Is the insular coastal tourism of Western Greece at risk due to climate induced sea level rise?

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Abstract

Beaches are among the most common areas for tourism activity constituting valuable economic resources. However, due to their location in the coastal zone they are particularly exposed to the impacts of Climate Change (CC), which is expected to have broad implications for the development prospects of the economy and human welfare, as a result of, amongst other, extreme events and sea-level rise. Looking beyond 2050, it is considerably important for beach tourism managers to have developed proper adaptation strategies. The main scope of the paper is to support tourism adaptation planning, in response to sea level rise impacts on beach zones at a regional scale, and in specific in the touristic beaches of Ionian Islands (Greece). The methodology follows the AR6 (IPCC, 2022) approach for Risk Assessment along with the concept of the Impact Chain according to which Risk is expressed as a function of factors (i) Hazard (H), (ii) Vulnerability (V) (sensitivity and adaptive capacity) and (iii) Exposure (E). Adaptation prospects consider both physicogeographical and tourism information to respond to climatic risk and highlight the priorities to indicate case-by-case proper adaptation measures.

Keywords

Ionian Islands; sea level rise; impact chain; beach tourism adaptation; beach retreat; tourism risk assessment; vulnerability

1. Introduction

Beaches, a vital natural capital, are important economic resources promoting tourism development along the coastline and associated beach recreation activities synonymous with the 3S (Sea, Sun, and Sand) tourism (Mestanza-Ramón et al. 2020). Beaches, as low-lying systems consisting of unconsolidated sediments, have been categorized to be among the most dynamically changing and vulnerable coastal landforms, prone to erosion and inundation (e.g., Vousdoukas et al. 2020; Phillips 2018; Di Paola et al. 2014). Global warming induced changes and associated sea level rise (SLR) and extreme weather events (i.e., sea storms) are expected to further intensify beach loss hence, loss of valuable recreational accommodation space. Given the popularity of the coastal areas for beach tourism and other marine activities, a notable part of coastal touristic infrastructure is at risk from the phenomenon of coastline retreat (Lithgow et al., 2019), which influences the value of recreational experience, affecting tourism demand and expenditure (van der Weide et al. 2001; Özhan 2002; Phillips & Jones, 2006; Houston 2008).

To address the growing importance of beaches as social environments and economic resources, it is critical to re-examine the discussion on SLR impacts on coastal tourism that started as far back as the 80's decade (Gable 1987). In this framework, scientists pivoting from various disciplines investigate the impacts of climate change on tourism from different perspectives. An attempt to group the numerous approaches reveals that several studies during the last two decades regard either the natural environmental (physical) impacts of SLR on touristic beaches (e.g., Dube et al. 2021;Tzoraki et al. 2018; Antonioli et al. 2017; Monioudi et al. 2016; Sagoe-Addy and Addo, 2013), or the economic consequences of these impacts on the tourism industry (e.g., Uyarra et al. 2005), with some of them focusing on the joint physical and economic impacts (e.g., Alexandrakis et al. 2015).

Apparently, beach tourism long-term sustainability depends on the preservation of beaches as natural and economic resources and, consequently, the problem of its management as ecosystem service is fully driven by tailored planning and policy implementation that will achieve adaptation to SLR impacts. Alongside, the importance of beaches as natural and economic resources necessitates immediate responses to prevent or mitigate the impacts of SLR on the coastal environment. To this direction, a definition of a conceptual model in a "common language" is provided by the Intergovernmental Panel on Climate Change (IPCC 2014; 2022) and the derivative Impact Chain (IC) tool (GIZ 2017). The IC tool can be both a practical tool, integrating quantitative and qualitative findings, and a participatory tool, facilitating a better understanding and dialogue with communities, policy makers and stakeholders (Arabadzhyan et al. 2020) and, therefore, it is deemed the most appropriate model for risk assessment, enabling technical development of climate policies (Abadie 2018; Tangney 2019). The systematic approach of the IC tool analyzes the complex relationship among the interaction of climatic, environmental and anthropogenic factors that can result in catastrophes, the aspects of dealing with the underlying risks, and the imperative role that non-climatic factors play in defining impacts (Birkmann 2006; Turner et al. 2003).

All things considered, the scope of this study is to estimate and respond to the anticipated impacts of SLR on tideless touristic beaches at a regional (insular) scale, enabling tourism adaptation and minimizing effects on tourism industry. In this context, also considering beach tourism as a main economic activity that will immediately respond to SLR with certain disruptions, this study investigates SLR tourism risk for the short term (2050) anticipated SSP5-8.5 scenario of 0.25 m sea level rise (IPCC, 2021) in the Ionian Sea. This work's challenge deals with tourism risk at a (geographically) large scale, i.e., the Ionian Islands (Greece, eastern Mediterranean), extending beyond the scale suggested by other studies which, in their majority, attempt to manage impacts at local scales.

2. Materials and methods

2.1. Study area

The present investigation uses the Ionian Archipelagos as a case study, the sea found along the western coast of the Greek mainland (eastern Mediterranean) which consists of a cluster of 32 islands and islets, with a total subaerial area of some 2300 km^2 and population of 200 thousand people. The largest islands, in terms of administration, are Kefalonia, Kerkira, Zakinthos, Lefkada, Ithaki and Paxoi (Figure 2a). The Ionian Islands Region constitutes a great touristic destination concentrating over 11.5% of the total touristic income of Greece (www.insete.gr).

