Identifying Insular Tourism Hotspots at Fire and/or Flood Risk – Case Study Rhodes Island, Greece

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Abstract. In the Climate Change (CC) era, frequency, duration, and intensity of wildfire and flood incidents across Mediterranean areas is predicted to amplify, raising thus policy concerns as to the risks inherent in, among others, tourism hotspot regions, including the insular ones. Experience gained from recent CC-related fire/flood incidents and their devastating impacts on the natural/built environment – particularly in Mediterranean highly-urbanized, tourist-overloaded coastal parts – calls for broadening the scope of planning and policy making in order for resilience of these areas to be strengthened. This highlights the necessity for feeding planning endeavours with spatially-defined fire/flood risk assessments, especially in coastal tourism hotspots, i.e., areas displaying an intense accommodation and tourists' overload. That said, this study develops a framework for identifying tourism hotspot zones that are prone to fire and/or flood risk, with this perceived as a critical input in proactive planning studies aiming to minimize fire/flood risk or conduct fire/flood management plans. This framework integrates: a literature-based indicators' set for featuring tourism hotspots; the Random Forest algorithm through the Forest-Based Classification tool for fire risk assessment; and the officially-delineated flood-prone zones. Implementation of this framework is conducted in Rhodes Island, i.e., a major flagship of Greek tourism; a well-known, of global reach, destination; and a prominent example of Mediterranean island region, exposed to both CC and (over)tourism repercussions. Linking fire/flood hazards with tourism patterns offers insular destinations a useful ground for featuring proactive CC adaptation strategies and/or emergency planning.

Keywords: Insular Territories · Tourism Hotspots · Fire/Flood Risk · Spatial Analysis · Machine Learning

1 Introduction

Mediterranean regions nowadays are perceived as remarkable *tourism hubs*, attracting about 30% of the global tourist flows [1]. Actually in these regions tourism is grasped as a developmental lever and is mainly expanded in the coastal part of both the mainland and the insular territories, taking mostly the form of mass tourism. Speaking of the *insular*

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territories, being at the heart of this work, tourism is grasped as the 'engine' of the islands' economic profile, building the foundation for a Tourism-Led Growth (TLG) paradigm [2], with noticeable contribution to GDP, employment, and foreign exchange earnings. However, the industry's quite extensive and, in many cases, uncontrolled growth [3] is also a main source of: commercialization and degradation of the natural/cultural capital; wasting of scarce resources; intense urbanization of coastal land; extensive urban sprawl along the coast [4]; to name but a few. The latter – i.e. coastal urban sprawl – brings coastal urban zones in close proximity to neighbouring forested areas, giving thus rise to, among others, fire prone Wildland Urban Interfaces (WUIs). Taking into consideration the rapidly expanding tourist flows in the Mediterranean [1], the aforementioned tourism repercussions are expected to further escalate, while the state of *overtourism* is currently presenting a visible trend/threat and a main accelerator of the degradation of fragile natural coastline areas and the identity loss of coastal and particularly insular territories [3, 5–8].

Further to the tourism-originating pressure and related threats, introduced by the mass model prevailing in the Mediterranean coastal and particularly the insular territories, a key challenge that is expected to largely affect the future of these Mediterranean mass tourism hubs is *Climate Change*. CC, as various studies claim, places coastal communities at stake by threatening their livelihoods, infrastructure and ecosystems [9]. Mediterranean in the CC era is confronted with higher risks than the rest regions of the world, as a CC hotspot, heating 20% faster than world average [10]. Primary CC impacts, coastal communities must contend with are the rising sea levels, the escalating storm intensity, the coastal erosion and the habitats' loss; all largely affecting the socioeconomic environment of Mediterranean coastal/insular communities, including tourism as a highly important industry of this region. In addition, insular territories, despite their low contribution to CC, seem to be much more vulnerable to CC-driven impacts, with this vulnerability being largely dependent on their peculiar attributes, e.g. islands' size, morphology, geographical location, adaptive capacity.

CC repercussions are further intensified by the combined influence of non-climatic factors, particularly land use changes. Of critical importance in this respect, as various studies claim [11], are Mediterranean *tourism hotspots*, i.e., highly-sensitive and intensely-urbanized coastal parts, displaying a strong dependence – apart from tourism – on a range of coastal-related economic sectors (e.g. fishery, maritime transportation, marine energy) [12]. That said, the unique vulnerabilities and adaptive capacities of such tourism hotspots as well as their resilience or adaptive needs [13, 14] remain rather underrepresented in relevant CC and developmental studies. Most importantly, the spatial pattern of such vulnerabilities and their relationship with tourism hotspots lacks a well-documented approach which – taking into account also technological advances – can strengthen the context of *placed-based policy decisions*, targeting resilience of these hotspots but also preparing for extreme events' management.

