Linking Tourism Hotspots and Vulnerability to Climate Change – Case Study Rhodes Island, Greece

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Abstract. Tourism in Mediterranean regions is an important developmental lever. Nevertheless, it also constitutes a main source of degradation of the natural/cultural capital, while it exposes tourist destinations to severe pressures (energy/water stress, traffic congestion, urbanization, pollution, etc.) that are mainly due to the prevailing mass tourism model across the Mediterranean coastline. This holds especially true in insular regions, i.e. highly attractive areas due to their natural/cultural wealth and uniqueness, but also extremely vulnerable due to the insularity condition as well as other global-wide challenges, such as Climate Change (CC), coastal urban sprawl, biodiversity degradation, etc. Currently, many islands demonstrate signs of extreme tourism overcrowding, rendering them 'tourism hotspots', a state that threatens sustainability and resilience objectives. Having Rhodes Island, Greece, as a case study – namely a highly reputed tourist destination in the global scenery – this work aims at establishing a methodological framework for 'bridging' tourism hotspot areas with climate change risks. This is accomplished by the use of spatial, quantitative and qualitative, data that forms the ground for: identifying the spatial pattern and dynamics of tourism hotspot areas in Rhodes Island; and linking them with past and potential CC incidents in order for risks to be identified and relevant, more informed policy decisions, serving sustainability and resilience objectives to be articulated. Results designate critical concerns as to the risks inherent in Rhodes tourism hotspots, calling for the deployment of relevant resilience plans, coupled with the discharging of tourism load in relevant areas.

Keywords: Tourism hotspots · Climate change risks · Spatial analysis

1 Introduction

In recent decades, tourist development and its repercussions in spatial, ecological/environmental, economic, social, cultural, psychological, etc. terms have been placed at the heart of the international planning and policy discourse [1–4], in alignment with

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relevant policy directions at the glocal (global-local) level, addressing sustainability, resilience and socio-economic cohesion [5, 6]. At the epicentre of this discussion lay coastal, mostly mass tourism destinations – both in mainland and insular territories –, demonstrating a notably linear form of tourism activity along the coastal part. In fact heavy tourism overload of *coastal space*, especially in Mediterranean coastal and insular regions [7], coupled with the quite dense residential pattern of these regions (more than one third of the population in Mediterranean countries lives in coastal administrative entities) [8], is source of environmental degradation of vulnerable land and marine ecosystems. Further to that, this pattern sets up also the scene for severe sectoral conflicts to emerge in seeking for coastal or marine space from various actors/stakeholders (e.g. residential, fisheries, agriculture, tourism, commercial and passenger port activities). Last, but not least, this overloading of the coastal space results in highly dense built-up patterns, which are definitely heavily exposed to severe Climate Change (CC) incidents [9]. Such incidents are currently a major threat for the Mediterranean region as a CC hotspot [10, 11]; while they constitute a source of multiple socioeconomic stresses [12], burdening the region's stability and prosperity.

As various studies demonstrate [13, 14], *insular regions* in the Mediterranean seem to be more affected by CC repercussions, with islands being perceived as the most susceptible to CC areas of the world. Such regions, being at the heart of this work, are highly endowed and attractive areas, with their charm being associated with their rich maritime heritage and cultural tradition as well as an unrivalled diversity of landscapes and nature-based populations. Based on these remarkable attributes, they act like a magnet to tourism flows, witnessing a continuously escalating volume of visitors. In fact tourism constitutes the 'engine' of islands' economic profile, leading to a Tourism-Led Growth (TLG) model [15], with noticeable contribution to GDP, employment, and foreign exchange earnings. Despite the economic benefits of their popularity, however, such a trend has led to the violation of their carrying capacity constraints, giving prominence to the new threat of overtourism [4], a state that places enormous pressure on local resources while definitely affecting the pursuance of sustainability and resilience objectives.

Within such a context, *tourism planning* nowadays, particularly in fragile insular regions, is grasped as a highly complicated task, taking into consideration vulnerability of the tourism sector in a number of abrupt or long term developments, occurring at the global level. Such developments are the outcome of technological advances and the sharing economy, economic stability, demographic changes and lifestyle/consumers' preferences, migration patterns, health crises, CC and natural disasters, to name but a few. That said, an additional task when tourism planning is conducted involves *vulnerability assessments* of tourism destinations to various threats and their spatial implications in order for more effective policy decisions to be enabled. In fact such assessments can be used from either a proactive tourism planning viewpoint, i.e. plan of tourism products that are properly addressing vulnerabilities of a destination to external and internal driving forces; or a reactive one, i.e. being prepared to effectively cope with adverse incidents of driving forces that can cause severe damages to a destination. In order for this to be attained, more precise estimations of human activity along the coastal strip are needed. However, certain *knowledge gap* is noticed in this respect that hinders effective planning

and articulation of developmental strategies for coastal regions [3]. In addition, planning and developmental strategies are rather superficially handling or integrating into the planning practice information on specific risks, e.g. CC, faced by each single region in order for resilience to emerging threats to be incorporated into policy decisions that are coming out from the planning discourse. Thus although the pressures of mass tourism on Mediterranean islands and the increasing frequency of climate-related hazards are well acknowledged, there remains a notable *gap* in the literature regarding spatially integrated approaches that concurrently assess tourism density/intensity and climate vulnerability. Existing studies often examine these dimensions in isolation, lacking a common analytical framework for effectively informing regional spatial planning and resilience strategies. This paper seeks to address this *gap* by proposing a geospatially-informed methodology that overlays tourism hotspot identification with spatial risk assessment of climate-induced hazards—namely floods and wildfires. Applying this approach to the case of Rhodes Island, Greece, the study offers both methodological and empirical contributions to current debates on sustainable tourism development and territorial resilience in coastal and insular contexts.

Having the aforementioned in mind, the *focus* of the present paper is on tracking the human footprint in the coastal part of Rhodes Island, Greece by means of identifying tourism hotspots; and assessing the CC risks related to these hotspots. More specifically, a methodological framework is established aiming at 'bridging' tourism hotspot areas with CC risks, a fact that aims to uncover critical spatial relationships and vulnerability patterns in the study area. Such an experiment results in certain fact-related connotations, namely awareness raising and informing policy reaction for handling CC risks associated with these hotspots; and preparing for the damage such risks can cause to highly populated areas. This effort is accomplished by use of qualitative and quantitative data and GIS tools, properly selected for demonstrating the high exposure of Rhodes' tourism hotspots to combined CC risks.

The structure of the paper has as follows: in Sect. 2 the methodological approach is presented; Sect. 3 elaborates on the tourism supply dynamics of the study region, i.e. Rhodes Island, Greece, aiming at highlighting tourism hotspots; Sect. 4 attempts to gain insights into CC risks inherent in the area of concern from a geospatial perspective and link them to tourism hotspot areas; finally in Sect. 5 discussion of results and certain key conclusions are drawn.

