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Impacts of Medicanes on Geomorphology and Infrastructure in the Eastern Mediterranean, the Case of Medicane Ianos and the Ionian Islands in Western Greece

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Abstract: Despite being relatively rare, Mediterranean tropical-like cyclones, also known as Medicanes, induce significant impacts on coastal Mediterranean areas. Under climate change, it is possible that these effects will increase in frequency and severity. Currently, there is only a broad understanding of the types and mechanisms of these impacts. This work studied Medicane Ianos (September 2020) and its effects on the Ionian Islands, in Greece, by developing a database of distinct impact elements based on field surveys and public records. Through this archive, the study explored the range of Ianos' impacts to develop a systematic categorization. Results showed different types of effects induced on the natural and the built environment that can be grouped into 3 categories and 39 sub-categories in inland and coastal areas, indicating an extensive diversity of impacts, ranging from flooding and geomorphic effects to damages in various facilities, vehicles and infrastructure. The systematic description of the typology of Medicanes' effects presented in this study is a contribution to a better understanding of their consequences as means to improve our ability to prepare for, respond to, and recover from them, a necessary stepping stone in improving the overall preparedness of both the general public and relevant authorities.

Keywords: Medicanes; flooding; storm surge; landslides; debris flows; Mediterranean; storm; extreme events; Ionian Islands

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1. Introduction

Mediterranean tropical-like cyclones, often referred to as Medicanes, although relatively rare, induce a variety of catastrophic impacts on Mediterranean coastal regions, including flooding of low-lying areas [1], large amounts of precipitation [2], storm surges and erosion [3], mass movement phenomena triggered by intense rainfall [4], damages due to strong winds and high waves [5–8], as well as loss of life and injury [9]. These effects and the subsequent hazards induced have the potential to cause disruption in various aspects of socioeconomic activities, creating important economic impacts [9,10], damaging infrastructure, and inducing power outages and structural damages to buildings [10,11] and transportation facilities [12], and it has become a threat to coastal communities [9].

In the Eastern Mediterranean region, these effects can occur on high-value land [13–16], hosting expensive and elaborate infrastructure [17], as well as complex socioeconomic processes that are critical to economic development [15,18–20] and the safety of individuals. In particular, coastal areas are home to a large portion of the population [21] and to critical activities such as trade, tourism, recreation, fishing, and transportation, making them particularly exposed to disruptions from extreme events [22]. The extensive effects of previous events, although not recorded in detail, have shown that local communities experienced significant setbacks and provided indications that local authorities were not prepared for the diversity and the extent of impacts [9].

Recent studies find that the literature does not contain a systematic assessment of the impacts, including only a broad description of the diversity of effects of Medicanes, as acknowledged, for instance, by Nastos et al. [7] and Hochman et al. [23], despite the large number of works focusing on their characteristics and formation [8,24–28]. Previous works such as that of Bakkensen [10], Flaounas et al. [29], and Nastos et al. [7] stressed the lack of systematic recording of Medicane impacts.

In this sense, a better understanding of the range of potential impacts of Medicanes is particularly useful in enhancing preparedness and recovery capabilities for both authorities (from a civil protection standpoint), risk professionals, and engineers (considering the sustainable design of infrastructure), as well as the general public [30,31].

To understand the magnitude and criticality of the problem, one should also take into account the following three key issues. First of all, recent research indicates that high-intensity Medicanes are expected to become more frequent and more severe [32–35]. Secondly, the Mediterranean region is one of the most sensitive to climate change [36,37], and therefore the increase of Medicane-associated phenomena and hazards (i.e., floods, landslides, debris flows) can be a threat in rise as well. Finally, the recent increase in seasonal population and a large number of visitors, along with the fact that tourism is increasingly a larger part of the local economy, is increasing the overall vulnerability of the region, making climate change one of the main challenges for its sustainability [38–41].

Taking into account all the above, it becomes evident that a deeper understanding of the potential effects of Medicane events would benefit the current practice and knowledge of the expected impacts and enhance the efforts to mitigate risk. In this context, and given that to the best of the authors' knowledge, there is no systematic recording of the types of effects of Medicanes in the Eastern Mediterranean; this work studied the case of Ianos Medicane and its impacts on the Ionian Islands in western Greece. This study aimed to explore and classify the types of effects and examine their spatial distribution on this characteristic example of a coastal region of the Mediterranean, which is the Ionian Islands. The objective of the study was to contribute to the understanding of Medicane consequences in the region by providing a more systematic categorization, currently lacking in the literature.

2. Study Area

The Ionian Islands are located along the coast of western Greece and span the Ionian Sea from north to south (Figure 1). The islands are situated roughly at the boundary between the Western and Eastern Mediterranean, making them a passageway for many weather systems coming from the west into the Eastern Mediterranean region. Weather systems coming from the main cyclogenetic areas [42], including the Northwestern Mediterranean basin (Gulfs of Lions and Genoa, Adriatic and Balearic Seas) and the Southwest (Gulfs of Gabes and Sidra) [7,42–44], reach the Ionian Sea and the islands moving eastwards towards mainland Greece, and eventually Turkey and Cyprus [45]. Intensified by the warm Mediterranean waters, these systems often produce large amounts of precipitation. The islands have a very diverse Mediterranean climate characterized by hot, dry summers and mild, wet winters (Tables S1 and S2 in Supplementary Materials according to the Hellenic National Meteorological Service [46]), with occasional strong winds, especially during the winter months. The islands have experienced a range of extreme events [47].

Figure 1. Location map of the study area, showing the central and south Ionian Islands (Lefkada, Ithaki, Cephalonia, and Zakynthos), along with certain important locations. Map source: ESRI, Maxar, GeoEye, Earthstar Geographics.

On different occasions in the recent past, the area has been hit by high-intensity storms and at least four Medicane events [43,48], inducing important damages as well as various hydro-geomorphic phenomena (most commonly slope failures and flooding).

The geomorphology of the islands is largely characterized by mountainous terrain, accompanied by narrow valleys and small plains, such as the Vassiliki plain in Lefkada and the Pylaros basin in Cephalonia. The coastline is generally rugged, with many coves, bays, and inlets. The islands are relatively small in size, with Cephalonia being the largest (780.6 km^2), followed by Zakynthos (405.3 km^2), Lefkada (300.5 km^2), and Ithaki (96.7 km^2).

In terms of hydrology, the islands are home to a number of small ephemeral mountain torrents with little or no water at all for most of the year. Their catchments are relatively small in size ranging from 0.05 km^2 to 89.5 km^2 (average size: 6.05 km^2), and are characterized by high slope inclination. In Zakynthos, the torrent network (average size: 4.5 km^2) is split into roughly two groups draining Vrachion Mt. towards the west-southwest and towards the east and northeast. The latter group consists of larger catchments (up to 65.4 km^2) and has a history of flooding episodes, inundating the low-elevation areas of the central and southeastern parts of the island. In Lefkada, mostly small watersheds (average size: 4.9 km^2) drain the mountainous central part of the island (Elati Mt.), with the larger Katourlou river basin (66.2 km^2) that flows southwards through the Vassiliki plain in the south part of the island that has a history of flooding [49]. The Ithaki drainage network consists of very small catchments (ranging from 1.0 to 11.0 km^2), draining the hilly central axis of the island. In Cephalonia, the local torrents (average basin size: 9.6 km^2) drain mostly the mountainous area of the Ainos and Agia Dynati mountains, as well as the hilly areas of the Paliki and Erisos peninsulas. The island has a history of flooding, debris flow, and landslide events that have caused significant impacts in the past [50,51].