The insular geomorphological characteristics are the mountainous relief, with rather significant altitudes for islands, and the presence of a great number of "pocket" beaches. In the absence of astronomical tides (tidal range <20 cm; Tsimplis 1994) the wave regime dictates neashorore hydrodynamics, depending on fetch distances and associated beach geographical location and orientation. The largest offshore waves rarely (annually ca. 0.02%) exceed 6 m of height and periods of 12 s period (Soukisian et al. 2007), while the most frequently (67%) incoming offshore significant waves are characterized with periods <5 s and heights <0.5 m. A significant shift in the frequency of wind and wave occurrence and direction from S-SW-W to N-NW-NE of extreme storm events, since the 1980s, has been reported (Poulos et al. 2014, Ghionis et al. 2016). On the other hand, extreme storm surges have documented to exceed the 30 cm mean astronomical tidal range (HNHS) at several coastal areas of the Ionian Sea, as in the case of IANOS low-pressure system, when seawater run-up extended up to 200 m inland (Androulidakis et al. 2023).

In terms of sea level change, the rate of SLR for the period 1992-2013 has been estimated at 2-3 mm/yr (EEA 2021), while the median projections of regional SLR, relative to a 1995-2014 baseline for 2050-decade ranges between 18 and 25 cm with respect to the SSP1-1.9 and SSP5-8.5 emission scenarios, respectively (sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool). Although, this risk in SLR is assumed to be moderate in relation to the rest of the Mediterranean coastal areas is anticipated to result in significant impacts such as loss of coastal habitats, amongst others (e.g., Dimitriadis et al. 2022).

2.2. IC tool Risk assessment methodology

Following the definition for *risk assessment* provided by IPCC (2022), in this study, Risk denotes the potential for impacts on tourism activity due to loss of beach accommodation space caused by SLR and subsequent shoreline retreat (climate impact). Hence, Risk considers all significant parameters expressed mainly as a function of (i) hazard (H), (ii) exposure (E), (iii) vulnerability (V) [expressed as capacity (C) and sensitivity (S)] and is, subsequently, interactively mitigated through Response (R) actions (IPCC 2022).

$$\text{Risk} = f\,(H, E, V)$$

The methodology for risk assessment is based on the concept of the Impact Chain (IC) (GIZ 2017), which is used in various spatial scales (globally, regionally, and locally), in scientific and decision-making (e.g., Schneiderbauer et al. 2020, Viezzer et al. 2018) studies, and allows the detection and collection of indicators for each risk factor that provide and integrate quantitative and qualitative information about specific situations or conditions.

By this means and based on the IPCC AR5 (IPCC 2014) and AR6 definitions (IPCC 2022), herein, the term Hazard (as climate signal) refers to the anticipated SLR of 0.25 m, as it is mainly stated for the Ionian Sea in the SSP5-8.5 scenario for 2050 (IPCC 2021, https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool). However, as Hazard does not automatically translate into Risk, it is important to also consider Vulnerability and Exposure. Therefore, the propensity or susceptibility of beach zones to be adversely affected entails the vulnerability factor. Considering the diversity of the features defining coastal zone dynamics, vulnerability encompasses all natural (physico-geographic/oceanographic) and anthropogenic attributes of beaches (Table 1) that depict their sensitivity or adaptive capacity and determine the potential extent of SLR consequences.

Among the natural attributes, beach slope, beach width, dune presence and wave heights are considered to be the most important ones. Beach slopes determine the relative vulnerability to sea-level inundation and the potential rate of shoreline retreat. Coastal areas with gentle slopes are expected to recede faster than areas with steeper slopes. Dune presence and beach width information are included in the IC as they confer the adaptive capacity of a beach to erosion processes. Dunes play a regulatory role by hindering erosional processes, whilst the large beach width protects beaches from wave run-up equal to or greater than the total beach width. Similarly, wave heights define the magnitude of energy influencing beach hydrodynamics (i.e. wave runup). Finally, the presence of human structures in the coastal area interferes with the sedimentological balance (by altering or inhibiting along and on-shore sediment transport) and feeding of the beach with sediments (e.g., inhibiting riverine sediment fluxes and cliff erosion), increasing beach sensitivity.

In turn, the function of both hazard and vulnerability factors, i.e. the impact of sea level rise to beach with regard to its attributes corresponds to the Physical (Intermediate) impact of beach retreat.

Finally, the Exposure component includes indicators describing the extent of beach tourism valorisation or, else, the magnitude of beach touristic assets' exposure. The exposure analysis was performed to estimate the popularity i.e. perceived quality and tourist traffic from the travelers' choice perspective through TripAdvisor information, which provides a useful alternative approach for touristic evaluation behavior, especially in cases where official statistics are not available for the spatial unit of interest (Niavis 2020). More explicitly, the beach review rate was utilized as an indicator of satisfaction of the visitors (perceived quality) whilst the number of concentrated comments from each beach was evaluated as an indicator for beach tourist traffic.

Table 1. Risk factors, indicators and corresponding source of information

Risk Component	Factor	Parameter Indicator	Data Source
Hazard (Climate Signal)	Sea level rise (SLR)	Height of anticipated sea level rise (in m)	IPCC (2021)
Hazard Intermediate (Physical) Impact	Beach retreat	Extent of estimated beach retreat (in m)	Bruun Model
Vulnerability (Sensitivity)	Sediment grain size category	Sediment grain size decrease (in mm)	Satellite Imagery
	Change in wave height	Increase of wave height (in m)	Estimate based on oceanographic characteristics
	Magnitude of beach slope	Decrease of beach slope (%)	Terrestrial and bathymetric DEM
	Extent of human intervention	Human infrastructure existence (residences, roads, tourism facilities etc)	Satellite Imagery
Vulnerability (Capacity)	Range of beach width	Percentage of available width (with respect to the initial width) to be maintained after SLR	Satellite Imagery
	Dune presence	Dune landforms presence in the backshore zone	Satellite imagery and Photographic Gallery (e.g. TripinView, TripAdvisor)
Exposure	Perceived Quality	Beach review rating	TripAdvisor
	Tourist traffic	Number of tourist comments	TripAdvisor

Figure 1 shows a schema of a simplified Impact Chain for Tourism Risk due to SLR. In the described IC, the role of hazard (SLR) is unidirectional, straightforward, and tangibly leading to beach retreat, the extent of which depends on beach attributes, whilst beach touristic popularity (perceived quality and traffic) input information provides risk assessment.