2 The Methodological Framework

The methodological approach of this work consists of the following steps (Fig. 1):

- Step 1 is dedicated to a thorough insight into the study region in order for the social, economic, cultural, environmental, historical etc. *profile* to be grasped.
- Step 2 pays attention to the specifics of the tourism sector per se, exploring its dynamics as well as the tourism density and intensity in the area of concern. In this respect, certain literature-based indicators can be applied, provided that relevant data are available. More specifically, density of tourist accommodation (e.g., hotel and Airbnb beds per km^2), proximity to key attractions, land cover change (e.g., impervious surface expansion), and NDVI loss are frequently used to assess tourism pressure

and environmental stress. Coastal built-up expansion in the study area, as well as the spatial pattern of hotel and Airbnb accommodation, the expansion of large-scale tourism infrastructure through time, etc. are also falling into this step, leading to the identification of *tourism hotspots.*

- Step 3 aims at illuminating *vulnerability concerns* of the study area that are due to CC impacts. Spatial data elaboration is forming the ground for relevant inferences to be drawn with regards to mainly flood and fire risks inherent in the vicinity of tourism hotspots, and the island's soil sealing to the detriment of the agricultural land. In addition, past events (fire, flood) are explored based on information provided by relevant works, elaborating on risk assessment at the case study level.
- Step 4 aims at bridging work carried out in Steps 2 and 3. Out of this step, *vulnerability concerns* of the study area are downscaled to tourism hotspot areas in order for the type and intensity of risk to be roughly sketched.

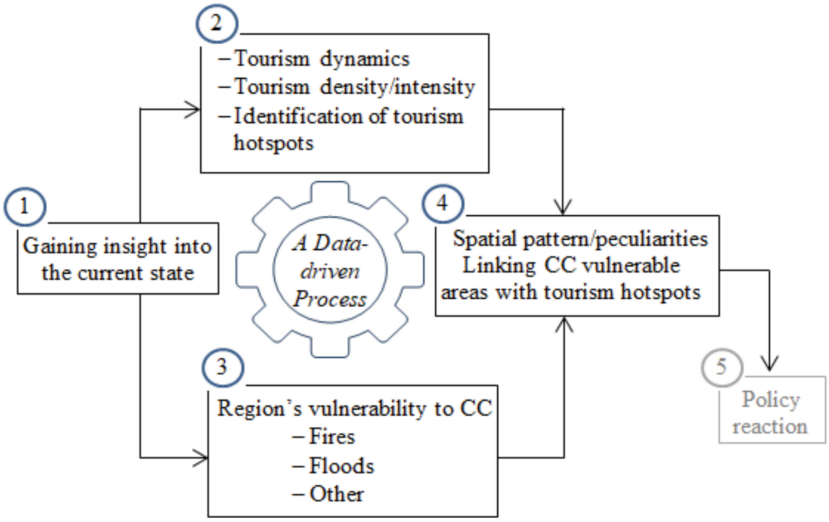

Fig. 1. Steps of the methodological approach.

Results of this process can be utilized for articulating policy reaction at the case study level, i.e. formulating proactive and reactive policy measures for minimizing repercussions of risk incidents and strengthening resilience of tourism hotspot areas.

3 Featuring Tourism Dynamics in the Island of Rhodes

The island of Rhodes is the largest one in the Dodecanese Prefecture, Greece, and is situated in the Southeastern Aegean Archipelagos. Due to its privileged geopolitical location, the island's trajectory through the centuries is marked by a strong maritime presence. In addition, Rhodes has a rich history, ranging from the Hellenistic period to the Byzantine era, the period of the medieval Knights of Rhodes, the Ottoman Empire

and the occupation by the Italian conquerors, joining finally the Hellenic Republic in 1948. This history has left remarkable cultural remains on the island's land, which, combined with the rich natural environment, sets up the ground for quite an attractive tourism destination. In addition, in the capital of the island of Rhodes lies the Medieval or Old Town of Rhodes, being the best-preserved medieval town in the world and a UNESCO's World Heritage Site.

The island of Rhodes owns an area of 1401 km^2 and a population of 125,113 inhabitants [16], half of which resides in the island's capital – also capital of the Dodecanese Prefecture – the city of Rhodes. In the time span 2011–2021, the island displayed a population increase of 8.4%, in contrast to the general population of Greece as a whole, which declined by 4.13%.

According to relevant studies [17], the island of Rhodes, together with the one of Kos, falls into the group of Dodecanese islands' complex which demonstrate a high tourism performance. More specifically, Rhodes displays a remarkable tourism and population dynamics, coupled with high rates of built-up expansion. The tourism dynamics is mostly attributed to large scale hotel accommodations, manifesting a high concentration of beds and arrivals and causing a rising seasonal population density as well. In order for this pattern to be grasped, a further insight into the dynamics of the sector is attempted by use of properly selected, literature-driven, absolute indicators demonstrating developments of tourism supply; as well as relative indicators, unveiling tourism density and intensity in the destination [4]. In addition, the spatial distribution of tourism supply is explored in order for *tourism hotspot areas* to be identified.

More specifically, the dynamics of the tourism sector in the island of Rhodes is definitely witnessed by the steadily expanding tourism supply in the island. In fact during the last decade (2014–2023), tourism supply displays an increase of 8.32%, 16% and 20.36% in the number of hotels, rooms and beds respectively (Fig. 2). Worth noticing is the rising of 5* hotels (Rhodes Island rates first in the Dodecanese islands' complex, owing 60% of 5* hotel beds), reaching an increase of 105.9% in this decade; while the increase in 4* hotels amounts to 35.51% (Fig. 2a). A smaller increase of 13.53% is noticed in 3* hotels, while the 1* and 2* hotels display a certain downward trend (−10.41% and −14.03% respectively). A relevant pattern is noticed when considering the number of hotel rooms (Fig. 2b), where 5* hotel rooms display an increase of 113.25%, 4* rooms are rather stabilized (+6.58%) and 3*, 2* and 1* hotel rooms demonstrate a remarkable decrease (−16.79%, −27.73% and −14.89% respectively). A similar to hotel rooms' pattern seems to be followed by the number of hotel beds (Fig. 2c). This tourism supply image demonstrates the pathway of the tourism sector in the island, directed so far towards a mass tourism, high class destination model; while in spatial terms this implies the prevalence of large scale tourism accommodation infrastructure, mainly concentrated in the eastern and north-eastern coastal part.

