination with sediment replacement. It is the only viable solution that ensures stability in the region and does not pose a risk either to the tourism industry or to the properties of the inhabitants. It will give Kamari the opportunity to be one of the most competitive tourist attractions in Santorini as it will keep intact the environment and the infrastructure that make it up.

Climate change and its immediate impact on the coastal environment has created the need to establish frameworks for assessing the sensitivity of the coastal ecosystems. The DESSIN framework is an innovative solution that successfully manages to combine ESS assessment to policy making in a holistic approach. Direct comparison between management frameworks can be difficult as they are designed to serve specific purposes and often rely on more theoretical conclusions than analytical results. But the majority of modern practices has acknowledged the value of the ESS framework and its integration in coastal management solutions.

De Alencar et al. (2020) adapted the method "Circles of Coastal Sustainability" to create a framework capable of covering both local and large-scale studies. They proposed an approach of evaluating the coastal sustainability based on four axis, economics, environmental, social and politics, while emphasizing the need of further sub categorization for a holistic assessment. The method is especially useful for the identification of the problem and provides the policy makers a way to easily understand the relationship between ecosystem services and human well-being. DESSIN includes many of those aspects, but it focuses more on solving a specific problem. Furthermore, it forecasts problems and suggests solutions as future scenarios in order to assess the long-term impact on the coastal ecosystem services.

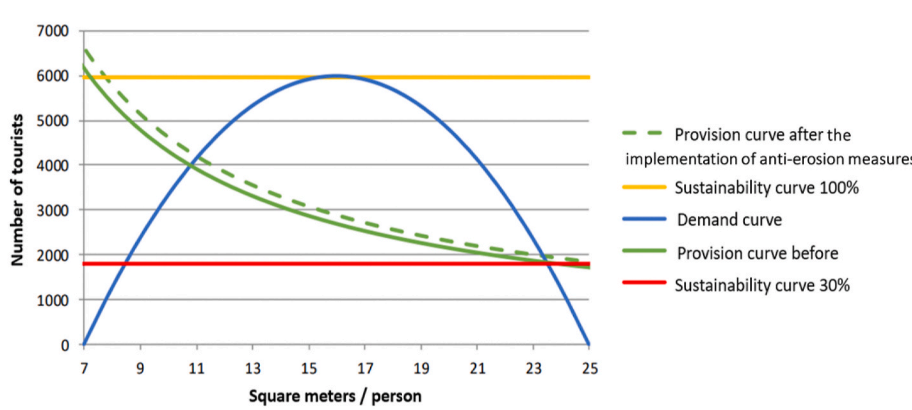

Fig. 6. Demand - supply model based on the adaptation of breakwaters and of sand replenishment of the Kamari beach.

Furlan et al. (2021) developed a multi-dimensional coastal zone vulnerability index which was applied to all coastal areas of Italy aiming at the identification of the impact that climate change will have to the Italian coastline. Compared to the CVI index applied in the case of Kamari, the above method evaluates the region by applying the indicators twice, with current and future data, while at the same time incorporating economic parameters such as gross domestic product (GDP). The results of the study capture the best and worst case of vulnerability, thus giving a complete picture of the effects of climate change on the coastal zone. Even though the study does not aim to provide a complete coastal management framework, but rather an assisting tool for decision makers, it is a prime example of how the flexibility of DESSIN incorporates different methodologies for assessing the vulnerability of Kamari.

5. Conclusions

This case study presents a holistic decision-making tool for monitoring beaches and evaluating the best possible approach for preserving them. It encompasses potential threats due to environmental conditions and anthropogenic activities both economic and social. It provides a proposition for sustainable development and blue growth by taking into account the immediate benefit of the public, economically and in terms of ecosystem services.

The DESSIN framework exhibited great potential for application in the coastal zone. The risks were carefully mapped and a future prediction of the effects of the response was made. With this information, it was possible to decide which anti-erosion measure would be best for protecting the shoreline, both from the sea and the land, and which would more economically viable, saving resources from the municipality which could be prove valuable in investing in other areas, for the benefit of the public.

DESSIN is an efficient research tool for studies with contributions from a variety of disciplines and large databases. The application of the framework is described by five key parts, which facilitate the research process, in particular in multidisciplinary studies. Although the structure of the framework is predetermined, it gives freedom of choice of indicators and methodologies for optimal implementation. A large part of DESSIN is based on the well-known DPSIR framework, making the innovative framework easy to learn and apply.

An important part of the framework is based on the analysis of ecosystem services. The innovation of the model is marked with the incorporation of two notable tools, FEGS, and CICES. The in-depth analysis of ESS can be taxing as the process is both time consuming and complicated. The analysis is performed from two perspectives, the use of ESS and the stakeholders that are immediately affected by them. The framework evaluates the ESS based on the relationship they have with the stakeholders, distinguishing the most important ones that have a direct impact on human wellbeing. One limitation that arises from the methodology is that due to its complexity, there is a significant uncertainty of the results.

The indicators that were selected depended on the available data. Since the main problem was the erosion of the beach, the main goal was to identify the areas that posed the greatest risks as well as the primary pressure behind the erosion phenomenon. The indices CVI and SocCVI were appropriate tools for this study, as they related the morphological parameters of the beach to the socio-economic parameters. It should be noted, that the accuracy of these indicators is directly related to the available data and the researcher's skill in GIS applications.

The modified supply-demand model allowed us to determine the viability of the suggested anti-erosion measures and their long-term impacts. It allowed the evaluation of each scenario in a spherical point of view by considering all aspects of the system, namely ecological, economical, and social. Necessary data for its application were commonly available but again it requires multidisciplinary knowledge for the results' interpretation.

The use of the online travel agency platform, as a source of information about the Kamari, functioned as a tool for ranking the systems' ESS. Although the methodology highlighted the importance of entertainment services in Kamari, only a small percentage of comments were used. The method would be more effective with the automated analysis of the comments in a larger sample supplemented by additional databases. Even though the framework demands a large dataset in order to be applicable, the process is straightforward and flexible enough to use in many, different cases. The data and methodologies used in this paper are not mandatory, but rather made based on data availability, the morphology of the area and the nature of the problem. Implementation of the framework should follow a case-by-case approach, first investigating the state and the problem, and then deciding which decision plan is more suitable. For example, DESSIN is not restricted only in usage for anti-erosion measures installment. It could be used in infrastructure placement, the establishment of underground drainage systems, coastal zone recreation, declaration of new marine protected areas, blue energy wind park building and in marine spatial planning.

CRediT author statement

Alexandra Ćulibrk: Conceptualization, Methodology, Data curation, Writing. **Ourania Tzoraki:** Methodology, Supervision, Writing – review & editing. **Michelle Portman:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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