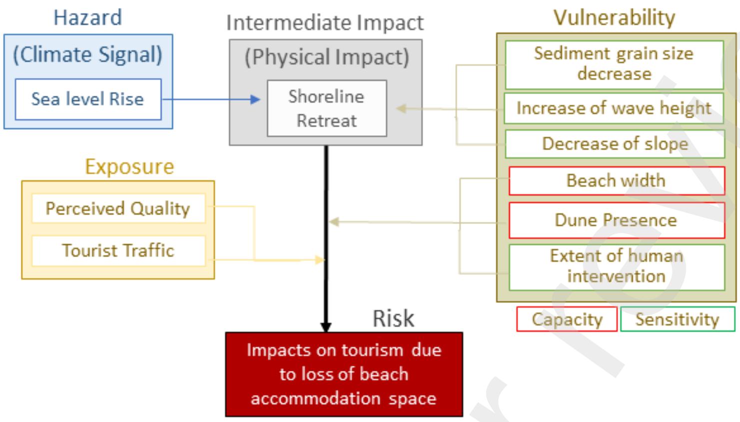

Figure 1. Theoretical impact chain for the potential risk for impacts on tourism activity due to loss of beach accommodation space caused by SLR and subsequent shoreline retreat (following the GIZ (2017) approach). The different colored boxes represent the various Risk components (hazard, vulnerability, exposure) whilst the white boxes represent the factors of these components.

As gathered datasets for each indicator are often in different units and, thus, not directly (inter)comparable, normalization is needed to rescale the magnitudes of the parameters to a unique scoring scale. Therefore, the min- max approach was applied to convert all datasets into sets of unitless values (Formula 1) with a standard scale ranging between 0 and 1 (0 is the optimal condition, 1 is the critical condition).

$$x_i,1 = \frac{(x_i - x_{min})}{(x_{max} - x_{min})} \qquad [1]$$

where, x_i is the input data to be transformed, x_{min} and x_{max} represent the lowest and the highest values of the indicator and $x_i,1$ the normalized value between 0 and 1.

Following the described normalization procedure, each indicator and, thus, component contribution has to be weighted, based on the importance of its influence. It is precedent that the sum of all indicator weights is equivalent to 1. Therefore, a weight is given to each component and the Risk score is calculated using Formula 2. For the needs of weighting, five experts with different backgrounds (researchers, practitioners, and stakeholders specialized in the hazard, exposure, or vulnerability components) and a long-standing/ considerable experience in the studied risk were interviewed and guided across a two-step weighting process. The experts were asked to rank each indicator based on its relevance for the risk and accordingly their opinions were averaged.

$$Risk = I_{haz} * w_{haz} + I_{vul} * w_{vul} + I_{exp} * w_{exp} \qquad [2]$$

The scoring values for each component are divided into a five-class category scheme so as a subsequent five-class risk categorization to be extracted according to the classification of Table 2.

Table 2. Risk classification

Risk score	*Risk score class*
0.8-1.0	Critical
0.6-0.8	High
0.4-0.6	Medium
0.2-0.4	Low
0-0.2	Optimal

2.2.1 Data gathering

The information of the geo-spatial beach characteristics of Ionian beaches was abstracted by the BEACHTOUR Project Beach Database (www.beachtour.gr; Karditsa et al. 2016), which has been developed based on optical information recording of Satellite images available in the Google Earth Pro application. In this attempt, the identification of beach characteristic has assumed that beaches are defined as the low-lying coastal sedimentary bodies delimited in their landward side by either natural boundaries (vegetated dunes and/or cliffs) or permanent artificial structures (e.g., roads, seawalls, and buildings) and in their seaward side by the shoreline (Monioudi et al. 2017). Regarding the lateral extent of individual beaches, these have been delimited by natural barriers, such as rocky outcrops, promontories, abrupt slope change. Hence, the digitization of beach polygons provides the required beach spatial characteristics (beach areas, lengths, maximum widths, and orientations). Small beaches, i.e., less than 50 m in length and/or 5 m width, have been excluded from this analysis.

Additional natural characteristics as backshore cliff slope or dune presence were recorded, as well as human interventions such as coastal artificial structures (coastal protection works, ports, fishing shelters, seawalls etc) and backshore infrastructure/properties (coastal roads and/or roads facilitating beach access, buildings density). Assessment of the beach sediment texture, i.e., sand, gravel and mixed material, was also carried out on the basis of optical information and was accordingly classified into sand (>70% sand content), mixed (gravel and sand) (20-70% sand content) and gravel (<20% sand content) material which, in turn, was matched/related to the corresponding median particle size (d_{50}, mm) following Folk's (1980) nomenclature.

Collecting actual data on beach visitors to the study area would be a highly demanding and almost impossible task as the entrance to most of the beaches is free. Therefore, no official data on occupancy is collected and the only way to get a reliable measurement of beach tourist traffic and occupancy would be under constant monitoring of all beaches for a certain amount of time. To overcome these difficulties, an alternative strategy for quantifying the tourism value of the beaches was adopted. More precisely, the present study draws data from the TripAdvisor website where users rate the quality of beaches and their perceived experience after visiting them. Two indicators are constructed. The first (Tourist traffic) refers to the interest of people regarding the beaches of the study area, demonstrated by the number of comments and reviews for each one of them on the relevant page of TripAdvisor. It is assumed that beaches with more comments accommodate higher tourist flows. The second

(Perceived Quality) has to do with the quality of the beaches. TripAdvisor provides a rating scale ranging between 0 and 5, with higher values denoting better quality of the beach and a more pleasant experience for its users.