In addition to the hotel infrastructure, Airbnb accommodation is gradually evolving as an important part of the tourism supply. In 2023, this amounts to 5149 accommodations and 15,447 beds [19]. It should be noted here that Airbnb development in the island of Rhodes, compared to other Greek islands (e.g. Mykonos and Santorini), remains yet relatively low in comparison to the hotel sector. However, alarming is the 19% increase

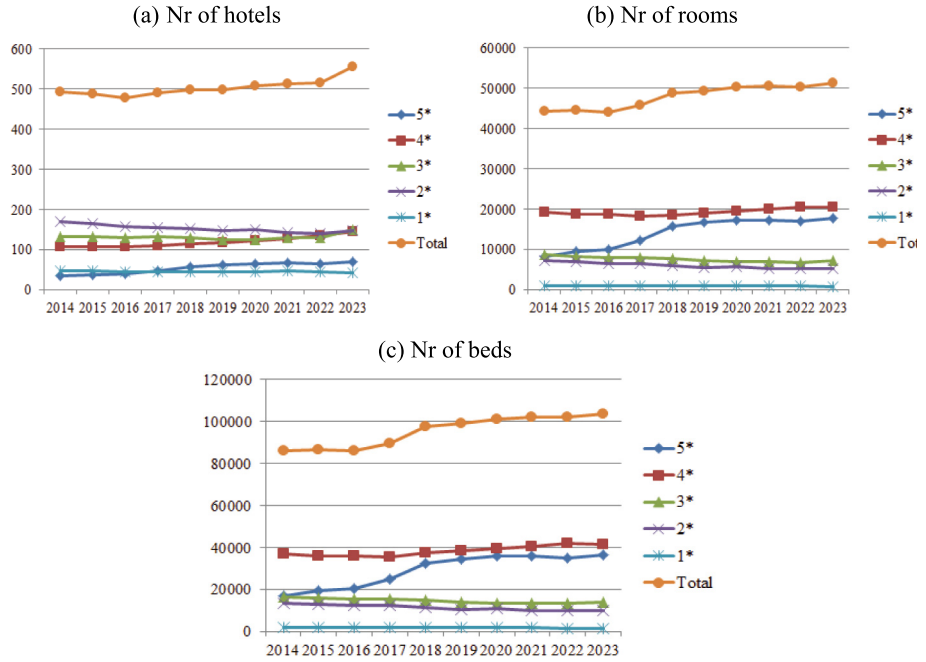

Fig. 2. Tourism accommodation developments in the island of Rhodes in the decade 2014–2023. Source: [18], own elaboration.

of Airbnb accommodation in the time span 2022–2023 [19], displaying the dynamics of Airbnb development.

In order for the tourism pressure in the study region to be identified, the relative indicators depicted in Table 1 are utilized, assessing tourism density and intensity. Performance of the island of Rhodes in these indicators demonstrates the island's position in the Dodecanese complex. More specifically, the island occupies the highest position as to the Tourism Density aspect (indicators TPI3 and TPI4); while with respect to the Tourism Intensity (indicators TPI1 and TPI2) it rates lower that the average value of the Dodecanese islands. Taking into consideration that the Tourism and Airbnb Accommodation Density (TPI3 & TPI4) highlight islands that accommodate mainly mass tourism and are most prominent in terms of land 'consumption', the aforementioned image provided by the values of these indicators reaffirms, in a way, the pressure exerted on the built environment of the island of Rhodes, a fact that is also advocated by the rising of 5* hotel accommodation. This rapidly expanding accommodation type is largely affecting the built space of the island with heavy tourism infrastructure projects, especially in its coastal part (Fig. 3).

The NATURA 2000 regions of the study area and the Human Settlement Layer in 2018 are demonstrated in Fig. 3a, b respectively. In addition, the spatial pattern of the tourism supply, i.e., location of hotel and Airbnb accommodation, is depicted in Fig. 3c, d. Inspection of the human intervention in the island of Rhodes delineates a rather crowded eastern coastal corridor that features specific concentrations – *tourism*

Table 1. Tourism pressure - Position of the island of Rhodes in the Dodecanese Complex.

Tourism Pressure Indicators - TPI	Short Description	Island of Rhodes Value	Dodecanese Island Complex Average Value
TPI1. Tourism accommodation intensity	[Total tourist accommodation (beds) / resident]	1.47	2.3
TPI2. Airbnb accommodation intensity	[Total Airbnb accommodation (beds) / resident]	0.10	0.14
TPI3. Tourism accommodation density	[Total tourist accommodation (beds) / island's surface]	130.96	102.4
TPI4. Airbnb accommodation density	[Total Airbnb accommodation (beds) / island's surface in km^2]	9.39	7.37

hotspots – in the neighbourhood of the Lindos, Afantou, Faliraki and Ialissos settlements as well as in the city of Rhodes (Fig. 3c, d); while part of these concentrations falls into or lays in close contact with NATURA 2000 protected areas (Fig. 3a). Furthermore, both hotel and Airbnb infrastructure deployment displays a similar pattern; while Airbnb accommodation seems to be further expanding to the island's mainland in NATURA 2000 protected areas (Fig. 3d). The same holds for tourism-related entrepreneurship that is in alignment with the Airbnb distribution. This tourism-related infrastructure pattern on coastal land can be also viewed in the Human Settlement Layer performance indicator (Fig. 3b). In fact the degree of urbanization related to any human-made infrastructure represents an average built-up density of 23% that is mostly concentrated along the eastern coastal part of the island of Rhodes.

4 Exploring Areas Exposed to CC Risks in the Island of Rhodes

The island of Rhodes has recently been evidenced to exhibit high vulnerability to climate-induced risks and natural hazards, as a combined result of high systemic socio-ecological exposure and high vulnerability due to the:

- considerable lack of adequate infrastructure that is capable of securing resilience towards the immense tourist flows of the high-season period (May to September),
- inherent vulnerabilities related to geomorphology and climatic parameters with respect to existing land use/land cover patterns.

The exposure to a combination of vulnerability factors is magnified in the middle- to north-eastern coastal rim of the island, currently emerging as a *tourist hotspot corridor*. In this corridor, the most recent waves of development are concentrating, especially since the dawn of the 21st century.