Regarding geodynamic location, the study area of the central and southern Ionian Islands is located at the northwestern part of the Hellenic Arc, an area where the subduction of the Eastern Mediterranean lithosphere beneath the Aegean one terminates against the Cephalonia–Lefkada transform fault zone [52].

The islands are composed of alpine formations belonging to the Paxi and Ionian geotectonic units and post-alpine deposits, which lay uncomfortably on the alpine bedrock [53,54]. The main lithology that built the largest part of the Ionian Islands comprises limestones, with the clastic sequence and evaporites covering smaller areas. The clastic formations include flysch deposits with a variety of lithologies such as marls, clays, and mudstones, and the evaporites sequence comprises a limited occurrence of gypsum beds and limestone breccia [53,54].

As far as the tectonic structure is concerned, the study area evolves under the influence of the Cephalonia–Lefkada Transform fault zone [55–57]. It constitutes the most active fault zone in Greece and one of the most active in the Eastern Mediterranean region. It is the causative structure of many strong earthquakes in the study area [58] with destructive impact on the population and elements of the natural and built environment, including buildings and infrastructure [59] and extensive earthquake environmental effects (Lekkas et al. [59] for Lefkada, Lekkas, and Mavroulis [60], for Cephalonia and Ithaki and Mavroulis et al. [61] for Zakynthos).

The onshore tectonic structure is characterized by large fault blocks, mostly bounded by active faults, which not only adversely affect the geotechnical characteristics of the geological formations but also form extended zones of increased instability, particularly susceptible to slope failures when a triggering factor occurs. In the case of recent earthquakes that have affected the central and southern Ionian Islands (the Mw = 6.1 and Mw = 5.9 Cephalonia earthquakes in early 2014, the Lefkada Mw = 6.5 earthquake in November 2015, and Zakynthos Mw = 6.8 earthquake in October 2018), slope failures comprising mainly rockfalls, debris flows, and slides were triggered along fault scarps and steep slopes [59,60,62–64] and formed zones of high and critically high landslide susceptibility [51].

The economy of the Ionian Islands is primarily based on tourism, agriculture, and fishing, as they have become popular tourist destinations, attracting visitors from all over the world to their scenic coastal areas and beaches and their historical sites. With regard to the population, the majority is situated in towns and villages near the coast, reaching approximately 200,000 [65]. The most populous island is Corfu, with a population of 97,464, followed by Zakynthos (40,508), Cephalonia (34,924), Lefkada (21,759), Ithaki (2774), and Paxi (2383) [65]. However, the islands experience an influx of seasonal population and visitors due to the tourism industry.

3. Medicane Ianos

On 16 September 2020, a depression developed in the northwest of the Gulf of Sidra, near the Mediterranean coast of Libya, and moved towards the Ionian Sea, forming a Mediterranean cyclone (Medicane) (Figure 2). On 18 September, the system, named "Ianos", made landfall reaching the Ionian Islands and caused widespread impacts on property and infrastructure, as well as human casualties, throughout much of the country, including the islands and the mainland [4,48,66]. High-intensity precipitation, strong winds, flash flooding, and wave action led to a diversity of effects, costing approximately € 700 million in damages and an additional € 31 million in insured losses (2453 insured vehicles, boats, and buildings) [67].

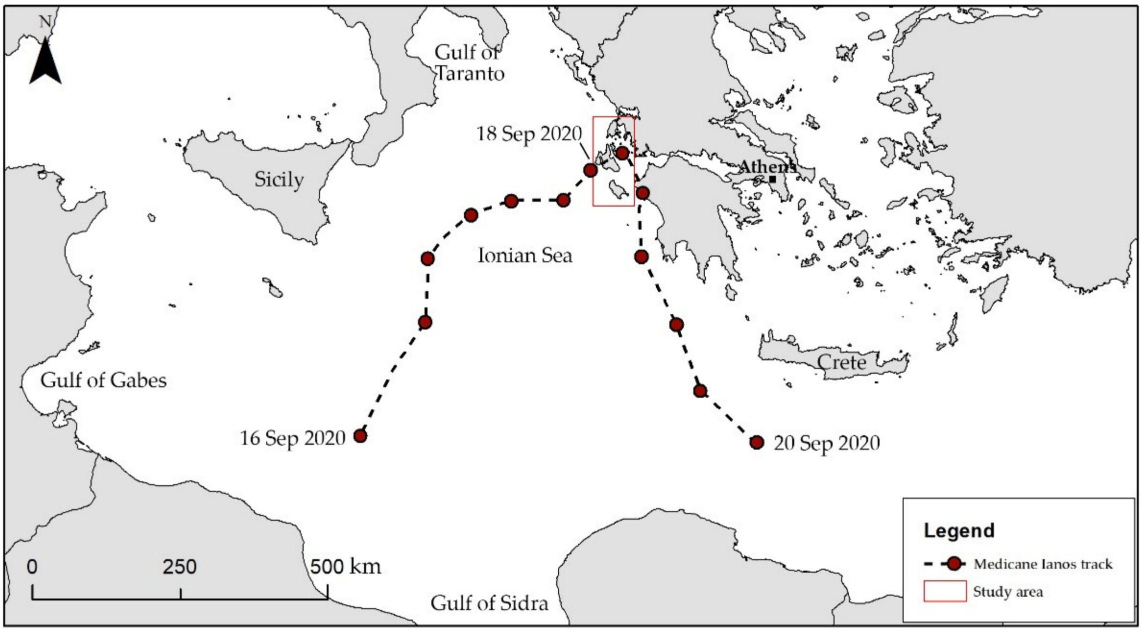

Figure 2. Approximate path of the core Medicane Ianos in the Mediterranean between 16 and 20 September 2020, starting near the Libyan coast, through the Ionian Sea and the study area [68].

Medicane Ianos affected the central and southern parts of the Ionian Islands (Cephalonia, Lefkada, Ithaki, and Zakynthos). Local weather stations showed that the maximum rainfall in Western Greece was recorded in Cephalonia and Zakynthos Islands, recording a value of 769 mm and 250 mm, respectively, in 48 h [48,69]. The higher rainfall values appeared in the area between northern Cephalonia and Ithaki and southern Lefkada, whereas Zakynthos, northern Lefkada, and southern Cephalonia received smaller amounts [48]. Indicatively, these values are higher than the maximum 24 h rainfall accumulation recorded ever in Cephalonia (that is 192.6 mm in a period of 63 years of continuous measurements) and in Zakynthos (that is 184.8 mm in a period of 43 years of measurements) [70]. The value recorded in Cephalonia is, in fact, close to the average yearly precipitation of the island, calculated at 812.3 mm (Argostoli Station [46]). Ianos also exhibited hurricane-level winds with gusts reaching 54.2 m/s and 42.0 m/s in Cephalonia and Zakynthos, respectively, when all-time records in the area reached a value of 47 m/s [48], showing that both in terms of precipitation and wind speed Ianos was a rare event.