Within such a context, this work attempts to fill the aforementioned gap, by exploring risks tourism hotspots in insular regions are confronted with. Such risks are the outcomes of CC implications but also anthropogenic pressures, and are tightly interwoven with the rapid urbanization of coastal land and the intense urban sprawl for serving the steadily

rising tourism demand. More specifically, *flood and fire risk* and their spatial manifestations in a highly-rated tourism destination, Rhodes Island, Greece are explored; and these are overlaid onto the spatial pattern of tourism hotspots in order for destinations prone to fire and/or flood risk to be identified and thus more informed and proactive policy reaction to be articulated. It should be noted here that this work attempts to step further authors' previous research endeavour [15] by focusing on the field of fire risk assessment using Machine Learning Methods and more specifically the Random Forest algorithm through the Forest-Based Classification tool. Rigorous documentation in this field adds value in the proposed methodological framework, aiming at paving transition pathways of insular but also coastal territories that favour climate-resilient tourist development.

The structure of the study has as follows: in Sect. 2 the methodological approach is presented, coupled with the data sources used for identifying tourism hotspots in the study area and feeding the Forest-Based Classification tool for fire risk assessment; in Sect. 3 results obtained from the implementation of the proposed framework are demonstrated; while in Sect. 4 compound results are critically discussed and key conclusions are drawn.

2 Data and Methodology

2.1 The Methodological Approach

The steps of the methodological approach have as follows (Fig. 1):

- Step 1 delves into the key features of the study region. As such, Rhodes Island is used, being part of the Southern Aegean Region, Greece.
- Step 2 elaborates on the tourism dynamics of Rhodes Island. Towards this end, a good insight of tourism into the study region is accomplished, coupled with the calculation of a number of critical, literature-based, tourism density and intensity indicators and the demarcation of the spatial pattern of tourism infrastructure. Based on this knowledge, the pressure exerted by tourism in the study area is grasped, while tourism hotspots are also identified, i.e. places marked as overloaded due to the excessive tourism accommodation infrastructure and the large seasonal tourist flows.
- Step 3 indulges into the vulnerability assessment of Rhodes Island against the CC and anthropogenic pressures and more specifically against flood and fire risk. Flood prone areas are identified by inspection of the Flood Risk Management Plan, Water District of Aegean Islands, conducted in accordance with the provisions of Directive 2007/60/EC. Then the factors contributing to fire risk in the specific area are explored and the relevant data set is established. This was used as input to the Random Forest algorithm through the Forest-Based Classification tool for assessing fire risk of the various spots of the study region. Results obtained were validated by comparing fire prone areas with those beat by past fire events.
- Step 4 attempts to merge spatially-related results emanating from Steps 2 and 3, in an effort to identify fire and flood prone areas in Rhodes Island and their relationship with the tourism hotspots. Inferences out of this step can feed relevant policy reaction, targeting the protection of both the natural/built environment and the population/visitors of the specific tourism hotspots.

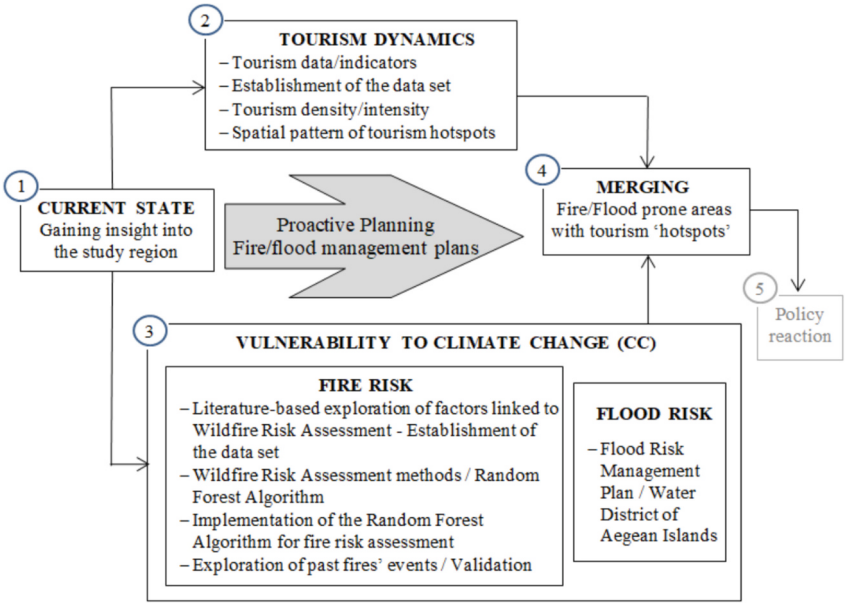

Fig. 1. Steps of the methodological approach. Source: Own elaboration.

2.2 Framing Tourism Pressure in Rhodes Island

The island of Rhodes displays a remarkable tourism and population dynamics, coupled with high rates of built-up expansion [15]. Large scale hotel accommodations prevail in the tourism infrastructure profile, manifesting a high concentration of beds and arrivals and resulting in a rising seasonal population density [16]. To analyse tourism pressure in this island, a set of literature-driven tourism density and intensity indicators was selected, which was meant to capture the key components of tourism supply (accommodation infrastructure). These indicators were calculated across three spatial scales, namely: Rhodes Island, the close neighbourhood of Dodecanese islands' complex, and the broader spatial context of the Region of Southern Aegean; enabling thus a comparative assessment of tourism pressure and unveiling the role of Rhodes as the tourism flagship of this Region. The selected indicators (Table 1) aimed to assess the pressure exerted by tourism accommodation infrastructure – both hotels and short-term rentals advertised on Airbnb – on the local population and the island's natural/cultural resources. The data sources used to compile and calculate these indicators are presented in Table 2.