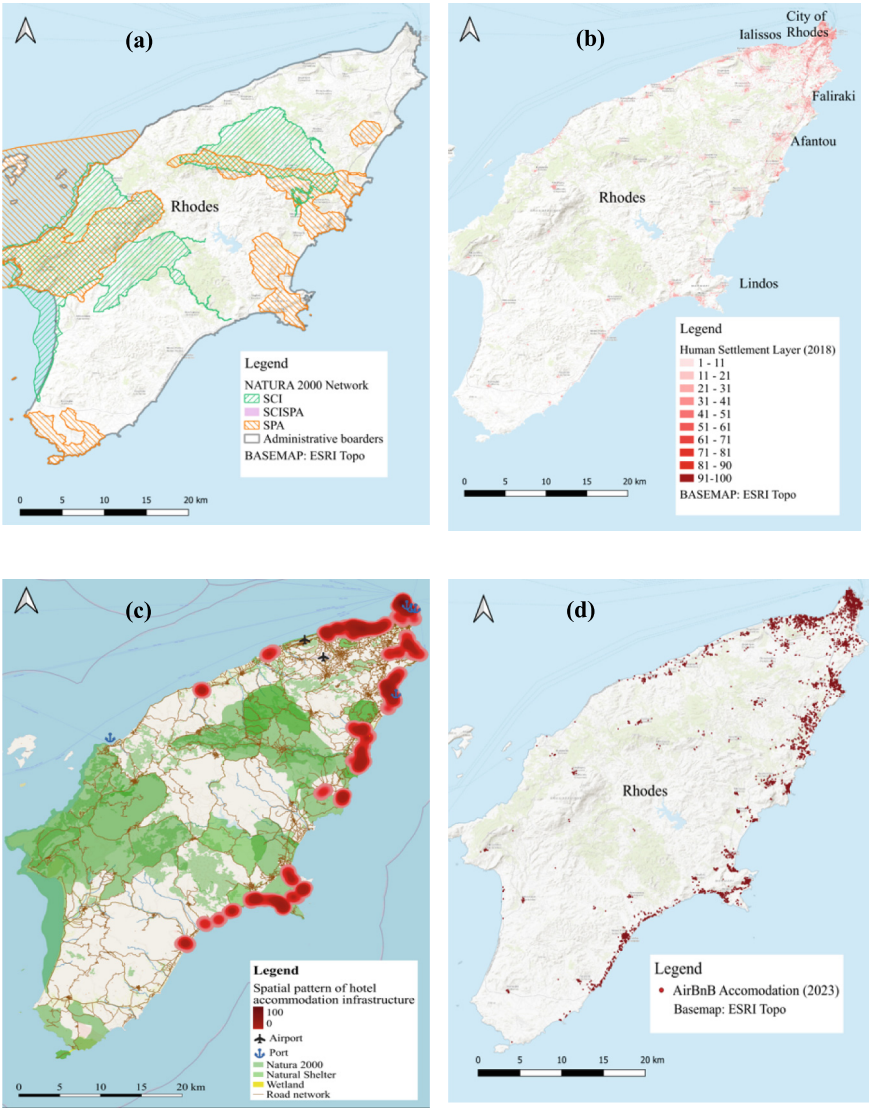

Fig. 3. Island of Rhodes. (a) Natura 2000 regions, (b) Human Settlement Layer (2018), (c) Spatial pattern of hotel infrastructure, (d) Spatial pattern of Airbnb accommodation. Source: Own elaboration based on data from (a) [20], (b) [21], (c) [22] and (d) [19].

The hazardous situation in the island of Rhodes due to CC impacts has been observed and highlighted during the *mega-wildfire* of July 2023 [23]. As witnessed during this wildfire crisis and explicitly stated in the respective report of the Rapid Mapping Service of Copernicus [24], thousands of residents and visitors of inland and coastal villages and large resorts were ordered to evacuate. Fire started on 19/07 in a mountainous inland forest part, reaching after four days the south-eastern coast close to the Glystra

Beach and Genadi Beach in the neighborhood of Lindos peninsula, burning facilities and infrastructure along its way, and ultimately destroying 17,653 ha of forest and transitional scrub land [24]. Evacuation was proven to be a very difficult task for the Civil Protection's agents, as thousands of people were found trapped for several hours between the mountain and the sea [25], with 16,000 people being transported across land and another 3000 by the sea.

However, wildfires are not the only major threat of the urbanized tourist model of the island of Rhodes and the specific coastal corridor. Certain urban constellations of this corridor are also exposed to severe risk of *floods*, particularly affecting specific parts of the coastline zone. Climate change is accentuating both flood and fire risk, while pressure is exerted on coastal wetland ecosystems and woodland areas. In the foreseeable future, estimations at the local level predict considerably lower mean precipitation rates (20–25% reduction) as well as increased drought, accompanied by an increase in Hot Days (i.e. the number of days within a year where Maximum Temperature is greater than 35 °C) [26]. Furthermore, according to Skrimizea & Parra [27], water stress is already high in certain parts of the island. As early as in the 1990s, a study carried out by the United Nations Environment Programme [28], identified signs of saturation in different tourist places around the city of Rhodes, raising concerns regarding the effects of the island's unbalanced socio-economic development on water resources, ascribed to the growth of tourist activities and a concomitant accelerated rate of water use [27].

Within such a context, in this section, the effort is to gain insights and identify such combined risks from a *geospatial perspective*. For a number of well attested reasons, particular focus is placed on the eastern coast/corridor (Fig. 4), due to:

- The higher vulnerability to combined flood and fire risk.
- The less planned character of tourism development and relative urban infrastructure with respect to the northern highly-urbanized part.
- The more intense accentuation of built up activity, as evidenced by new artificial cover during the past decades.
- The higher environmental vulnerability due to the concentration of Natura 2000 and other wildlife sites close to the coast, with important natural areas already impacted by the 2023 fire and previous hazardous events,further affected by large population and tourism constellations falling into these coastal NATURA sites (Fig. 3).

The focus area (eastern coastal corridor - Fig. 4) is actually expanding in a 5-km depth zone along the eastern coastline. This is a large area, of an over 80-min drive (70 km) from the city of Rhodes to the southern end, crossing a relatively rough and heterogeneous landscape. A considerable part of high-valued agricultural land is concentrated in this zone (olives, vineyards, etc.), with the total agricultural land adding up to 26% of the focus area. In addition, significant ecosystems from the mountainous ranges are ending up to the sea; while parts of the coastline are marked by the presence of sandy beaches, thus presenting high vulnerability to soil erosion [29]. Two quite distinct highly-developed coastal tourist areas are situated along this eastern corridor, namely the Lindos peninsula and its surroundings (Fig. 4) and the Faliraki resort.