The impacts of Ianos heavily disrupted many aspects of socio-economic and everyday activities, including but not limited to transportation, trade, industrial production, agricultural activities, recreation, tourism, education, services, and others. Ianos also caused four fatalities and multiple cases of injuries, mostly in mainland Greece, while hundreds were left homeless and remained stranded or trapped in flooded buildings [48,66].

4. Data and Methods

The study exploited different systematic records of the impacts of Medicane Ianos created by local authorities, the central government, international initiatives, and scientific publications. The table below shows the diverse sources used and the types of data contained in them (Table 1). In addition to the available impact records, we carried out four field surveys in Cephalonia, Lefkada, Ithaki, and Zakynthos after the storm to record and classify the types of impacts, including identifying the type of mass movement phenomena. The visits took place in September, shortly after the event, as well as in October and November 2020. In addition, we developed a database containing descriptions, as well as detailed visual material for every distinct impact of the event, accompanied by information on the exact location and the timing of occurrence. We used Geographical Information Systems software to gather, systematize, and display the collected data to explore their spatial distribution on the islands. Finally, we categorized the recorded effects in groups based on their characteristics, drawing from existing research in the field of natural disaster impact typology and impact severity mapping [71,72].

Table 1. Sources and detailed description of the data used.

Dataset	Description	Sources
Regional authorities of the Ionian Islands	Detailed description of the phenomena, and their impacts, detailed imagery, as well as information on exact location and timing	[73–75]
Scientific publications and reports	Description of the forcing phenomena and impacts, as well as information on location, with visual material depicting the effects	[66,76,77]
Local and National Press	Visual material of phenomena and impacts, with information on location, and details of the timeline of events	[78,79]
Field work	Detailed description of the phenomena, the types of effects, the exact location and timeline of events, as well as detailed visual material from multiple angles	

5. Results

Overall, we identified 331 distinct impact locations/elements of various types. We categorized them into three groups, namely (a) impacts on the built environment, (b) impacts on the natural environment, and (d) impacts on mobile objects/vehicles.

With regard to impacts on the built environment, we identified three categories of damages: (i) the road infrastructure and its various elements, (ii) infrastructure and facilities not related to the transportation network, and (iii) private or public buildings. In each of the three categories, we identified different types of effects that were split into different sub-groups, as shown in Figure 3. The map below presents the spatial distribution of the impacts of Ianos Medicane on the built environment on the Lefkada, Cephalonia, Ithaki, and Zakynthos islands (Figure 4), while Figure 5 provides characteristic imagery of these impacts. Most impacts on the built environment appeared near and around the Pylaros basin in northern Cephalonia, but also along the road network that was constructed around the steep slopes of Ainos and Agia Dynati mountains at the southeastern part of the island. Smaller clusters appeared in the lowlands of Zakynthos (near Zakynthos town and at Laganas in the south) and in the south part of Lefkada (along the Vassiliki plain), which suffered heavy flooding as well as near Syvros village. In addition, at the Paliki and Erisos peninsulas in the western and northern Cephalonia and along the eastern coast of Ithaki, the coastal road network and the villages of Frikes and Vathy suffered extensive damages (Figure 4).

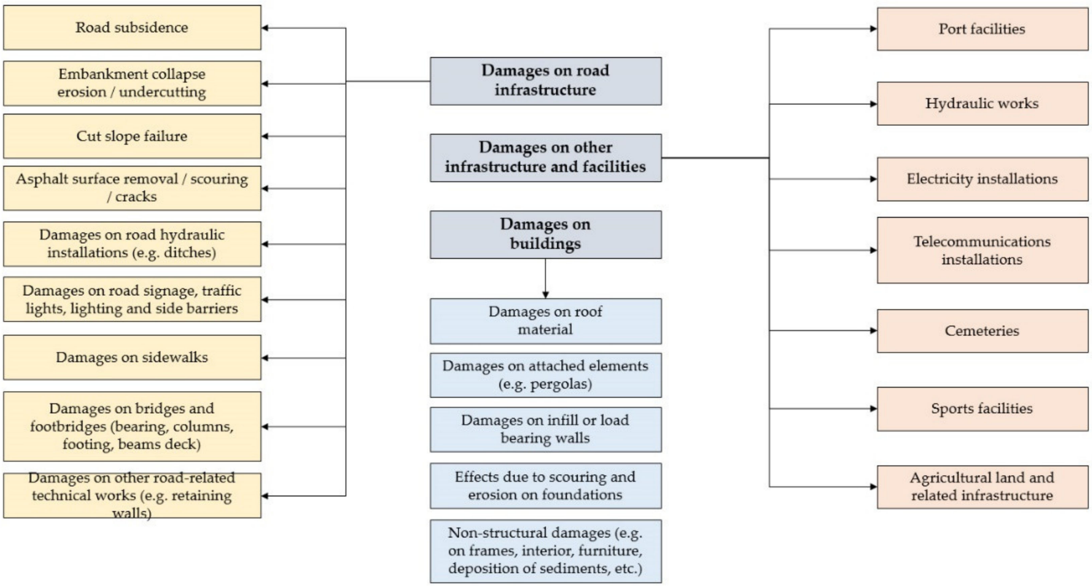

Figure 3. Types of effects on various elements of the man-made environment, regarding road-related infrastructure, buildings, and other facilities.