Apart from the sedimentological information, beach slope and wave characteristics were also required for the needs of the modeling application. In this scope, and considering the extended spatial scale of the numerous beaches which did not permit in-situ measuring, the derivation of subaerial beach slope (βa) was conducted through the processing of a slope (%) model developed in GIS based on a Digital Elevation Model (DEM) of the official Greek Service for comprehensive recording of real estate and property metes-and-bounds i.e., the Hellenic Cadastre (https://www.ktimatologio.gr/en), using a 5m resolution. Therefore, the subaerial slope of each beach zone was extracted asbeach polygon, whilst subaqueous slope values were extracted by the GEBCO gridded bathymetric data (https://www.gebco.net).

Furthermore, the studied beaches were identified according to their orientation, while the effective fetch lengths were calculated for the main direction of incoming offshore waves that affect each beach. Accordingly, calculations of wave characteristics (Hs, Tp) for intense winds (>5 Beaufort) were based on JONSWAP-PM methodology and Pierson-Moskowitz spectrum, for the fetch limited and fully developed sea, respectively (Monioudi and Velegrakis 2014).

3 Results and Discussion

3.1 Geospatial characteristics of the beaches

A total number of 322 beaches were mapped on the seven (7) main Islands of the Ionian Archipelagos (Figure 2a), distributed on Kefalonia (73), Kerkira (99), Lefkada (40), Zakinthos (43), Ithaki (42), Paxoi (18) and Antipaxoi (7). The maximum width of the beaches are less than 60 m, of which approximately 18.2% have a maximum width of <10 m, 33.5% <20 m and 36.9% <30 m. Therefore, a relatively small percentage of the beaches (11.5%) present moderate width (30-60 m), found on Lefkada and Zakinthos islands (where ca. 31% are > 30 m wide) and on the island of Kefalonia (where ca. 43% are 20-30 m wide).

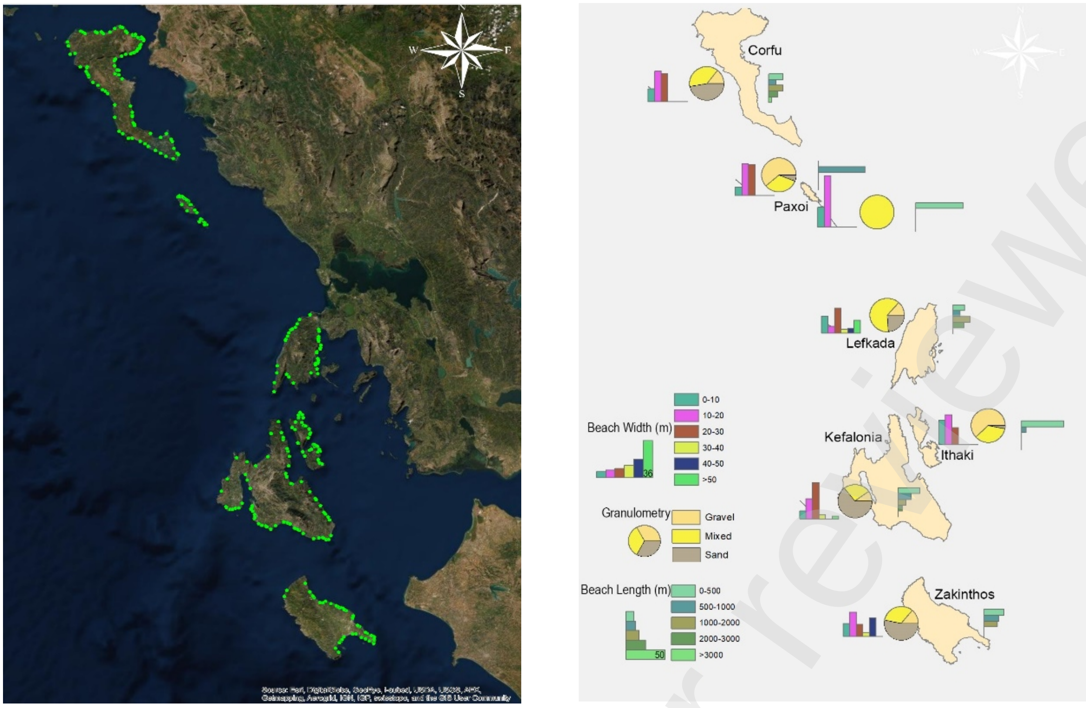

Figure 2. (a) Location of the 322 beaches on the Ionian Islands (>3 m width and >100 m length), (b) Major physical characteristics of the Ionian Islands beaches

Regarding beach length, the Ionian Island beaches were found to be of moderate length with 38.7% of them being <500 m, and another 19.0% exhibiting a length of <1000 m. Approximately 26.1% of the beaches presented maximum shoreline lengths <2000 m, and 9.0% <3500 m. Moreover, the longest beaches (2500-3500 m) were detected on Lefkada (23.7%) and on Kerkira (11.7%), while beaches of 2000-2500 m length on Kerkira (13.9%) and Kefalonia (8.76%). On the other hand, all the beaches on Paxoi and Antipaxoi Islands were found of limited length (max 1000 m).

In relation to sediment type (Figure 2b), the Ionian beaches consist mainly of sandy or mixed (sand and gravel) material (39.9% and 38.9%, respectively), with Kefalonia, Zakinthos and Kerkira having the highest percentages of sandy beaches (63.9%, 53.5% and 46.6%, respectively). Coarse grained material (gravels) is less common i.e., 21.3% in total, representing 62.5% of the beaches on Ithaki and 61,1% in Paxoi.

In terms of beach slope, 8.5% of the Ionian beaches were found to have beach slope <3%, 60.2% 3-5%, and 31.2% >5%. Hence, all islands most commonly have beaches of medium slope (>60%), with the exception of the Lefkada Island that presents approximately equal percentages (~44%) of beaches of both medium and high slopes.