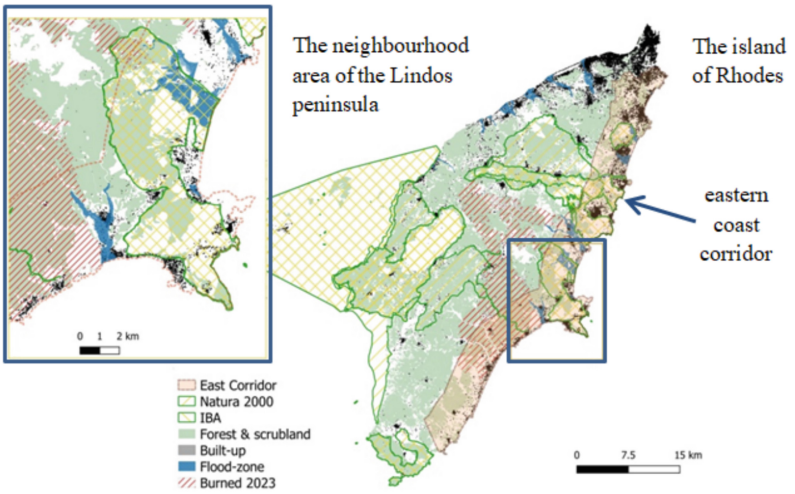

Fig. 4. Combined fire and flood risk in the eastern coastal rim of Rhodes Island in the neighborhood of the Lindos peninsula, Source: Own elaboration.

4.1 Flood-Prone Areas

Flood-prone areas are directly obtained from the official Web-GIS database of the Greek Ministry of Environment and Energy [30]. The Flood Hazard Maps, Flood Risk Maps, and Flood Risk Management Plans are in alignment with the Directive 2007/60/EC [31], setting the general framework for the assessment and management of flood risks; while the geographical unit for implementing the Directive 2007/60/EC as to the flood risks assessment and management is the River Basin District (Water District).

The applied methodology assessed flood risk within the inundation areas, resulting from the hydraulic analysis for the examined return periods, with flood risk depending on [30]:

- The extent and intensity of the flood for the return period within the Flood Risk Management Zone.
- The potential impacts/damages and the significance/value of existing land uses.
- The vulnerability of these land uses to flooding, in terms of their susceptibility based on flood characteristics.

Specifically, for the island of Rhodes almost all flood-prone areas are concentrated on the central eastern part, while the southern one (also considerably less developed and impacted by tourism or urbanization) is less affected. Highly attractive mass tourist areas, like Lindos peninsula (Fig. 4) and Faliraki, situated along the focus corridor in the middle- and north-eastern coast, have been severely flooded during the past decades. These regions constitute *tourism hot spots*, where settlements and tourism infrastructure are raising in adjacent to flood-zones and natural reserves. Severely flooded is also the Ialissos settlement, situated in the north-western coast, close to the city of Rhodes. An estimation of the distribution of flood-prone areas and their relation to built-up areas and tourism facilities (Airbnb) is presented in Tables 2 and 3.

Table 2. Flood-zone statistical data and built-up areas.

	Total Island's Surface		Eastern Island's Zone	
	(ha)	% of total	(ha)	% of zone
Land within flood zone	2396	1.65%	1526	4.38%
Built-up areas within the flood zone	117	4% of total built-up area	52.9	4.8% of zone's built-up area
Tourism facilities within the flood zone	Yes (approx. 150 Airbnb)	2.7% (total 5400)	Yes (approx. 130 Airbnb)	4.7% (total 2728)

Table 3. Built-up area falling into the major flood zones.

Flood_AREA* (ha)	Within the Eastern Focus Corridor (Yes/No)	Built-up area (ha)	% built up area of flood-zone area
219.0	NO	24.0	11.0
195.9	YES	16.8	8.6
418.1	YES	14.6	3.5
123.8	NO	14.1	11.4
171.5	NO	6.6	3.8
132.2	YES	6.2	4.7
168.0	NO	5.9	3.5
145.9	YES	3.5	2.4
7.8	YES	2.7	34.5
17.4	YES	1.8	10.1
116.4	YES	1.2	1.0
19.7	NO	1.1	5.7

* Return Period of 1000 years - T1000 [30] is used due to the fact that Climate Change renders such mega-flood events more probable in the short-term.

By this information, it can be observed that the most extensive flood zones with concentration of built-up areas within them (up to 30% of certain flood zones are covered by structures) are more particularly concentrated in the coastal middle-eastern zone. The same holds for almost all Airbnb accommodations, with 130 out of a total of 150 Airbnb units operating within potential flood zones. Generally, the density of Airbnb per km^2 of land in the studied corridor is around 8 times higher than the overall Airbnb density at the island's level.

4.2 Land Use/Land Cover Analysis

To identify land cover types, the Coastal Zones Land Use/Land cover Database of the European Union's Copernicus Land Monitoring Service [32] is used. The Coastal Zones (CZ) product provides a detailed Land Cover/Land Use (LC/LU) dataset, extracted from high resolution satellite and other available data. Class definitions follow the CORINE Land Cover classification, adapted to the specific characteristics of coastal zones. A Minimum Mapping Unit (MMU) of 0.5 ha and a Minimum Mapping Width (MMW) of 10 m are used. The last available reference year is 2018, including change mapping since 2012.

Specifically, for mapping and analysing the built-up environment several methods and respective datasets have been proposed [33]. To identify recent changes in the island's *soil sealing pattern* through various types of construction, the Imperviousness Classified Change Layer (IMCC database) [34] is used, i.e. a suitable geodatabase for investigating the impact of human activity on the landscape. Imperviousness Classified Change Layer (raster 20 m) covers the period 2006–2018 and provides the degree of imperviousness change in the categories of sealing change (unchanged no sealing, new cover, loss of cover, unchanged sealed, increased sealing, decreased sealing) between each two Imperviousness Density status layers [34]. Rasters of the database were processed according to the methodology described by Lagarias [35].

A comparison of land cover types between the island level as a whole and the focus corridor (Table 4) shows that artificial land along the eastern corridor (6.8%), despite the fact that major urban areas are omitted, is higher than the overall islands' mean percentage (4.0%). Forest land covers this corridor by 10.3%, compared to the 21.5% for the total island; while most of the land cover is classified as semi-natural land, including scrubs and transitional vegetation.

Table 4. Types of land cover in 2018.

	Island of Rhodes in ha & percentage of land	Focus corridor in ha & percentage of land
Forest land (CZ)	30,489 (21.5%)	3571 (10.3%)
Semi-natural land	72,178 (51%)	18,092 (52.1%)
Agricultural land	27,691 (19.6%)	9254 (26.6%)
Artificial land	5666 (4%)	2349 (6.8%)
Other	5458 (3.9%)	1446 (3.9%)
Total area	144,547	34,781

4.3 Identifying the most Recent Built Up Developments

The simple inspection method facilitates a rough evaluation of land-use change area in the most recent period, covering the years beyond 2018, where both CZ and IMCC

database ceased to be updated. This process includes the following steps, using a script in the Google Earth Engine platform:

- Creation of a point-based Area of Interest (AOI). An AOI is created with a buffer around it for a larger search area, and the administrative region is selected for clipping.
- Setting the Time Periods & Sentinel-2 Data Filtering. The script defines two periods: summer 2017 and summer 2024 for comparing the N*ormalized Difference Vegetation Index* (NDVI). The date ranges are set to focus on the summer months of each year. Sentinel-2 images are filtered based on the AOI and time period, also using Sentinel-2 SCL band to remove clouds and cloud shadows.
- NDVI calculation and comparison. NDVI calculation is processed using the Visible and Near Infrared (B8) and Red (B4) bands. The mean NDVI for both periods is calculated and the difference between them is computed.