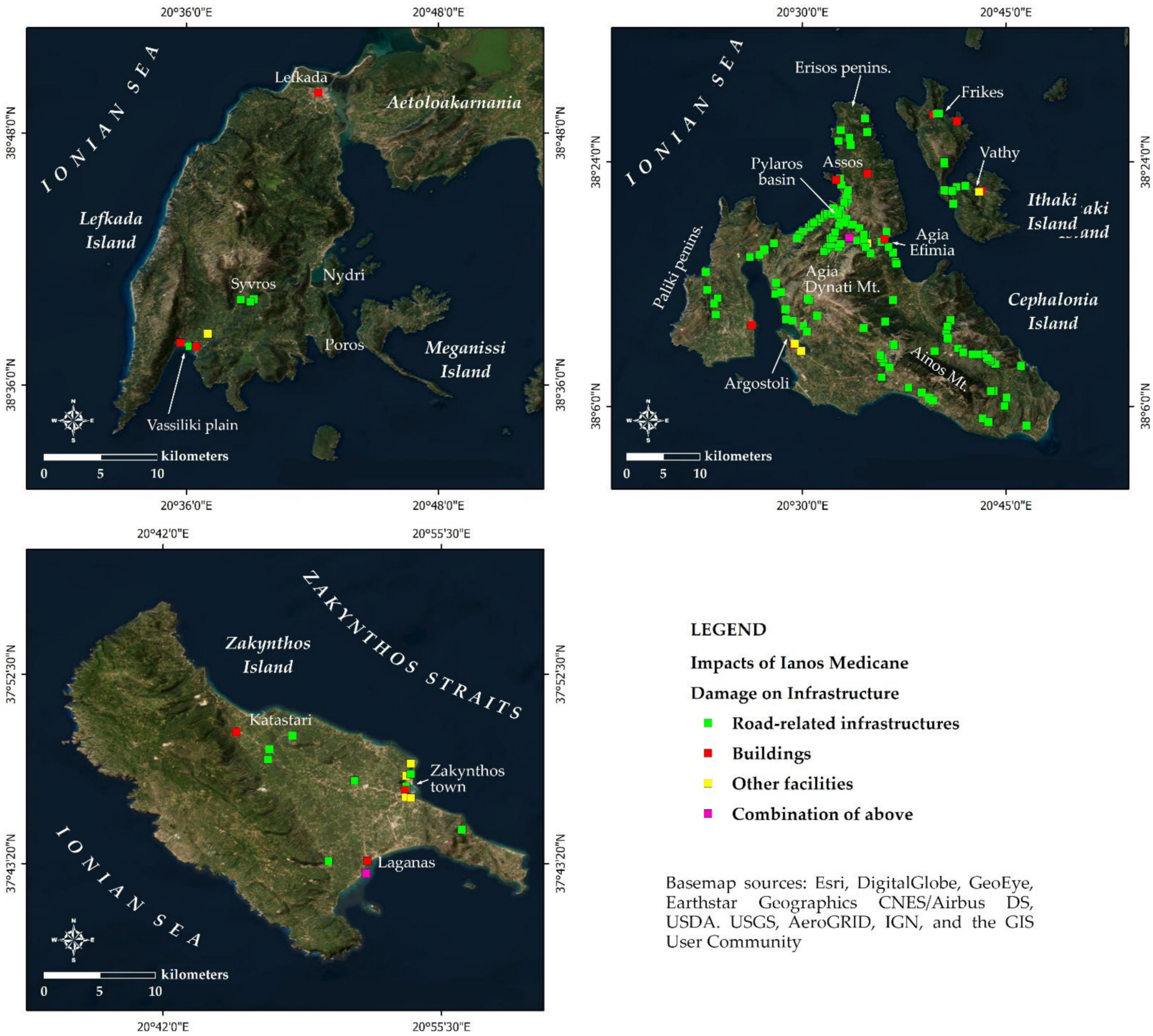

Figure 4. Map of impacts of Ianos Medicane on the built environment of Ionian Islands, including road-related infrastructure, buildings, and other facilities or a combination of them.

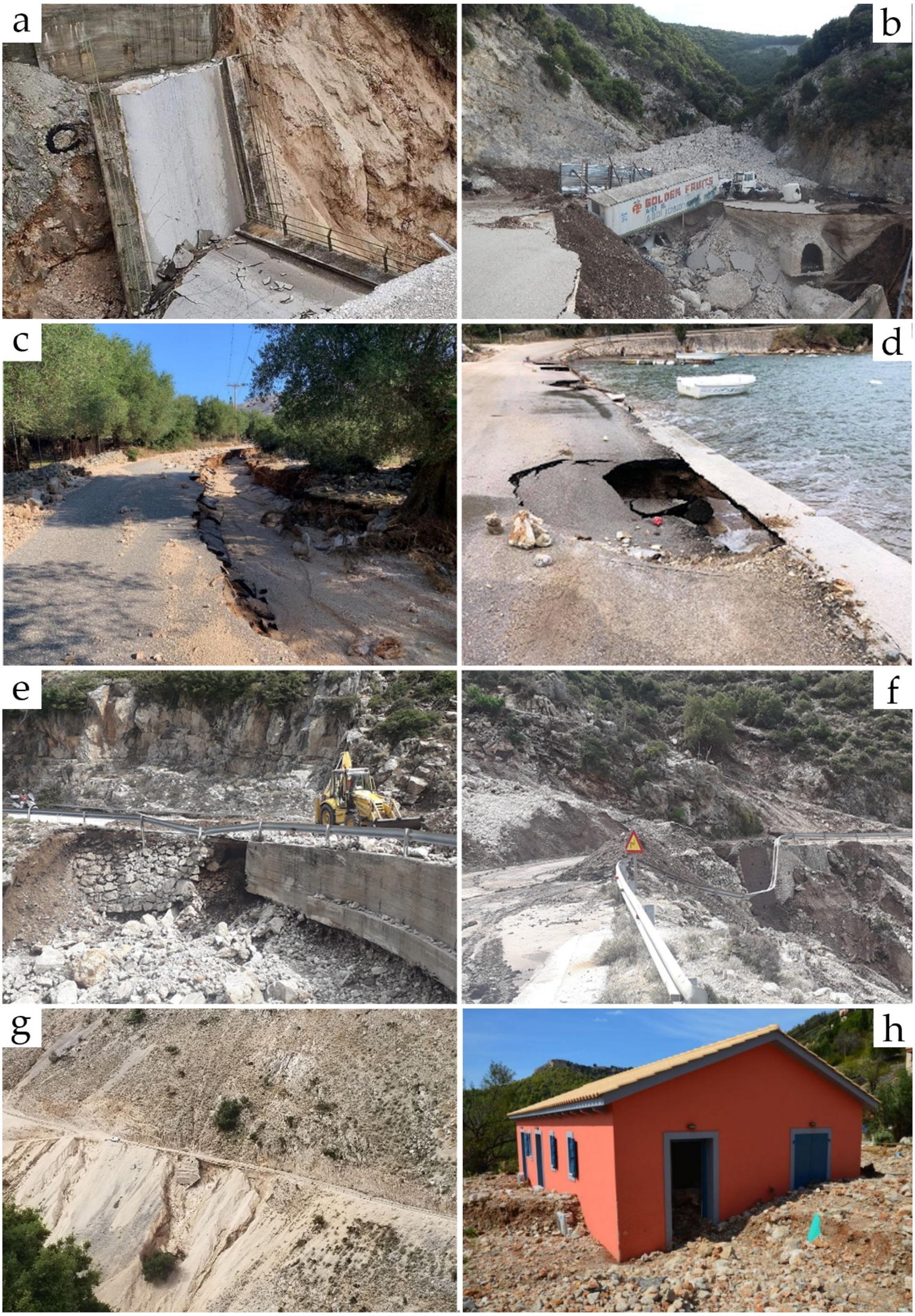

Figure 5. Characteristic images of impacts on infrastructure including (**a**,**b**) collapsed bridges in Cephalonia, (**c**,**d**) road embankment scouring, undercutting and erosion in Ithaki, (**d**–**f**) road embankment collapses in Cephalonia, (**g**) road subsidence and slope failure, and (**h**) building structural damages.

With regard to impacts on the natural environment, we identified 14 distinct types of geomorphic impacts mass movement phenomena in the interior, as well as the coastal zones of the islands, as shown in the following figure (Figure 6). Figure 7 shows the spatial distribution of these impacts in the study area and their basic categories, while Figure 8 provides imagery showing typical examples of the said types. The vast majority of impacts were clustered around the Pylaros basin, near Agia Efimia and in the northern and western slopes of Agia Dynati Mt., whereas smaller numbers of impacts gathered in the Paliki peninsula, around Ainos Mt. Smaller clusters appeared in Vassiliki plain as well as between Syvros, Poros, and Nydri villages in the south and southeast Lefkada. Fewer impacts were identified in the plain of Zakynthos, mainly near Katastari village and around Zakynthos town (Figure 7).