With respect to the calculated incoming offshore waves, the vast majority (86.6%) of the Ionian beaches are exposed to open sea incoming wave conditions, with significant wave heights of >4 m (e.g., Kefalonia: 97.7%; Zakinthos: 61.1%; Lefkada 80.0%; and Kerkira: 58.3%).

3.2 Exposure

Among the 322 beaches mapped on the seven Ionian Islands, 152 of them are classified as touristic beaches according to the selected criteria (TripAdvisor information) and they are assessed hereby regarding the risk of their loss due to SLR. Beach exposure to SLR varies across the Ionian Islands with 25% of them being extremely touristic and 53% highly touristic, whilst the remaining 22% are moderately touristic. The distribution of beaches by island showed that the most exposed (touristic) islands are Kerkira and Kefalonia (26%), followed by Zakinthos (19%), Ithaki (12%), Lefkada (10%), Paxoi (5%) and Antipaxoi (1%). An individual assessment per island revealed that all the beaches on Antipaxoi are extremely and highly exposed, as its limited number of beaches offers very few tourist destinations choices. Kerkira Island showed the highest percentage of extremely (46%) and highly (additional 39%) touristic beaches followed by Zakinthos and Kefalonia, with 32% and 26% (extremely touristic) and 43% and 56% (highly touristic) beaches, correspondingly. Lefkada Island presents the lowest percentage of extremely touristic beaches (2%) and a great amount of 67% of highly touristic beaches. Finally, none of the 75% and 39% of the touristically exploited beaches on Paxoi and Ithaki islands respectively is of extreme tourism activity.

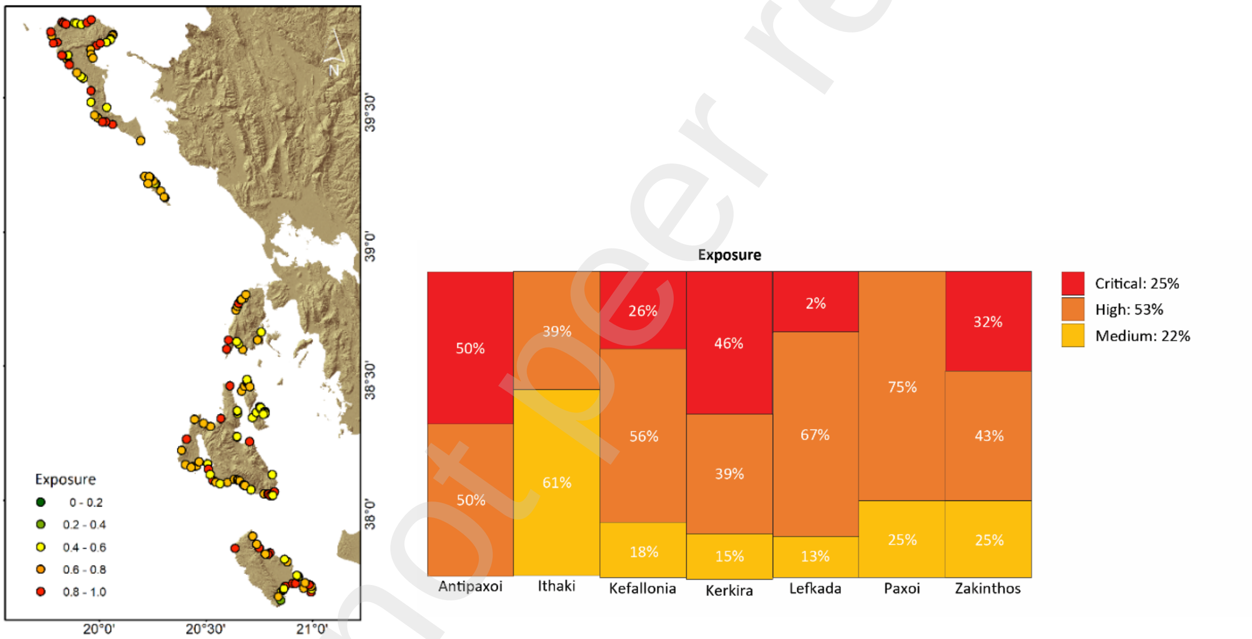

Figure 3. (a) Spatial distribution of normalized exposure scores (b) Mekko chart of the normalized exposure scores per island.

3.3 Vulnerability

Vulnerability, expressed in normalized values, varies across the Ionian Islands. Regarding sensitivity, Kefalonia, with 21% and 51% of its beaches being under extremely high and high sensitivity scores, exhibits the highest values, followed by Zakinthos (4% extremely high and 50% high), Kerkira (5% and 49%) and Lefkada (13% and 33%) extremely high and high respectively. In turn, Paxoi and Ithaki islands present less sensitive beaches with only 12% and 6% of their beaches being under high sensitivity, respectively. Beaches on Antipaxoi Island presented the lowest sensitivity scores amongst all islands.

As far as adaptive capacity is concerned, all islands are proved to be highly adaptive (>65% capacity scores) with the highest scores achieved for Paxoi and Antipaxoi islands. The extremely low capacity of Lefkada (7%), Kefalonia (13%), Kerkira (5%) and Zakinthos (4%) is mainly related to the beaches' geomorphological characteristics (e.g., slope) and to the absence of dunes.

Moreover, the spatial distribution of vulnerability scores indicates the strong influence of wave forcing as the majority of extremely and highly vulnerable beaches are located in the western and southern parts of the islands, which are exposed to intensive wave activity.