Results show that during the period 2017–2024 NDVI loss is observed (Fig. 5) in most of the Rhodes' island territory, a fact that is partly attributed to the drought conditions generally holding in the Southern Aegean Region [4]. Furthermore, in certain parts of the focus corridor of this work, NDVI loss identified is basically attributed to the effect of fires and built up developments, leading to complete loss of existing vegetation coverage. Some plots of agricultural land also exhibit heavy NDVI loss due to ex-cultivation of certain areas, possibly being cleared-off for future development.

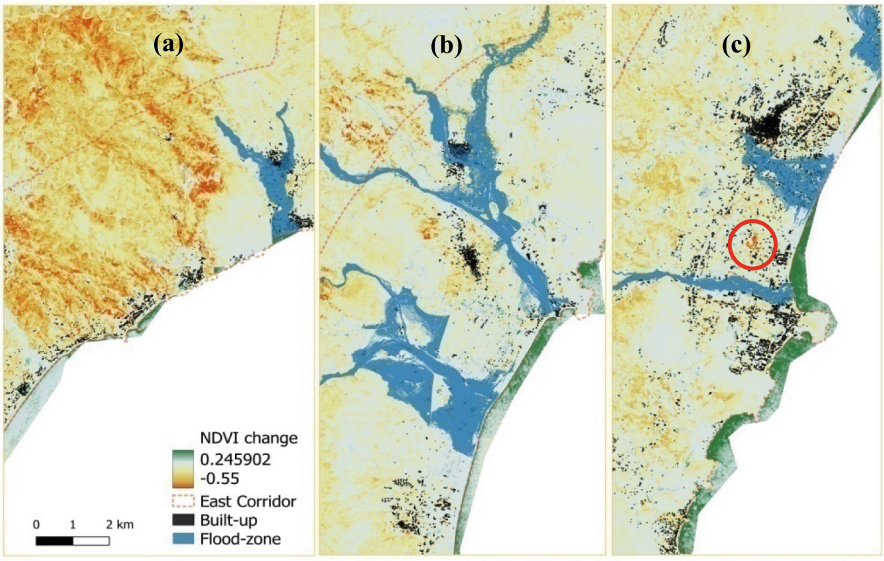

Fig. 5. NDVI change detection map 2017–2024 and flood risk in: (a) the Glystra resort in the southern of Lindos peninsula, (b) Kalathos-Vagies settlement in the northern of Lindos peninsula, (c) Afantou settlement in north-eastern coast and the new tourism development (in red circle). Source: Own elaboration.

That said and despite the dramatic experiences of the 2023 wildfire, but also the documentation and mapping of the flood-risk areas in the middle to north-eastern part of the island of Rhodes and the disastrous flood of 2024, severely affecting, among others, the settlements of Ialissos, Faliraki and Afantou – i.e. tourism hotspots in the study area – it seems that the Tourism-Led-Growth (TLG) model [15] still remains the prevailing direction in the island's economic profile, somehow leaving aside knowledge gained by the already witnessed and actually severe repercussions of Climate Change. This direction is largely supported by both the top-rated position of the island of Rhodes in the global tourism scenery; and the recent policy reforms, being the outcome of a decade of economic austerity Greece has gone through and the effort to 'reboot' the national/regional economy after the recent public debt crisis.

In fact within the focus corridor major new tourism development projects are currently deploying. Among them falls the 'Afantou Project' (Fig. 6a), perceived as one of the greatest projects in the Mediterranean. This is situated in the vicinity of the Afantou settlement, falling into the focus corridor of this work. The Afantou area is adjacent to a Natura 2000 site (GR4210029 - Birds Directive) and an Important Bird and Biodiversity Area (IBA), hosting 66 protected species of the Nature Directives [36], also including two important wetlands (ROD014 and ROD042 of the relevant national database). The site also contains extended archaeological zones and sites (Fig. 6b), as it has been the location of very ancient settlements and fortifications (Hellenistic wall – "Erimokastro, ancient tombs at the "Traounou" site, and ancient walls near the Ladiko Bay - [37]), with Afantou being a major Rhodian town since ancient times.

The proposal of the 'Afantou Project', initiated in 2012, is in alignment with the current Greek legislative framework that regulates the process of urban planning maturation of public properties, transferred to the Hellenic Republic Asset Development Fund [38]; and the assignment to them of an economically viable investment identity, with the aim of their utilization for reasons of significant public interest. The Afantou proposal, as approved and published in the National Gazette 180/AAP/2016 [39] suggests an overall plot ratio (or building coefficient) of 0.09, leading to tens of thousands new square meters; and a combination of various land uses serving the needs of about 5000 tourists, including [40]: tourism – recreation areas; business parks; theme parks; shopping and recreation centers; transport, technical, social, and environmental infrastructure and functions; holiday – tourist village; and public properties with mixed uses (Fig. 6b). A pre-existing old golf course that has been developed by the National Tourism Organization of Greece since the '70 s and is partly abandoned for several decades, is also planned to be revitalized by the developers.

The 'Afantou Project' is mandated to take into consideration possible environmental impacts. However, Climate Change parameters and specific examination of various hazards/risks, impacts on land use transition and new pressure posed on islands' water resources are not adequately addressed. This is totally aligned with other similar new tourism development proposals in Greece, with environmental impacts and hazardous risks being considerably underestimated in order for the license processing and their implementation to be facilitated.