Table 1. Selected Tourism Pressure Indicators TPI_i

Tourism Pressure Indicators - TPI	Description of Indicator (Calculations are based on 2024 data)
TPI1 – Tourism Accommodation Intensity	[Tourism Accommodation (Hotel and Airbnb beds) / Permanent Population (Residents)] ---- TPI1 features the pressure on population due to tourism accommodation infrastructure
TPI2 – Airbnb Accommodation Intensity	[Total Airbnb beds / Permanent Population (Residents)] ---- TPI2 highlights the pressure on population due to the Airbnb tourism supply
TPI3 – Tourism Accommodation Density	[Tourism Accommodation (hotel and Airbnb beds) / island's surface in km^2] ---- TPI3 features the pressure on its local resources due to tourism accommodation infrastructure
TPI4 – Airbnb Accommodation Density	[Total Airbnb beds / island's surface in km^2)] ---- TPI4 highlights the pressure on local resources due to the Airbnb tourism supply

Table 2. Data sources for Tourism Pressure Indicators

Type / Source of Data
Population: Data on permanent population is derived from the 2021 National Census of the Hellenic Statistical Authority (ELSTAT) / [17]
Hotel accommodation data: Data were derived from official records provided by the Hellenic Chamber of Hotels / [18]
Airbnb accommodation data: Data derived from the statistical processing and analysis of 2024 datasets published by the Institute of the Greek Tourism Confederation Intelligence (INSETE), with specific reference to the South Aegean Region / [19]
Land area: estimated through the Wikipedia / [20–22]

2.3 Framing Flood and Fire Risk Assessment

For grasping the *flood risk pattern* in Rhodes Island, the officially-delineated flood-prone zones are downloaded from the geoportal of the Greek Ministry of Environment and Energy [23]. Considering the rising CC-related risks, rendering mega-flood events more probable in the short term, the flood-prone zones have a return period of 1000 years (T = 1000) and are identified by inspection of the Flood Risk Management Plan, Water District of Aegean Islands, conducted in accordance with the provisions of Directive 2007/60/EC.

Speaking of the *fire risk assessment*, it is worth mentioning that state-of-the-art methodologies are gaining momentum in recent studies as they appear to be more reliable in assessing the risk and identifying the complexity of a research subject, such as

wildfire risk in the CC era [24, 25]. Due to their computing power, capability to handle large volumes of data and procedures' automation, state-of-the-art methodologies are increasingly replacing conventional ones, with the accuracy of their predictive outcomes becoming one of their strongest asset [24, 26]. In recent literature, a variety of fire-related research dimensions, such as fire susceptibility, fire risk, prediction of fire behaviour or fire occurrence are studied by means of advanced technologically-enabled tools, valuing also the geospatial predictive ability of those solutions [27]. That said, this work delves into the field of fire risk assessment by addressing relevant to the study region fire-risk related factors and variables; and using them as input to the Forest-Based Classification and Regression tool for assessing areas of Rhodes Island that are prone to fire risk.

The selection of fire risk assessment Factors – with *Topography*, *Climate*, *Environment* and *Urban Space* being the most commonly ones used in relevant studies – and related Variables constitutes a critical part of fire-related studies and is grounded in the particularities of the study region at hand. Of critical importance is also the comprehension of the interrelationships among those factors that is grasped through a thorough insight into the study area at hand. In fact, a well-rounded variables' selection process provides both crucial input on the area's particularities and information about the circumstances that can lead to fire occurrences [24]. In addition, a diverse variables' set is to the benefit of a holistic approach, allowing alternative choices for each single particular study area to occur [26, 28]. Furthermore, in the majority of fire-related studies, the selection of variables aims to cover all relevant factors, regardless of the emphasis on a specific research subject; while, a comprehensive list of variables largely contributes to the effective implementation of relevant methodologies and the production of trustworthy results [28]. The variables that are of relevance in fire-related studies are discussed by many researchers; while a literature-enabled analytical list of them is provided by Aksoy et al. [29]. The aforementioned fire risk assessment Factors are shortly discussed in the following paragraphs.

The factor *'Topography'* includes variables like 'Elevation', 'Slope' and 'Aspect', and features an area's morphology. These variables affect the progress of a forest fire event and the actions of firefighting forces [26]. More specifically: 'Elevation' is a decisive dimension of the prevailing meteorological conditions, largely affecting fire behaviour [30]; 'Slope's steepness plays a crucial role in the speed and spread of forest fire [30]; 'Aspect' is associated with the receiving sunlight and the probability of occurrence of a fire, rendering some of them – e.g., the south-southwest 'Aspects' in our study area – more susceptible, depending on the hemisphere [29].

The factor *'Climate'* is a crucial one in fire risk assessment since it directly relates to fire weather conditions; and has a remarkable impact on the progress of a fire event [31]. Extreme heat waves render 'Temperature' a crucial variable, affecting vegetation's flammability [32]. Temperature's combination with 'Precipitation' and 'Relative Humidity' variables is largely influencing vegetation and soil's moisture, thus defining fuel load and directly affecting fire ignition conditions [33]. Finally, 'Wind Speed' affects forest fire speed, therefore fire spreading, and is a major concern for fire suppression strategies [26, 30].