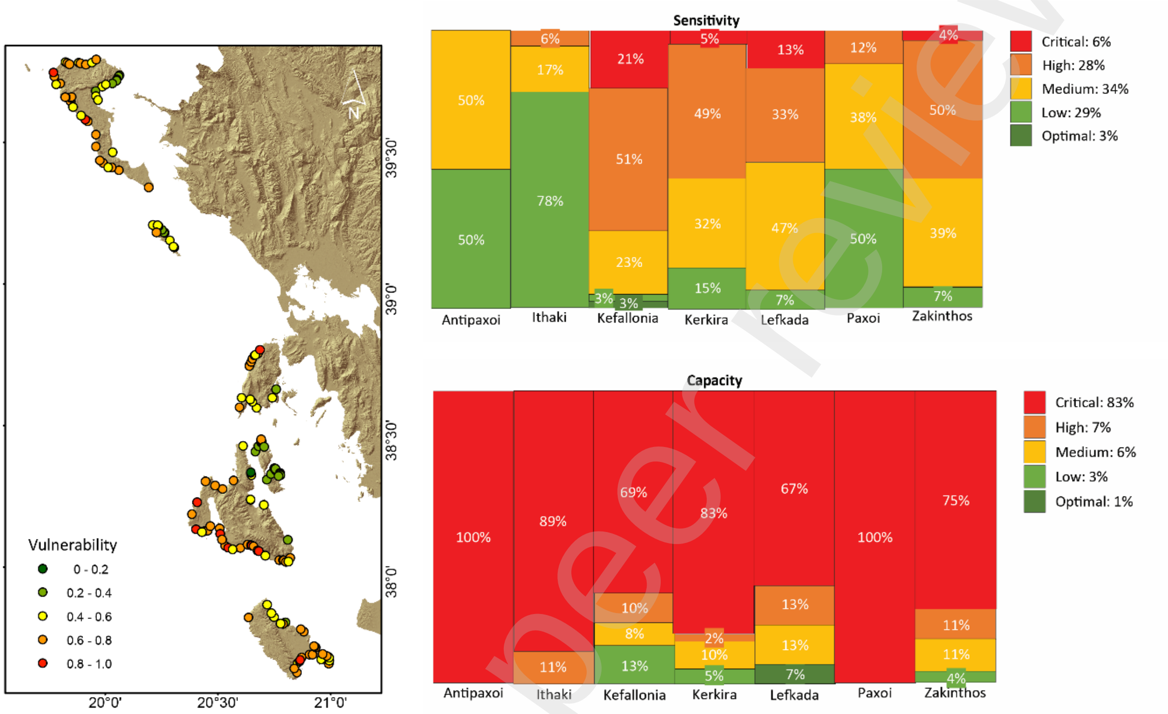

Figure 4. (a) Spatial distribution of normalized vulnerability scores (b) Mekko chart of the normalized sensitivity scores per island (c) Mekko chart of the normalized capacity scores per island

3.4 Physical Impact

The interconnection of hazard and vulnerability components corresponds to the physical impact of beach retreat (Figure 5). Although the physical impact is not considered to participate in the IC tool as a risk component by itself, it acts as a supporting component to interpret the cause-effect chain leading to risk. Morphodynamically, beach retreat due to SLR is assessed through the application of parametric and/or analytical modelling. The Bruun (1988) model is one of the most widely used models (e.g., Vousdoukas et al. 2020; Ranasinghe et al. 2013; Hinkel et al. 2009) based on the relationship [4].

$$s = \frac{l \times a}{hc + B_h} \qquad [4]$$

Where, (s) is the beach retreat, (a) the sea level rise, (l) the cross-shore distance to the closure depth (hc) and (B_h) the elevation (height) of the beach berm above the mean sea level.

Hence, given that the application of Bruun Model uses the cross-shore profile (embedding, therefore, the parameter of beach slope that is also related to sediment texture and wave forcing), it is assumed that these parameters are well included in the vulnerability component of IC as main contributing indicators to the impact chain analysis.

The application of Bruun Model for the extreme SLR scenario for 2050 in the Ionian Sea (25 cm) indicated that the retreat of Ionian beaches ranges from a minimum of 2.1 m (found on Kefalonia island) to a maximum of 17 m (found on Kerkira Island) (Table 3). Ithaki Island exhibits the lowest estimated beach retreat (lowest mean and Standard Deviation), whereas Lefkada the greatest retreat (Table 3).

Projections of the results revealed that even 25 cm of SLR is expected to have significant impacts on the Ionian beaches (Figure 5). More specifically, 83% of the touristic beaches are predicted to retreat by 20% of their maximum width, 27% to lose 50% of their maximum width and approximately 3% to extinct. The distribution of the corresponding retreats on each island is shown in Table 4, which indicates detrimental impacts (>70% beach extinction) for several (>10%) beaches of Lefkada, Kerkira and Zakinthos.

Table 3. Statistical results for Ionian Islands beaches

	Kefalonia	Kerkira	Lefkada	Paxoi	Zakinthos	Ithaki	Antipaxoi
min	2.1	3.0	3.1	3.0	3.9	3.0	4.0
max	9.9	16.9	12.6	5.7	5.9	4.9	4.9
mean	4.8	4.9	5.5	3.9	4.7	3.4	4.5
st.dev	1.9	2.6	2.5	1.0	0.8	0.8	0.6

Table 4. Estimated beach extinction percentages for SSP5-8.5 SLR emission scenario.