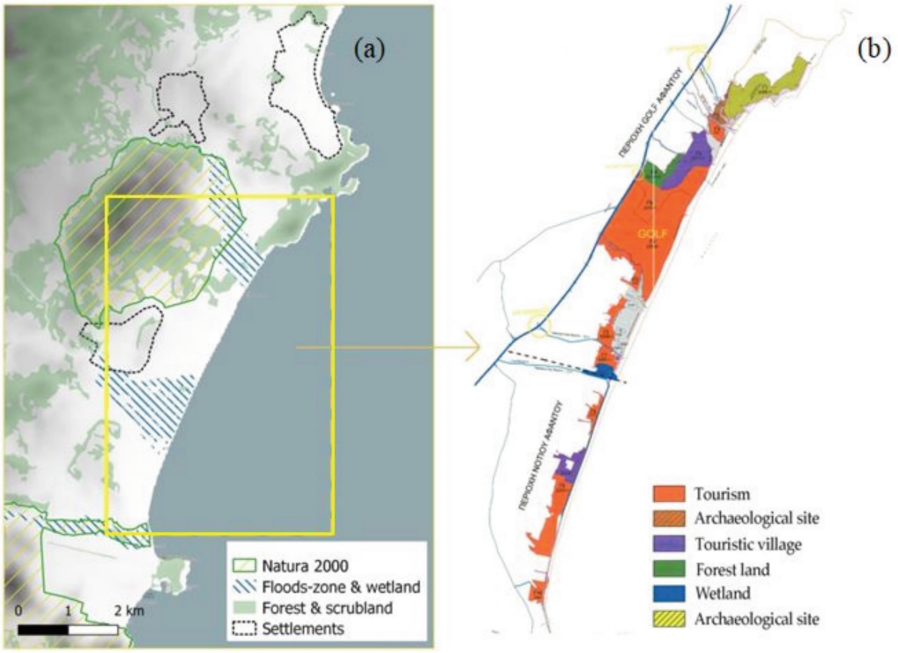

Fig. 6. (a) Location of the Afantou Project (yellow box) in relation to the risk-prone areas (in blue) and natural reserves (in green). (b) The plan of the Afantou Project in the north-eastern part of the island of Rhodes, Source: Own elaboration.

5 Discussion and Conclusions

The tourism supply dynamics of Rhodes Island – i.e., the flagship, together with Kos Island, of the Dodecanese complex, Southern Aegean Region – reflects a traditional mass tourism model, mostly based on large scale, steadily expanding, high class tourism infrastructure investments. This, in turn, implies consumption of valuable land and has adverse impacts on protected areas and other sectoral uses (e.g. agriculture), especially in the eastern coastal rim of the island, where the majority of tourism hotspots are situated. Such a dynamics is the outcome of developments in both the external and the internal decision environment. Speaking of the external environment, as critical issues are considered: the notable position of Rhodes island in the tourism arena, rendering this island a challenging option for tourism investments in the global scene; the role of Information and Communications Technologies (ICTs) as an accelerator of tourism growth, facilitating temporal and geographical concentration of tourist flows in certain well-established tourism destinations as the island of Rhodes; the overdependence on offshore tour operators, rendering local stakeholders less powerful in this bargaining game and rather unable to articulate a diversifying, more sustainable, tourism narrative; and the legislative framework in Greece, especially policies promoted after the 10 years recession period targeting the restart of the Greek economy, which have brought on board new spatial planning instruments for facilitating large-scale investments on both

public and privately-own plots. These policy directions surpass regulations of urban and periurban space that emanate by the General Urban Plans carried out at the municipality level; and play a critical role in promoting fast-track processes as enablers for serving global real estate interests and supporting large tourism investments in insular territories in general, including Rhodes. That said, it is noticeable the confined role of local administrations and population as partners in strategic policy decisions at the national and regional level, having thus a say in defining a destination's image that is in alignment with sustainability and resilience objectives at the local level.

In a CC era, Rhodes Island is confronted with the threat of losing off important landscape features and natural resources. More specifically, significant loss of forest land and tree coverage due to wildfires, loss of wetlands and beaches due to the CC impacts in combination with tourism encroachment and coastal erosion problems, and increasing soil sealing in the neighborhood of fire and flood-prone areas are placing resilience to several types of climate-induced crises at stake in the immediate future. In this respect, spatial planning seems to acquire a crucial role in the effort to embed in its processes, in a substantial way, various kinds of CC risks and provide options for ensuring sustainability and resilience objectives in this complex and uncertain environment, undertaking also the role of educating, raising awareness and empowering local communities to realize challenges and react in a risk-minimizing and resilience-maximizing way. Furthermore, future steps of this work could explore the integration, into the proposed framework, of the Urban Heat Islands (UHI) effects, i.e. a particularly relevant topic to such intensively built-up coastal tourist areas and a factor that can potentially exacerbate climate-related vulnerabilities.

References

1. Leka, A., Lagarias, A., Panagiotopoulou, M., Stratigea, A.: Development of a tourism carrying capacity index (TCCI) for sustainable management of coastal areas in Mediterranean Islands – Case study Naxos, Greece. Ocean Coastal Manag. **216**, 105978 (2022). https://doi.org/10.1016/j.ocecoaman.2021.105978
2. Lagarias, A., Stratigea, A., Theodora, Y.: Overtourism as an emerging threat for sustainable Island communities–Exploring indicative examples from the South Aegean Region, Greece. In: Gervasi, O., et al. (eds.) Computational Science and Its Applications – ICCSA 2023 Workshops. ICCSA 2023 Lecture Notes in Computer Science, pp. 404–421. Springer, Cham (2023). https://doi.org/10.1007/978-3-031-37123-3_29
3. Mokhtari, Z., Bergantino, A.S., Intini, M., Elia, M., Buongiorno, A., Giannico, V., Sanesi, G., Lafortezza, R.: Nighttime light extent and intensity explain the dynamics of human activity in coastal zones. Sci. Rep. **15**(1), 1663 (2025). https://doi.org/10.1038/s41598-025-85917-z
4. Leka, A., Lagarias, A., Stratigea, A., Prekas, P.: A methodological framework for assessing overtourism in insular territories—Case study of Santorini Island, Greece. Int. J. Geo-Inform. **14**, 106 (2025). https://doi.org/10.3390/ijgi14030106
5. UNWTO: Tourism and the sustainable development goals–Journey to 2030. (2018). https://www.undp.org/sites/g/files/zskgke326/files/publications/UNWTO_UNDP_Tourism%20and%20the%20SDGs.pdf, last accessed 16 Feb 2025
6. COM(2019) 640 final: The European Green Deal. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, European Commission, Brussels (2019)