The factor *'Environment'* correlates with vegetation. This determines the fire risk of an area and the progress of a potential event. It includes variables that demarcate

the vegetation attributes, such as 'Dominant Leaf Type' [DLT], 'Tree Cover Density' [TCD] and 'Normalized Difference Vegetation Index' [NDVI]. The type of leaves and the density of the vegetation determine ignition proneness and fuel load availability [30]. These, in turn, are directly influencing firefighting strategies in order for efficient suppression to be attained. Furthermore, vegetation's health condition, being indicated through NDVI, is an equally important variable, delineating fuel availability and vegetation's fire susceptibility [32, 33].

The factor *'Urban Space'* is of great significance, since recent studies indicate human action as one of the main causes of fire ignition and an important part in an area's fire risk probability [34]. Variables such as 'Distance from the Road Network', 'Distance from Rivers' and 'Distance from Settlements' correlate with the proximity to human activities, rendering the nearest forested areas and the Wildland Urban Interfaces (WUIs) more susceptible to fire risk [30]. 'Population Distribution' and 'Land Use' are closely related as well, since dense populated areas near vulnerable ones and specific activities amplify the risk of fire ignition [26, 33].

Taking into consideration the particularities of the study area of this work, coupled with the heavy tourist load and vulnerability to CC impacts, 15 independent variables were selected as input to the fire risk assessment methodology (Table 3). Data selection for the 15 variables was based on availability, accessibility and usability in fire risk assessment methodologies, prioritizing the need for an up-to-date representation of the study area.

Table 3. Variables used as input in the implementation of the fire risk assessment methodology

Raw Data	Factor	Variable	Source	Time Span
Digital Elevation Model (DEM)	Topography	Elevation (m) Aspect (°) Slope (%)	Copernicus	-
Tree Cover Density (TCD)	Vegetation	TCD (%)	Copernicus	2023
Dominant Leaf Type (DLT)		DLT	Copernicus	2023
Normalized Difference Vegetation Index [NDVI]		NDVI	Copernicus	2024
Temperature Wind Speed Relative Humidity Precipitation	Climate	Temperature (° C) Wind Speed (m/s) Humidity (%) Precipitation (mm/y)	E-OBS, Copernicus	2000-2024 Fire Season (May – Oct)
Population	Urban Space	Population Distribution (Nr)	ELSTAT	2021
Settlements		Distance from Settlements (m)	ELSTAT	2021
CLCplus Backbone		Land Use	Copernicus	2023
Road Network		Distance from Road Network (m)	Geofabrik	2026
Hydrographic Network		Distance from Rivers (m)	Geofabrik	2026
Burned Areas	-	Fire/No Fire (Dependent Variable)	EFFIS, Copernicus	2000-2024

All necessary preprocessing procedures and modifications were conducted so that the emerging dataset to be appropriate for use as input to the Forest-Based Classification and Regression tool, which is incorporated in the Modeling Spatial Relationships toolset in ArcGIS Pro software [35]. This tool uses the supervised Machine Learning Random Forest algorithm, developed by Leo Breiman and Adele Cutler [36]; and is grounded in the construction of a model that creates a forest of decision trees, generated from a random subset of the training dataset. These decision trees are used for validating predictions of unknown values of the testing dataset, using the same set of independent variables. The final prediction is an aggregation derived from the entire forest, i.e. the predictions of each decision tree. For classification tasks, the outcome derives from majority voting, whereas for regression tasks this occurs from averaging. As to the performance of the Forest-Based Classification and Regression tool, a number of metrics are automatically derived from this tool, namely 'Accuracy', 'Recall' and 'F1 Score'. 'Accuracy' measures the overall predictive capability of the method; 'Recall' refers to its ability to correctly identify and predict actual positive instances; and 'F1 Score' serves as a balanced metric of the overall performance. Important advantages of the tool are its ability to provide predictions with a smaller set of independent variables, calculate variables' importance and reduce overfitting [35].

3 Implementation of the Methodological Framework - Results

3.1 The Study Region

The Island of Rhodes, located in the Region of Southern Aegean, Greece, is a well-known, highly attractive Mediterranean insular destination. Rhodes is the largest island of the Dodecanese Islands' Complex of this Region and a major administrative and tourism hub. It covers an area of 1401 km^2 and, according to the 2021 Census of the Hellenic Statistical Authority, owns a population of 125,113 inhabitants [17]. Population distribution displays a rather concentrated pattern in the north-eastern and northern coastal part (Fig. 2a).