With regard to coastal erosion, due to the sharp relief of many of the coastal cliffs in the Ionian Islands, we identified phenomena of wave cutting off the base of the cliff that resulted in minor slumps, including rotational and planar slides, rock or debris falls and slides, influenced by lithology, geological structure, and the geotechnical conditions of the material of the cliff [80]. Apart from effects on the cliffs, we identified scouring in the various segment of the beach, including the swash zone and the backshore (e.g., upper berm), leading in some cases to shoreline recession. Figures 9 and 10 provide characteristic imagery of the impacts on coastal zones and vegetation across the study area.

Further, we identified various man-made mobile objects of different sizes and types that were impacted, washed away, and damaged from different phenomena during Ianos Medicane (Figure 11). In detail, near ports around the Ionian Islands, there was a significant number of boats of various sizes that were sunk, suffered damages in the hull, suffered broken masts, or were washed ashore by wave action and/or the wind. These damages appeared all around the studied islands but mainly around Cephalonia (Assos, Lixouri, Argostoli, and Agia Efimia ports) and Ithank (Frikes and Vathy ports). In addition, mostly near basin outlets to the sea, we identified road vehicles buried under debris, washed away into the sea, and suffered extensive damages (characteristic imagery in Figure 12). In addition, there were numerous instances of household items, building materials, trash bins, and other objects of various sizes that were transported by water (Figure 13).

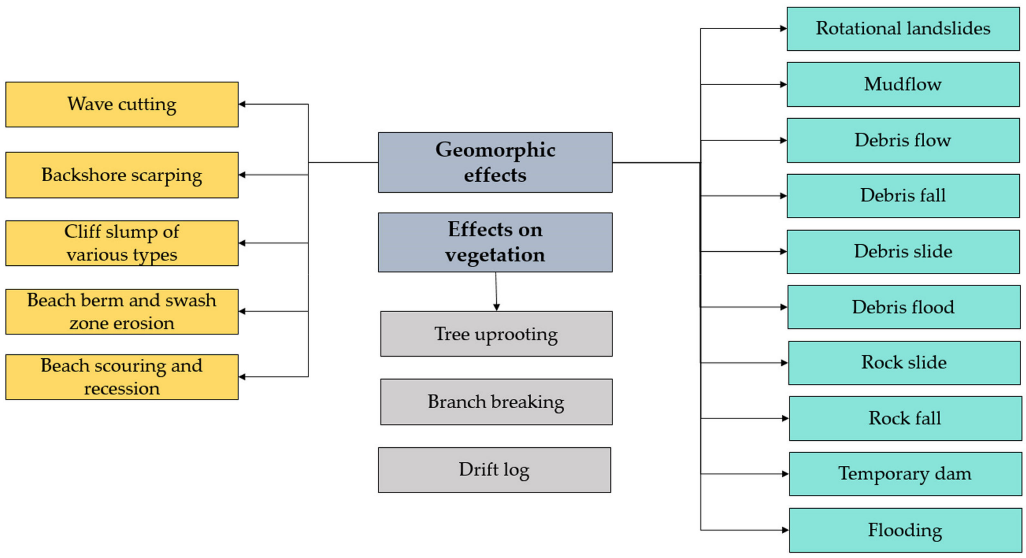

Figure 6. Types of impacts of Ianos Medicane on the natural environment, including geomorphic effects and vegetation.

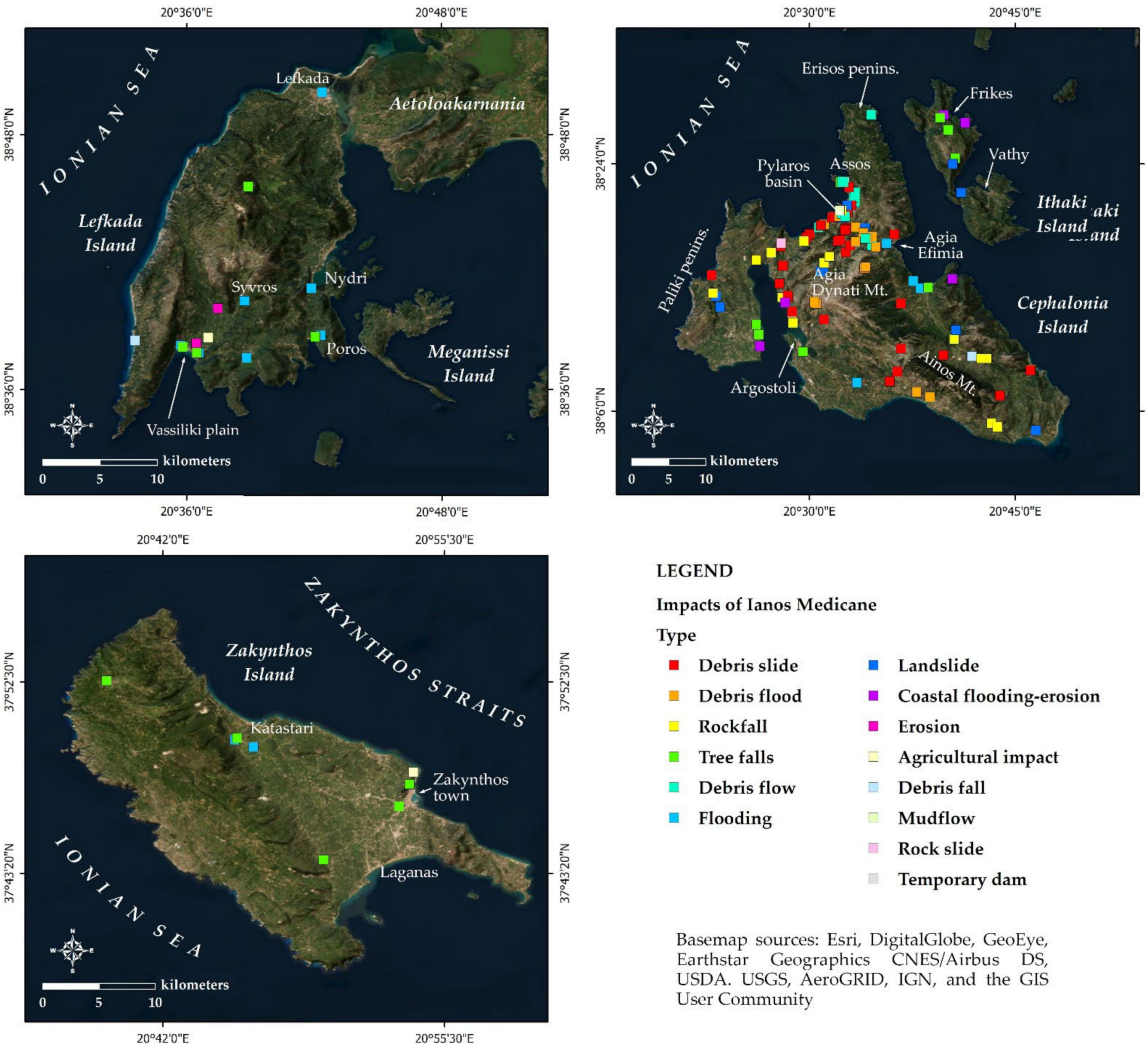

Figure 7. Map of impacts of Ianos Medicane on the natural environment of Ionian Islands, including geomorphic effects and effects on vegetation.