	Beach loss		
	20%	**50%**	**70%**
Antipaxoi	100%	-	-
Ithaki	100%	39%	-
Kefalonia	97%	33%	5%
Kerkira	95%	41%	12%
Lefkada	73%	53%	13%
Paxoi	100%	50%	-
Zakinthos	92%	43%	11%

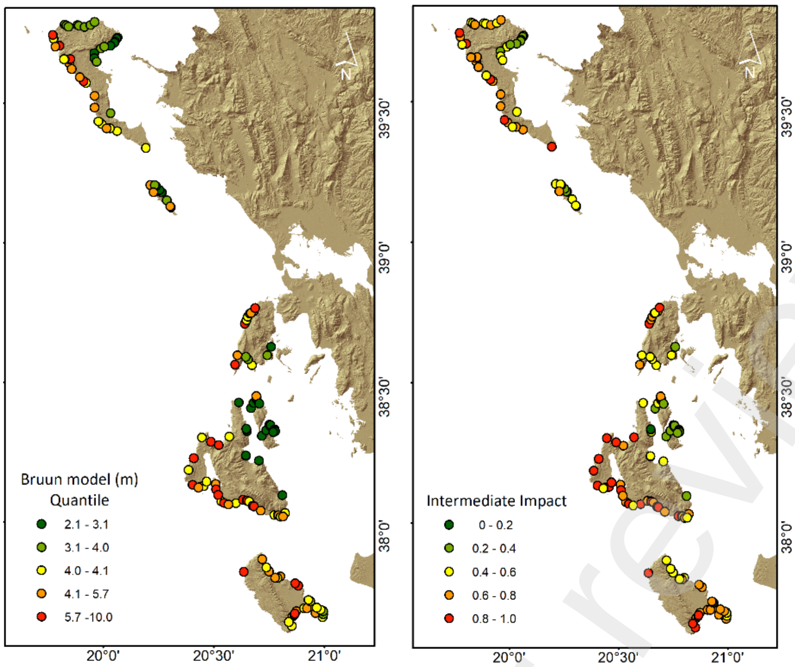

Figure 5. (a) Spatial distribution of estimated retreat values (b) Spatial distribution of Intermediate Impact values

Moreover, Spearman's rank correlation was carried out between the Bruun Model results and the physical impact scores. The statistically significant correlation between them (rho=0.86, a=0.01) confirms the validity of physical impact scores and is well explained considering the correspondence of the indicators included in both the intermediate impact and the Bruun Model analysis.

3.5 Risk Assessment

The risk scores regarding the hazard of 25 cm of SLR were calculated based on the IC tool application and are indicated in Figure 6. According to the results, approximately 19% of the beaches present very high to high risk values, whilst the majority of the beaches (87%) appear to be of moderate risk.

Considering that hazard component is constant, the contribution of the other two risk components (vulnerability, exposure) to the final risk value is depicted in Figure 6 (b) where it is obvious that high risks are mainly produced by high exposure.

With respect to their geographic distribution, extreme/high risk beaches are located on the west coast of the islands, principally as the result of high/very high vulnerability and high/very high exposure. However, it is notable that there are many highly touristic beaches (very high exposure) that do not present very high risk scores, as their attributes (vulnerability) provide high adaptive capacity that in turn downgrade their risk scores. On the contrary, in many cases moderately touristic beaches are estimated to be under high risk, most likely are expected to be touristically degraded in the future, due to their high sensitivity (vulnerability) and the associated loss of recreational space.

Moreover, as risk variability among Ionian beaches results from both exposure and vulnerability, an additional analysis was performed in order to investigate in which way the vulnerability categories are distributed in high and low exposed beaches, i.e., in touristic and not touristic. The analysis showed that the distribution of vulnerability categories remains the same for touristic and non-touristic beaches, while at the same time, the number of critical vulnerability beaches prevails over the ones of medium or low vulnerability (p<0.1).

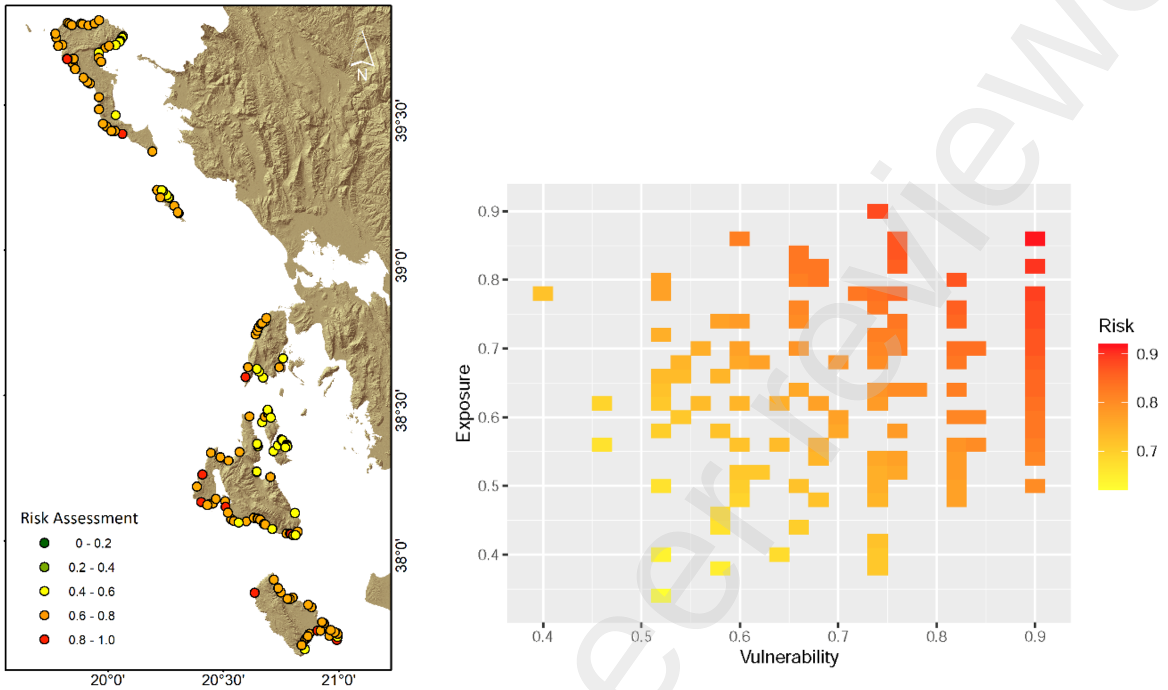

Figure 6. (a) Spatial distribution of normalized risk values (b) Plot of risk values in relation to vulnerability and exposure

4 Discussion and Conclusion

In this study, an effort to support tourism adaptation planning, in response to sea level rise impact on beach zones at a regional scale, is attempted. The results demonstrate that SLR exposes beaches to considerable risk, leading to severe loss of accommodation space for tourism activities. This loss could subsequently decrease the value of recreational activity and lead to a severe reduction of tourism revenues. Apparently, impacts due to SLR are imminent for all beaches, whether touristic or not. However, the effects of climate change on tourism are of particular interest as tourism forms a dynamic sector of the Mediterranean economy. The alarming findings of this study call for the prioritization of adaptation measures, including impact mitigation and restoration.