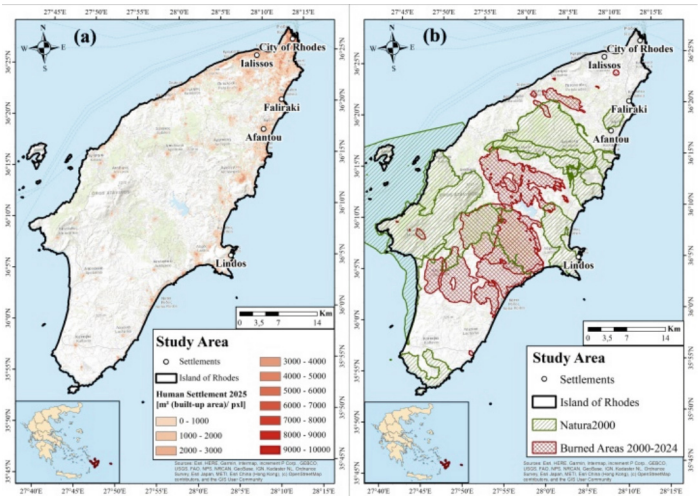

Fig. 2. Rhodes Island - (a) Human Settlement Layer, (b) Natura 2000 regions and Burned Areas in the time span 2000–2024. Source: Own elaboration based on the data from: (a) [37], (b) [38, 39].

Speaking of the island's morphology, Attavyros Mountain dominates in Rhodes landscape, followed by lower hills along with extended Natura 2000 protected areas (Fig. 2b). The island is actually displaying a topographical diversity that is coupled with an extensive urban sprawl, mainly in the coastal seaside. This is due to the population's growth and respective settlements' pattern as well as deployment of the rapidly escalating tourist accommodation infrastructure [15]; and results in expanded Wildland Urban Interfaces (WUIs), i.e. urban and peri-urban zones that are in close proximity to rough terrain morphology, extended across the island's coastal part. The rising seasonal population during summertime, a period coinciding with the fire season (May to October), coupled with the expanded WUIs raises vulnerability concerns and calls for assessment of relevant risks – fire and flood in this work – in order for proactive planning strategies and fire/flood management plans to be properly informed and resilience to such crises to be strengthened [26].

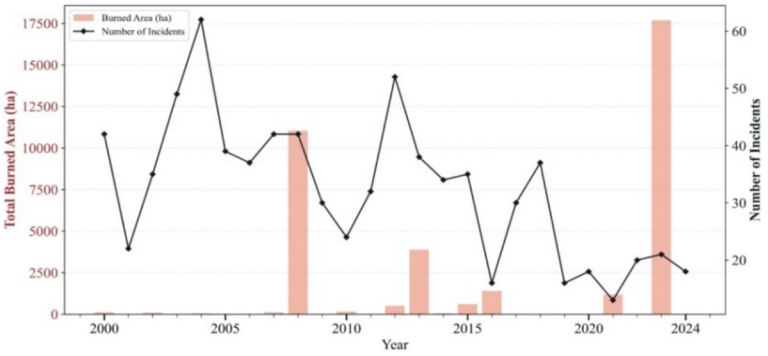

Fig. 3. Wildfire incidents and cumulative Burned Areas (ha) in Rhodes Island during the Fire Season (May – October) for the time span 2000–2024. Source: Own elaboration based on data from the Hellenic Fire Service [40].

Open data from the Hellenic Fire Service demonstrate the number of *fire incidents* occurred in Rhodes Island, coupled with the cumulative burned areas (in ha) throughout the last 24 years (2000–2024) (Fig. 3) [40]. Notably, the wildfire of July 2023 was the most devastating one, with severe consequences to forested areas (17,653 ha of burned areas) and noticeable failures in rapid and safe emergency evacuation of both residents and visitors [41]. Next to this destructive fire incident of 2023, in November 2024 the largest *flood phenomenon* in the island's history occurred, beating the northern coastal part of the island with a volume of water equivalent to three months falling in a few hours.

3.2 Sketching Tourism Pressure in Rhodes Island

The steadily expanding tourism supply in Rhodes Island demonstrates the dynamics of the sector. As authors' previous work featured [15], tourism supply during the last decade (2014–2023) displayed an increase of 8.32%, 16% and 20.36% in the number of hotels, rooms and beds respectively. Worth noticing was the rising of 5*, 4* and 3* hotels, reaching an increase of 105.9%, 35.51% and 13.53% respectively in this decade, while the 1* and 2* hotels displayed a certain downward trend (-10.41% and -14.03% respectively). A similar pattern was noticed in the number of hotel rooms, 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). This tourism supply profile is in alignment with a mass, high class destination model, marked by large scale, luxurious and resource-intensive tourism accommodation infrastructure.

Results presented in Table 4 provide interesting insights into the pressure that tourism exerts in the island of Rhodes. More specifically, Rhodes displays a slightly higher tourism accommodation intensity (TPI1 = 1.12) compared to the Dodecanese average (1.10), while it remains lower than the regional average in Southern Aegean Region (1.35). Similarly, Airbnb accommodation intensity (TPI2 = 0.29) exceeds the Dodecanese average (0.26), yet remaining significantly below the regional level (0.62). These

findings suggest that in terms of visitors to population ratios, Rhodes experiences a moderately higher tourism pressure than the Dodecanese average, while not as intense as the broader regional context demonstrates. However, a different picture emerges when examining density indicators. Rhodes exhibits substantially higher tourism accommodation density (TPI3 = 99.20) compared to the average in both the Dodecanese complex (83.90) and the Southern Aegean Region (83.96). This indicates a strong spatial concentration of accommodation infrastructure (hotel and airbnb) in the island. A similar pattern is observed in Airbnb density (TPI4 = 25.69), which is higher than the average in Dodecanese complex (19.75), though still lower than the Southern Aegean Region's average (38.74).