7. Lagarias, A., Stratigea, A.: Coastalization patterns in the Mediterranean: a spatiotemporal analysis of coastal urban sprawl in tourism destination areas. GeoJournal. **88**, 2529–2552 (2022). https://doi.org/10.1007/s10708-022-10756-8
8. GRID Arendal: https://www.grida.no/resources/5900, last accessed 11 Feb 2025
9. Theodora, Y., Stratigea, A.: Climate change and strategic adaptation planning in Mediterranean insular territories: gathering methodological insights from Greek experiences. In: Gervasi, O., et al. (eds.) Computational Science and Its Applications – ICCSA 2021 Workshops. ICCSA 2021 Lecture Notes in Computer Science, vol. 12958, pp. 100–115. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-87016-4_8
10. Stratigea, A., Leka, A., Nicolaides, C.: Small and medium-sized cities and insular communities in the Mediterranean: coping with sustainability challenges in the smart city context. In: Stratigea, A., Kyriakides, E., Nicolaides, C. (eds.) Smart Cities in the Mediterranean–Coping with Sustainability Objectives in Small and Medium-sized Cities and Island Communities, pp. 3–29. Springer (2017). https://doi.org/10.1007/978-3-319-54558-5
11. Nastos, P., Saaroni, H.: Living in Mediterranean cities in the context of climate change: a review. Int. J. Climatol. **44**, 3169–3190 (2024). https://doi.org/10.1002/joc.8546
12. Lionello, P., Platon, S., Rodo, X.: Preface – Trends and climate change in the Mediterranean region. Glob. Planet. Chang. **63**(2–3), 87–89 (2008). https://doi.org/10.1016/j.gloplacha.2008.06.004
13. Vogiatzakis, I.N., Mannion, A.M., Sarris, D.: Mediterranean Island biodiversity and climate change: the last 10,000 years and the future. Biodivers. Conserv. **25**, 2597–2627 (2016). https://doi.org/10.1007/s10531-016-1204-9
14. Lazoglou, G., Papadopoulos-Zachos, A., Georgiades, P., Zittis, G., Velikou, K., Manios, E.M., Anagnostopoulou, C.: Identification of climate change hotspots in the Mediterranean. Sci. Rep. **14**, 29817 (2024). https://doi.org/10.1038/s41598-024-80139-1
15. Balaguer, J., Cantavella-Jorda, M.: Tourism as a long-run economic growth factor: the Spanish case. Appl. Econ. **34**, 877–884 (2002). https://doi.org/10.1080/00036840110058923
16. ELSTAT – Population Census 2021. https://www.statistics.gr/documents/20181/17286366/APOF_APOT_MON_DHM_KOIN.pdf/41ae8e6c-5860-b58e-84f7-b64f9bc53ec4, last accessed 12 Feb 2025
17. Koutsi, D., Lagarias, A., Stratigea, A.: Assessing the tourism footprint in Dodecanese complex, Greece – An islands' typology approach. In: Gervasi, O., et al. (eds.) Computational Science and Its Applications – ICCSA 2024 Workshops. ICCSA 2024 Lecture Notes in Computer Science, vol. 14822, pp. 388–406. Springer, Cham (2024). https://doi.org/10.1007/978-3-031-65318-6_26
18. Hellenic Chamber of Hotels: https://www.grhotels.gr/category/epicheirimatiki-enimerosi/statistika/, last accessed 18 Feb 2025
19. Inside Airbnb Platform: https://insideairbnb.com/, last accessed 18 March 2025
20. European Environment Agency (EEA): Natura 2000 Viewer. https://natura2000.eea.europa.eu, last accessed 12 Jan 2025
21. Global Human Settlement Layer: https://ghsl.jrc.ec.europa.eu/, last accessed 25 Feb 2025
22. OSM – OpenStreetMap Data / Geofabric Downloads: https://download.geofabrik.de/europe/greece.html, last accessed 20 Feb 2025
23. Makineci, H.B.: Investigation of burned areas with multiplatform remote sensing data on the Rhodes 2023 forest fires. Ain Shams Eng. J. **15**(10), 102949 (2024)
24. MSR675: Wildfire on Rhodes Island, Greece. (2023). https://rapidmapping.emergency.copernicus.eu/EMSR675/download, last accessed 16 Feb 2025
25. BBC: https://www.bbc.com/news/world-europe-66295972, last accessed 18 Feb 2025
26. Georgoulias, A.K., Akritidis, D., Kalisoras, A., Kapsomenakis, J., Melas, D., Zerefos, C.S., Zanis, P.: Climate change projections for Greece in the 21st century from high-resolution

EURO-CORDEX RCM simulations. Atmos. Res. **271**, 106049 (2022). https://doi.org/10.1016/j.atmosres.2022.106049
27. Skrimizea, E., Parra, C.: Social-ecological dynamics and water stress in tourist islands: the case of Rhodes, Greece. J. Sustain. Tour. **27**(9), 1438–1456 (2019)
28. United Nations Environmental Programme - UNEP: Guidelines for integrated management of coastal and marine areas - with special reference to the Mediterranean Basin. In: UNEP Regional Seas Reports and Studies No. 161. Split, Croatia, PAP/RAC (MAP-UNEP) (1995) ISBN 92-807-1487-2
29. Zaimes, G.N., Gounaridis, D., Iakovoglou, V., Emmanouloudis, D.: Assessing soil erosion risk for Rhodes Island, Greece with a GIS-based multi-criteria decision analysis. In: Proceedings of the IASTED International Conference on Water Resource Management, Gaborone, Volume: Africa Water Resource Management (AfricaWRM 2012), Botswana (2012). https://doi.org/10.2316/P.2012.762-008
30. Greek Ministry of Environment and Energy: https://gis.floods.ypeka.gr/, last accessed 18 Feb 2025
31. Directive 2007/60/EC. On the assessment and management of flood risks. Off. J. Eur. Union L 288/27, 6.11.2007, 27–34 (2007)
32. Coastal Zones Land Use / Land cover Database of the European Union's Copernicus Land Monitoring Service: https://land.copernicus.eu/en/products/coastal-zones, last accessed 6 Feb 2025
33. Lagarias, A., Stathakis, D.: Towards a more realistic estimation of urban land take by combining cadastral parcels and building footprints. Environ. Plann. B Urban Analyt. City Sci. **52**(5). 1091–1109 (2024). https://doi.org/10.1177/23998083241282092
34. European Environment Agency (EEA) - Copernicus Land Monitoring Service: High Resolution Layer Imperviousness (2018). https://land.copernicus.eu/en/products/high-resolution-layer-imperviousness, last accessed 6 Jan 2025
35. Lagarias, A.: Impervious land expansion as a control parameter for climate-resilient planning on the Mediterranean coast: evidence from Greece. Land. **12**(10), 1844 (2023). https://doi.org/10.3390/land12101844
36. European Environment Agency (EEA): https://eunis.eea.europa.eu/sites/GR4210029, last accessed 28 Jan 2025
37. Archaeological Cadastre: https://www.arxaiologikoktimatologio.gov.gr/, last accessed 13 Jan 2025
38. Hellenic Republic Asset Development Fund: https://hradf.com/, last accessed 5Feb 2025
39. National Gazette 180/AAP/2016: Afantou Project. https://www.technologismiki.com/nomos/pd_9_8_16.php?toc=0&printWindow&, last accessed 2 March 2025
40. Geoplan: Strategic Environmental Impact Study - Afantou Rhodes. (2012) (in Greek). https://docplayer.gr/2595479-Stratigiki-meleti-perivallontikon-epiptoseon-s-m-p-e-afantoy-rodoy.html, last accessed 22 Jan 2025