Figure 8. Characteristic images of different types of geomorphic impacts of Ianos Medicane, including (**a**) rotational slides in the western part of Cephalonia, (**b**) debris flows in Assos, (**c**) rock slides, (**d**) debris floods in Pylaros basin of Cephallonia, (**e**) debris slides, (**f**) debris falls, and (**g**) rockfalls along the road network of Lefkada, Zakynthos, and Cephalonia, as well as (**h**) complex landslides near Myrtos beach in the western part of Cephalonia.

Figure 9. Characteristic images of the geomorphic impacts of Ianos Medicane on coastal zones of Ithaki, Cephalonia, and Zakynthos showing (**a**–**e**) scouring segments of the beach, (**f**) beach scouring and recession, (**g**) wave cutting at the base of the cliff and (**h**) wave undercutting a road embankment.

Figure 10. Characteristic images of the impacts of Ianos Medicane on vegetation (**a**–**f**).

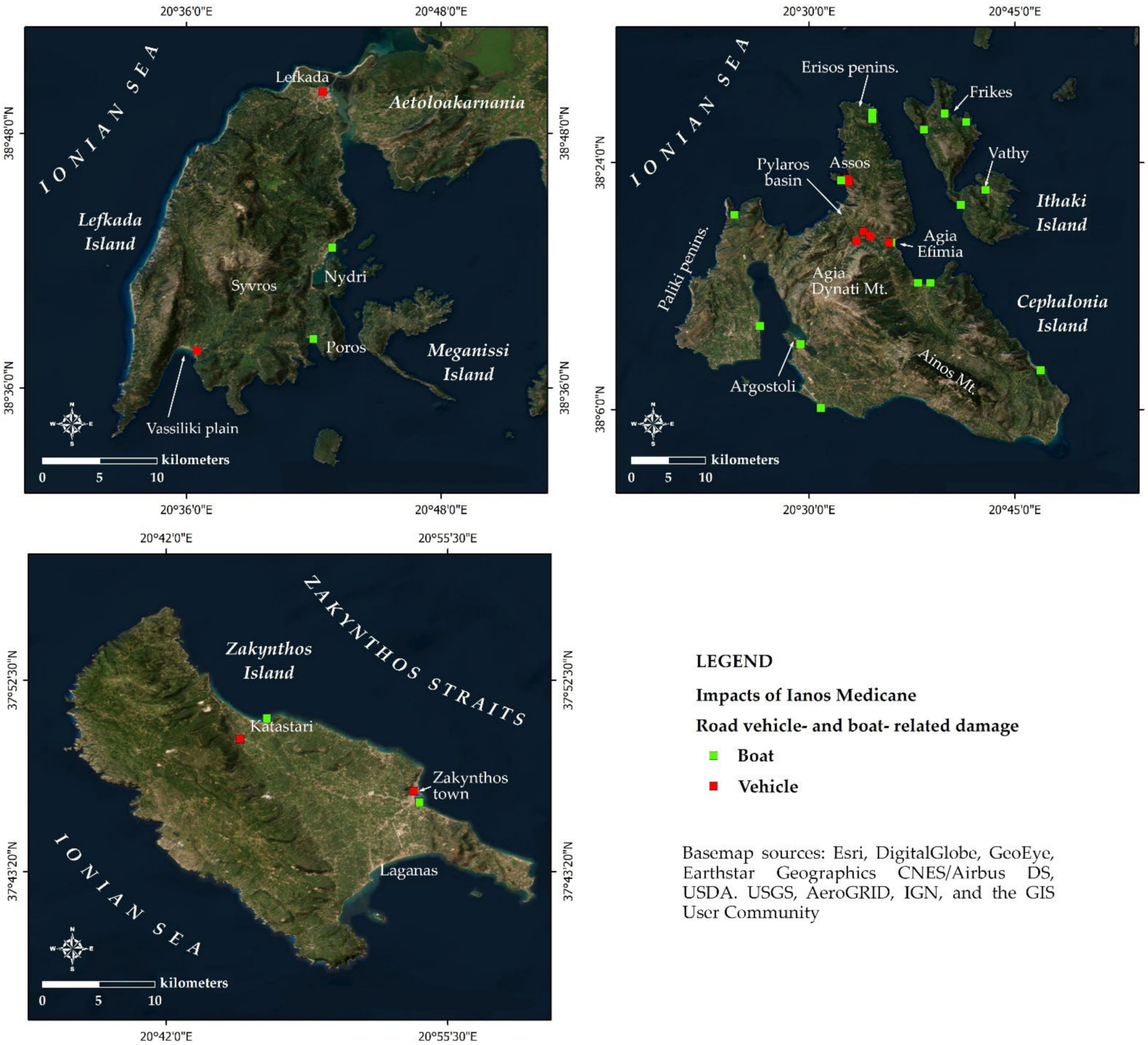

Figure 11. Map illustrating the spatial distribution of effects of Ianos Medicane on road vehicles (red) and boats (green).

Figure 12. Characteristic images from the impact of Ianos Medicane on road vehicles in (**a**–**d**) (examples from Assos and Agia Efimia in Cephalonia) and boats (**e**–**h**) (examples from Agia Efimia, Lixouri and Ithaki).

Figure 13. Characteristic images of mobile objects of various sizes transported by floodwaters (**a**–**f**).

6. Discussion

This work focused on creating a systematic record of the impacts of Ianos Medicane on the Ionian Islands, as a characteristic and recent example of tropical-like storms on the Mediterranean coastal areas.

By studying the impacts of such extreme events, this study contributed to an overall improvement in the understanding of their consequences, which in turn is a stepping stone to improving our ability to prepare for, respond to, and recover from them. This information can be used to inform policies, plans, and investment decisions [81] and enhance impact-based warnings [30], increase resilience, and reduce the risk [81,82]. Additionally, studying the impacts can also provide insights into the level of vulnerability and adaptation opportunities of different systems and communities, which can inform the development of targeted and effective risk-reduction strategies.

The added value of the present analysis lies mostly in the new information gained from these observations, which has the potential to improve our knowledge of the typology of Medicane impacts (acknowledged as a challenge in previous Medicane-related research [7,10,29]) that can be the foundation in enhancing preparedness against such extreme events. Anticipating the effects of such storms can be a useful tool in mitigating risks through taking preventive measures (e.g., improving vulnerable infrastructure or increasing vegetation management efforts). In addition, the use of GIS in impact mapping can be a useful tool for decision-makers in observing the spatial distribution of Medicane effects and exploring their spatial patterns in relation to various parameters (e.g., population, geology, etc.).

From the total of 331 distinct impacts of various types and extents in Cephalonia, Ithaki, Lefkada, and Zakynthos, Ianos' effects were grouped into 3 categories, namely (a) impacts on the built environment, (b) impacts on the natural environment, and (c) impacts on mobile objects/vehicles, and 39 sub-categories that illustrated the full span of the direct consequences of Ianos Medicane, providing a high-resolution mapping of their typology and distribution in the area.