Table 4. Tourism Pressure - Position of Rhodes in its broader neighbourhood

Tourism Pressure Indicator (TPI)	Rhodes Island (2024)	Dodecanese Islands' Complex (Average Value 2024)	Region of Southern Aegean (Average Value 2024)
TPI1 – Tourism Accommodation Intensity	1.12	1.10	1.35
TPI2 – Airbnb Accommodation Intensity	0.29	0.26	0.62
TPI3 – Tourism Accommodation Density	99.20	83.90	83.96
TPI4 – Airbnb Accommodation Density	25.69	19.75	38.74

Overall, the divergence between intensity and density indicators shows that tourism pressure in the island of Rhodes is not just a matter of the sector's size, but mainly of its spatial distribution. While intensity measures suggest a moderate pressure, density indicators reveal a strong geographical concentration of tourism accommodation infrastructure. This pattern intensifies localized pressure on land use, public infrastructure, and natural resources, particularly in coastal ecosystems. At the same time, the coexistence of hotel-based accommodation and the recently rapid growth of short-term rentals (Fig. 4a and 4b respectively) points to a dual tourism structure that may further reinforce spatial inequalities and intensify competition for land.

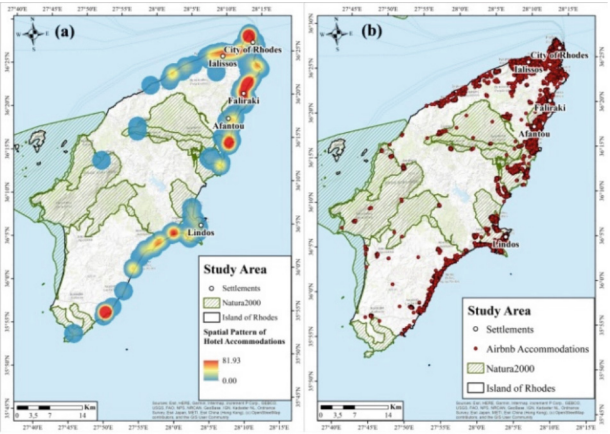

Fig. 4. Rhodes Island - Spatial pattern of: (a) Hotel accommodation, (b) Airbnb accommodation. Source: Own elaboration based on data from: (a) [42], (b) [43].

As a well-established mass tourism destination, the island of Rhodes hosts extensive tourism infrastructure, primarily concentrated along its coastline. A defining feature of the island is the strong presence and continuous expansion of 5* hotel developments, which represent a highly land-consuming form of tourism infrastructure, particularly in the already saturated coastal areas [15]. This pattern contributes to the formation of distinct *tourism hotspots* along the coastal part of the island (Fig. 4a and along the coastal part of the islandb), largely aligned with existing population distribution (Fig. 2a), while also expanding into environmentally sensitive land. As such can be mentioned the areas in the neighbourhood of Lindos, Afantou, Faliraki and Ialissos settlements as well as in the city of Rhodes. The spatial overlap between tourism constellations, Natura 2000 protected areas and other environmentally vulnerable zones (Fig. 4) questions sustainability and resilience achievements of Rhodes Island in the longer run. These patterns may further intensify the island's exposure to CC-related hazards, particularly wildfires and floods, as increasing land-use pressure and tourism-related infrastructure deployment place additional stress on natural systems and weaken local adaptive capacity.

3.3 Assessing Fire and Flood Risk

For assessing fire risk in the neighbourhood of the tourism hotspots of Rhodes Island, the Random Forest algorithm through the Forest-Based Classification tool was implemented. The dataset of the Burned Areas for the period 2000–2024 [39], provided by the European Forest Fire Information System (EFFIS) of the Copernicus Emergency Management Service (Copernicus EMS), was used to derive the fire occurrence points. These points were supplemented with non-fire points (unburned areas), establishing the binary dependent variable (Fire = 1; No Fire = 0) as training input for the implementation of the tool. The dataset was randomly separated into training (80%) and testing (20%) subsets. Table 5 presents the distribution of Importance Values of the 15 independent variables, as these were derived from the Forest-Based Classification and Regression tool.

Table 5. Importance values of the independent variables according to the Forest-Based Classification Tool

Variable	Importance Value (%)	Variable	Importance Value (%)
Humidity	8.59	Distance from Settlements	7.18
Precipitation	8.12	Temperature	7.00
NDVI	8.12	Distance from Rivers	6.18
Slope	7.82	Wind Speed	5.82
Population Distribution	7.70	Land Use	5.23
Aspect	7.53	TCD	3.18
Distance from Road Network	7.35	DLT	3.00
Elevation	7.18		