The selection of indicators as a basis for the semi-quantitative assessment and, particularly, the demand for proper data proved to be challenging due to lack of valuable, yet costly, in-situ physico-geographic data. Scarcity of high-resolution data of large-scale environmental applications constitutes a diachronic scientific challenge (Gorgoglione et al. 2020). Vice wise, information about tourism activity is scarce at such scales, as in most cases they originate from administrative data sources with greater spatial coverage (e.g., municipality or regional scale). For this reason, the collection of data is, in most cases, not feasible and a major constraint for the provision of specific measures for response actions.

To fill the gap, in this study, the approach that was followed through Trip Advisor data collection provided a sound methodology to evaluate tourism activity at regional scale (Niavis 2020).

The present investigation also revealed that the risk of beach tourism ranges with respect to beaches specific characteristics of vulnerability and exposure. It is notable that not all vulnerable beaches are of touristic interest, being, thus, of low tourism risk. In addition, highly touristic beaches (of extreme and high exposure) are not necessarily assessed as high risk due to their low vulnerability to SLR (induced by specific beach attributes), which consequently reduces their risk scores. On the opposite, there are many cases of moderately exploited touristic beaches that are estimated to be under high risk, due to increased loss of accommodation space. This diversity in risk assessment raises the demand for multifaceted adaptation (operational or policy driven) approaches in order to address the impacts.

When beach space for tourism activities becomes inadequate, a potential response could be the exploitation of alternative beaches to relocate tourism activity. Nevertheless, the success of such shifts depends on the suitability of the alternatives, as determined by their physicogeographic characteristics, e.g., sediment size, beach subaerial topography and underwater bathymetry, beach width etc. Yet, even if a beach exhibits favorable conditions for tourism activity, it should also demonstrate low vulnerability conditions. Herein, the analyses demonstrated that there are 171 mapped beaches that, based on the data mined by TripAdvisor, appear as not touristically exploited; these beaches may potentially constitute new tourism destinations. Amongst these, there are 131 sandy and mixed material beaches that are of neutral (or lower) vulnerability, whilst 49 of the latter (i.e. 29% of the non-touristic beaches) already exhibit a low residential development. These beaches, as low vulnerable, may provide space for prospective tourism relocation and expansion of tourism development.

Integrated coastal management (ICZM) regarding current and projected beach retreat suggests the inclusion of timely preventive measures, such as the provision of buffer zones (i.e., “setback” zones). More specifically, the ICZM Protocol of the Barcelona Convention [Art. 8(2)] foresees a setback zone of 100 m beyond swash maxima (i.e., the maximum recorded wave run-up) in which no further construction is allowed, aiming both at alleviating from human pressures and securing future activities. Although this approach is still limitedly applied in practice, it should be set as a priority for timely adaptation planning (eg. Lincke et al. 2020; PAP/RAC 2021). Nevertheless, this measure cannot be applied to all types of beaches, as in the case of beaches which are backed by natural barriers (e.g., cliffs). In the case of the Ionian Islands, 19 (12%) of the high risk touristic beaches present low slopes and low development in the backshore area and could indeed be suitable for the application of a buffer backset zone and the well-timed application of ICZM protocol.

Moreover, appropriate interventions to reduce beach sensitivity have been chosen in many cases in order to diminish SLR impacts. Beach replenishment is implemented often to mitigate existing beach retreat, combined in cases with hard defense works (e.g., breakwaters), to alter the physicogeographic characteristics of the beaches into a more resilient environment (e.g., ICES 2016; Bergillos et al., 2018). However, beach nourishment is assumed to be a demanding and expensive exercise (Mielck et al. 2019), impractical to be applied horizontally. For instance, among the Ionian (extreme and highly vulnerable) touristic beaches, the IC tool application provided 8 (5%) high risk, highly vulnerable beaches that consisted of sandy material, low/medium slope and exposed to high waves; these beaches could be set as priority for remediation with soft (preferably) and/or hard defense works.

The proposed methodology estimates risk assessment i.e. loss of beach accommodation space simply with regard to SLR (referred to as the climate hazard). Apparently, although not considered in this study, additional hazards, such as intense storms and extreme sea surges, may be synthetically considered in the IC. Moreover, in this study, the potential impact of SLR under SSP5-8.5 for the mid-century was assessed. As the differences of intermediate physical impact among the different SLR scenarios for 2050 are minor (0.5 cm), a comparative study among these scenarios would not add value in this analysis. In addition, SLR physical impacts are directly translated into socioeconomic impacts (e.g., beach tourism), thus, it is essential SLR estimations to be based on the worst-case scenario, taking into consideration that the appropriate impacts management needs sound measures.

In conclusion, the IC conceptual tool allows for a comparative analysis among beaches of various characteristics and based on their specific features, highlights areas of major concern (high risk), acting as the stepping-stone for the consequent analysis of selecting proper adaptation measures. The IC conceptual tool enables climatic risk assessment and allows to identify appropriate adaptation measures addressing the examined components. Moreover, it facilitates effective and timely preparation for the forthcoming climatic conditions, while in the meantime, it raises awareness and supports decision making, setting the background knowledge for capacity building.

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