Certain interesting observations can be made for the spatial patterns of impacts. First, the number and concentration of geomorphic effects follow roughly the spatial distribution of the amount of accumulated rainfall as shown by Lagouvardos et al. [48], which recorded high values in the north part of Cephalonia, as well as the south part of Lefkada and the north part of Ithaki. Geomorphic effects and impacts on infrastructure were found to be abundant, especially in the north of Cephalonia (around the Pylaros basin and Agia Dynati Mt), as opposed to the southern and western parts of the island that experienced far fewer damages. In a similar fashion, the plain of Vassiliki in the southern part of Lefkada experienced extensive flooding, while in the south-central part of the island, Syvros and Poros villages recorded significant mass movement phenomena triggered by rainfall. On the contrary, the north side of Lefkada, despite the concentration of property and infrastructure in and around Lefkada town, recorded limited impacts, reflecting the lower rainfall values [48]. In Zakynthos, the higher amount of rainfall received in the south and central part of the island was reflected in the impacts as well, with the majority of them recorded in the low elevation area between Katastari, Zakynthos town, and Laganas at the very south where the vast majority of the socioeconomic activities are situated. The northern and northwestern parts of Zakynthos, which are characterized by the limited presence of infrastructure, recorded only limited impacts.

Nevertheless, particular patterns in the distribution of impacts showed that other factors affected the dispersion across the islands. One example is Erisos in the north of Cephalonia, where, despite the high amounts of rainfall at the very north edge of this cape, the geomorphic and the infrastructure effects were not distributed uniformly along the peninsula. On the contrary, they clustered near its southern part around the Pylaros basin, as shown in Figures 4 and 7.

This distribution of geomorphic impacts and their concentration in Cephaloniaaround Pylaros basin and the slopes of Agia Dynati Mt and particularly (i) Agia Efimia, (ii) Assos, and (iii) just next to Assos in the coastal zone of Myrtos beach indicated that the particular geological and geotectonic characteristics are an important factor in the occurrence of a large number of mass movement phenomena in northern Cephalonia.

In detail, with regard to Agia Efimia, the asymmetric Pylaros Basin (Figure 14) is controlled by the Agia Efimia oblique-slip reverse fault zone (AEF zone that separates the Erissos Peninsula and Aenos Mt fault block) and the large-scale recumbent fold formed between the upper part of the carbonate rocks and the lower part of the clay-clastic sequence, both belonging to the Paxoi unit. The narrower NE part of the basin belongs to the hanging-wall block, characterizing a blocky and well-interlocked undisturbed rock mass [83] consisting of separate blocks formed by two or locally three discontinuity sets (bedding and two sets of joints). It has to be noted that debris-flow phenomena were very limited in this NE part of the basin. In contrast to this, the significantly wider SW part of the basin belongs to the footwall block, representing a disintegrated poorly interlocked and heavily fractured carbonate rock mass [83] with a mixture of angular and rounded rock pieces with a size ranging from one meter to several centimeters. The footwall block in this area is characterized by a very high frequency of open or shear fractures because it is neighboring to the branch point (branch line to the depth) between the AEF and KAF (a deeper oblique-slip fault zone that separates the Erissos Peninsula and Aenos Mt from the Paliki Peninsula) where the two faults interact and are physically linked (hard-linked). The result is an extensive zone of intensively fractured rock mass in the footwall of the AEF (Figure 14), giving the carbonate rock mass the form of a macro-cataclasite. These special geological conditions of the rock mass gave the material for the extensive debris flow phenomena along the SW and central part of the Pylaros basin during the Ianos Medicane. This appears to be a recurring phenomenon as evidenced by the main river deposits, where layers of loose sandy-clayey material alternate with layers of gravels, cobbles, and boulders, indicating past flood and debris flow phenomena.

In addition, with regard to the much smaller Assos Basin (which is located on the Erissos Peninsula of Cephalonia) and the hanging-wall block of AEF, the carbonate rocks of Paxi Unit also occur. Although the rock mass has increased mechanical properties (characterized as blocky or very blocky according to Marinos and Hoeck [83]), important debris flow phenomena were also observed in this basin, but they were more localized, mainly at the northern edge of the village and along the road leading to the small port. Almost the entire Assos Basin is formed not in limestone (such as the also "blocky" NE part of Pylaros Basin) but in dolomitic rocks (dolostone) (Figure 15). Dolomitization reduces the mechanical properties, presupposes shrinkage and volume loss of the rock mass, and seems to be the dominant factor that leads to the cataclasis of the rock mass, in this case.

Further, with regard to the coastal area of Myrtos, it is located at the NW edge of Pylaros Basin, where the Middle–Upper Miocene clay-clastic series of the Paxi unit and the scree mantle formation are dominant. The intense tectonic uplift along the western coastal zone of Erissos Peninsula results in an abrupt morphology characterized by steep slope values, which based on our field survey, exceed 50° locally. The reduced mechanical properties of the lithology, in combination with the intense dipping morphology and the similar dip of the bedding surfaces, generate large-scale failure phenomena, such as landslides, rock-falls, and debris flow [50].