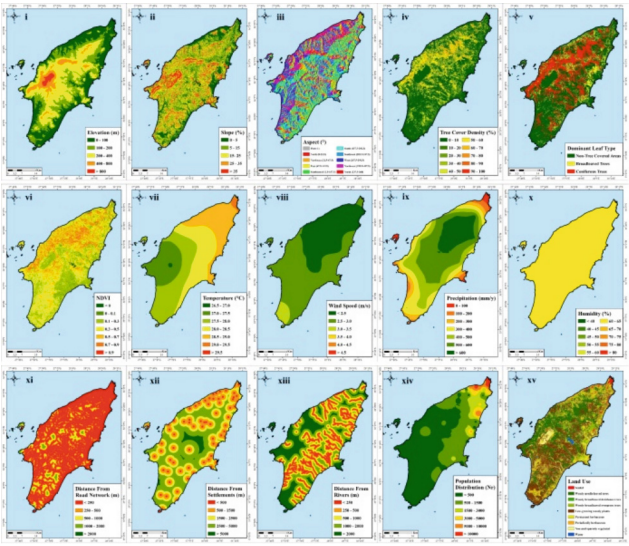

Fig. 5. Visualization of independent variables: i) Elevation, ii) Slope, iii) Aspect, iv) TCD, v) DLT, vi) NDVI, vii) Temperature, viii) Wind Speed, ix) Precipitation, x) Humidity, xi) Distance from Road Network, xii) Distance from Settlements, xiii) Distance from Rivers, xiv) Population Distribution, and xv) Land Use. Source: Own elaboration.

Visualization of all independent variables is presented in Fig. 5; while in Fig. 6 the probability of fire risk and its spatial pattern in the study area is displayed, i.e. the final output of the Forest- Based Classification tool. The fire risk assessment results are coupled with the (Fig. 6a to 6f respectively): Burned Areas for the time span of 2000–2024 [39]; Natura 2000 areas [44]; flood zones in Rhodes Island (T = 1000) [23]; settlements and population's distribution in 2021 [17]; distribution of Airbnb [43], and distribution of hotels [42]. ArcGIS Pro 3.3 was used for the implementation of the

Forest-Based Classification tool, the spatial analysis, the mapping of variables and the production of the final forest fire risk map (Fig. 6), displaying fire risk probability values that ranges from 0.00 to 0.87.

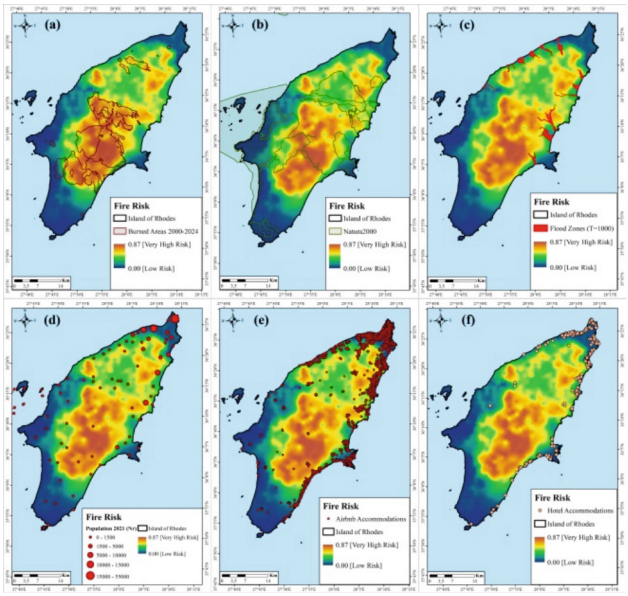

Fig. 6. Forest Fire Risk Assessment maps overlaid by: a) Burned Areas (2000–2024), b) Natura 2000, c) Flood Zones (T = 1000), d) Settlements and Population Distribution in 2021, e) Airbnb Accommodation and f) Hotel Accommodation. Source: Own elaboration based on data from: a) [39], b) [44], c) [23], d) [17], e) [43] and f) [42].

The *spatial pattern* of fire risk unveils very high fire risk values (brown colour) in the central part of the island, with a more pronounced occurrence in the mountainous areas, as well as the eastern and western coastal areas of the northern part of Rhodes Island. High fire risk values (yellow colour) appear in the perimeter of very high risk areas, followed by moderate fire risk values (green colour). These are relatively extended to the northern central area. Low fire risk values (blue colour) are mostly found to the northern and southern part, along with a part of the western coastal area.

According to the automatically derived evaluation metrics, results obtained present high consistency and predictive performance. During the training stage, the tool has displayed a high overall performance with a score of 0.98 to all three metrics (Accuracy, Recall, and F1 Score); while during the validation stage, these metrics demonstrated a more conservative yet successful predictive performance, with scores of 0.78 for Accuracy, 0.76 for Recall and 0.74 for F1 score.

Flood prone zones are presented along with fire risk spatial pattern in Fig. 6c. Flood prone areas seem to expand across the coastal part of the island, especially in the north-eastern and north-western coastline; and align with moderate to very high fire risk areas.

Taking into account that tourism hotspot areas are located at this intersection, this fact render them susceptible to combined fire- and flood-related risks.

4 Discussion and Conclusions

CC repercussions in the Mediterranean, particularly in coastal and insular tourist areas, lie today at the heart of the planning and policy discourse [10]. However, the lack of integration – in a concrete and spatially-defined way – of CC-related risks into urban/regional as well as disaster management planning discourse is noticeable. Exploration of the intensity and spatial reference of CC-driven risks, including the anthropogenic ones, seems to be a prerequisite for handling, in a proactive manner, destructive incidents and targeting sustainability and resilience objectives. This seems to be quite crucial in the Mediterranean area, i.e. an area which is featured, among others, as a combined *CC and tourism 'hotspot'* [45], with the repercussions in terms of damages in the natural and built environment as well as human losses being incalculable.

Having this in mind, this work established a methodological framework that is replicable to insular or mainland-based coastal areas; and attempts to identify/map tourism hotspots as well as address their exposure to mainly CC-driven but also anthropogenic fire and/or flood risks. The proposed methodology is implemented in Rhodes Island, Greece, a well-known and highly attractive Mediterranean insular destination. However, the modular structure of this methodology allows tourism-pressure indicators, fire-risk modelling variables, and flood-exposure layers to be adapted to data availability, planning context, hazard profile, and territorial characteristics of other destinations as well, ensuring thus its replicability. The targeted outcome of this methodology is the assessment of flood/fire threats ahead in overloaded tourist areas for informing planning endeavours and guiding more targeted policy decisions that mainly address resilience of tourism hotspots.

The effort to identify tourism hotspots in Rhodes Island is partly grounded in previous authors' work [15] and is based on well-established, literature-driven tourism density and intensity indicators as well as the spatial analysis of accommodation infrastructure – i.e. the tourism supply. The outcome of this stage unveils a highly concentrated pattern of tourism accommodation, expanding in the island's north-eastern and north-western coastal part and marked by a number of tourism hotspots, being the City of Rhodes and the settlements of Lindos, Afantou, Faliraki, and Ialissos (Fig. 4a and 4b).

Speaking of the fire risk assessment, being the core subject of this research for stepping further previous work, a well-round approach is established, displaying high predictive overall performance. Indeed, all three evaluation metrics exhibited a differentiation between the training and the validation stage, with validation performance being more rigorous and the noticed differentiation suggesting overfitting. As to the limitations of the proposed approach, the small size of the study area and the limited size of the dataset can be mentioned. Indeed, the high dimensional complexity of the research subject requires larger volumes of data and of higher quality in order for complex patterns and the interrelationships among contributing factors to be identified and more robust estimations to be produced, both influencing generalization and making it a challenging task. Accuracy performance (0.98/0.78) demonstrates a robust overall predictive capability, whereas values of F1-score (0.98/0.74) and Recall (0.98/0.76) indicate that the

proposed tool is capable of identifying fire prone and non-fire prone areas; and adequately capturing the complex patterns of fire occurrence. The spatial pattern of the predicted Forest Fire Risk (Fig. 6), demonstrates fire risk probability values ranging from 0.00 to 0.87.

By overlaying Burned Areas for the time span of 2000–2024, Natura 2000 areas, flood zones (T = 1000), the distribution of settlements and Rhodes' population in 2021, and the distribution of Airbnb and hotel accommodation onto the fire risk assessment map, certain interesting results are noticed. In particular, very high fire risk appears to be more prominent in the central mountainous part of the island, indicating strong compliance with burned areas of the past (Fig. 6a), and extending to the northern part of the island. Moreover, Natura 2000 protected areas (Fig. 6b) span on the central and upper central part of the island and the eastern coastline, aligning with fire risk areas ranging from low to very high values, rendering them areas of high risk due to their particularity and indicating the necessity for their steady monitoring for serving conservation purposes.

As far as the Flood Zones are concerned, these extend across the northern half part of the island, expanding towards both the western and eastern seaside (Fig. 6c). In the vicinity of the areas under flood risk are expanding the tourism hotspots of the island, e.g. Lindos, Afantou, Faliraki and Ialissos. Worth noticing is the fact that the aforementioned tourism hotspots lie in coastal parts of the island, where flood risk coincides with moderate to high fire risk (Fig. 6e and 6f); while the same holds for the majority of the island's settlements (Fig. 6d). Thus it seems that tourism hotspots, mostly coinciding with overpopulated settlements, are confronted with a *compound flood and fire risk*. Such a risk is expected to further intensify due to the rising climatic threats, the lack of well-established risk management plans as well as the continuously expanding and poorly planned urban sprawl, contributing to the enlargement of Wildland Urban Interfaces. That said, the spatial pattern of fire and flood risk, coupled with the developmental model of Rhodes Island that is grounded in mass tourism, indicates the aggravating exposure and vulnerability of the coastal zone. Provided that Rhodes Island is one of the most visited Mediterranean landscapes, proactive policies that are capable of managing CC and anthropogenic risks and maintaining the island's identity and integrity are of imperative need.

Such policy directions are further justified by recent climate change (CC) trends and projections, which stress the importance of developing climate-resilient urban and regional development pathways, particularly in the Mediterranean as a hotspot in multiple respects, including tourism and CC [45]. Contemporary spatial analysis approaches, tools, and technologies can produce more concrete and well-documented risk assessments, supporting targeted, place-based, and risk-sensitive spatial policies. Especially in the highly sensitive coastal land, hosting a variety of anthropogenic activities as well as valuable and vulnerable ecosystems, met also in the study area of this work, urban sprawl and further expansion of tourism zones should be limited, redirected, or being subject to stricter resilience standards, while more sustainable tourism modes should be sought. Such a direction is also supported by the IUCN [1], which calls for a fundamental shift in Mediterranean tourism from a growth-oriented paradigm towards one that is regenerative, inclusive and climate-resilient.

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