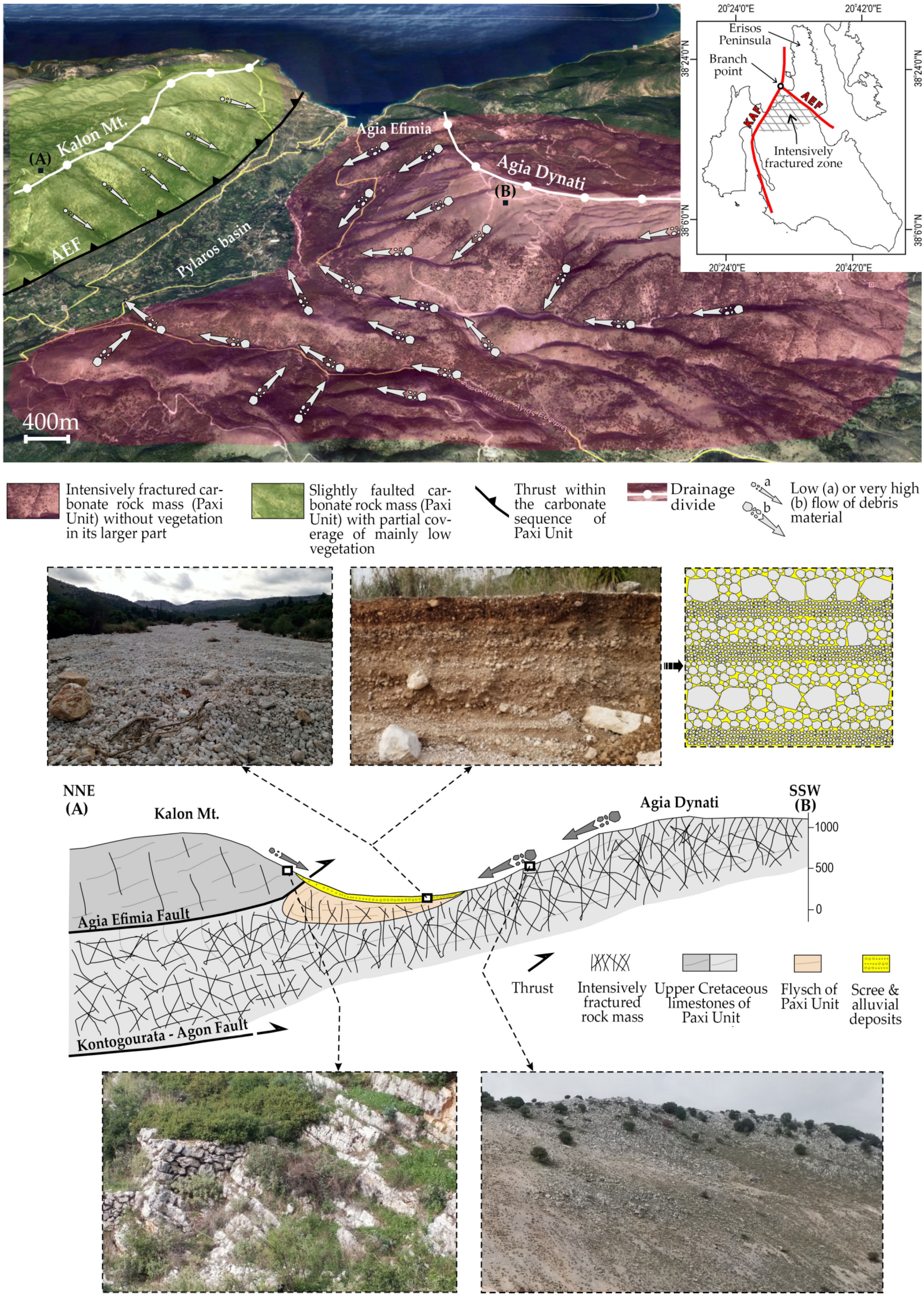

Figure 14. Schematic map and cross-section of Pylaros Basin near Agia Efimia in the northeastern part of Cephalonia, illustrating the geological conditions, as well as characteristic images of the local geological formations.

Figure 15. Schematic map of Assos village and Assos basin in the western part of Cephalonia Island, illustrating the basic geo-environmental parameters that contributed to the debris flow, as well as imagery from the basin's outlet near the beach where the debris was largely deposited.

Furthermore, impacts on infrastructure are consistent with descriptions of damages on bridges and other road infrastructure [12,84,85]. Scouring of foundations [86], erosion of embankments, and removal of asphalt surface [87], as well as instabilities in cut slope and road subsidence [88,89], have been associated before with large amounts of rainfall and are prevalent in this case as well. The mechanisms of inflicting structural damages on various elements of transportation infrastructure were found to be diverse. In some cases, the infrastructure in question was caught in mass movement phenomena taking place after slope failures or instabilities that occurred exactly at their location. In other cases, a slope failure that occurred upstream (far from the said infrastructure) led to a mass movement that crossed and damaged a road or a bridge in its path downstream (as, for example, a debris flow). In some locations, flooding or wave action affected parts of the infrastructure damaging critical elements through the scouring of the foundations (e.g., eroding embankments). Finally, strong winds toppled trees or poles, damaging other infrastructure, facilities, or objects (e.g., vehicles).

Geomorphic effects on the coastal zone identified in the present study are also consistent with previous findings, indicating high energy wave action (e.g., Scicchitano et al. [90], Foti et al. [91], Komar and Moore [80], Flaounas et al. [29]), which is considered to be rare in the past in the study area, in terms of wave characteristics [92].

With regard to vegetation, the overall effects on the islands cannot be fully appreciated as treefalls within the forested land were not fully surveyed, supporting the claim of Pinna et al. [24] regarding the lack of studies on the impacts of extreme weather events on vegetation. In this case, effects on vegetation were recorded mostly in areas with human activities or near infrastructure, where falling trees (due to the strong winds) led to damages in power lines and poles, that in turn led to power and telecommunication outages.

In addition, it has to be stressed that our findings suggested that damages in boats were inflicted in 20 different ports on all sides around the four islands, indicating that in such cases, vessels operations and anchoring, berthing, or mooring are characterized by high risk, regardless of the port orientation.

Overall, it should be noted that the results of this study cannot be compared directly with previous research works or reports on Medicane effects due to their differences in resolution. However, the broader types of impacts, acknowledged in previous works [1,7,10,29,48,90], were also recorded in the present study and fall within the categories developed here. The impacts identified in this study are also similar in type to the ones caused by tropical storms and hurricanes around the globe, although preliminary comparison indicates that they lack in spatial extent and severity [93–95]. It would be useful for future research to carry out a more objective and complete comparison between these two types of systems.

Comparison with other storms in the region provides indications that Medicanes present a higher diversity of types of effects based on the impact descriptions of other extreme events [96–100]. For example, Lekkas et al. [98] and Lagouvardos et al. [101] described important hydrogeomorphic effects but limited damages induced by wave action and strong winds. The findings of Scicchitano et al. [1] on the comparison of coastal impacts of Medicanes with those of seasonal storms are in agreement with this conclusion. This is probably attributed to the high severity of forcing and the variety of forcing phenomena (i.e., rainfall, strong wind, and wave action).

One of the limitations of the present work lies in the fact that it identified and recorded types of damages within the boundaries of the landscape surface properties of the study area. Thus, it is to be expected that the typology of impacts is influenced to a degree by the actual exposure of assets and the landscape of the area, which has the particular characteristics of the man-made environment and natural environment of the Ionian Islands. However, as the Ionian Islands is a typical example of the Mediterranean coastline in both environmental, administrational, and socioeconomic aspects, it is considered to reflect the typology of effects of most coastal areas across the region.

Future research should enhance the efforts to explore possible associations of the impacts' spatial distribution to the various potential influencing factors, including accumulated rainfall, rainfall intensity, geological formation, tectonics, vegetation, and others through statistical tests. In addition, understanding the impacts of Medicane events would benefit from further research on additional case studies and indirect effects (e.g., impacts on trade, transportation activities, tourism, etc.). In addition, in terms of practical implications, the local and regional authorities of Mediterranean coastal areas should establish a continuous and systematic recording of Medicane impacts (including the spatial distribution) that can be used to guide decisions about where to allocate resources for relief and recovery efforts and to inform plans for future disaster preparedness. Systematic recording of impacts, in the fashion carried out in the present study, can also help to inform research on disaster-related trends, identify areas where further study is needed and highlight areas where establishing infrastructure may be dangerous.

7. Conclusions

This study developed a systematic record of the direct impacts of Medicane Ianos on the Ionian Islands, in Greece, as a characteristic case study illustrating the potential effects of such an extreme event on a developed Mediterranean coastal area.

The findings showed that Mediterranean cyclones (Medicanes) have the potential to cause significant impacts, which can compromise safety and can be dangerous and disruptive to Mediterranean communities and their activities. Medicanes, such as Ianos, can cause an extensive diversity of impacts requiring increased preparedness on many fronts, including (but not limited to) safety of transportation on land and sea, maintenance of infrastructure, competent authorities, and communication of the potential risks to the general public. Impacts span from geomorphic effects to damages to infrastructure, damages to vehicles, buildings, and boats, and impacts on agriculture and vegetation affecting the man-made and the natural environment.

Studying Medicanes and focusing on these impacts can help improve our understanding of the risks, allowing for better predictions and planning for such events, as well as improved emergency management and recovery and strengthened from anticipating the impacts. This information can be used by authorities to inform policies, plans, infrastructure design, and interventions that aim to mitigate risk from extreme events.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w15061026/s1, Table S1: Climatological information from Argostoli Station in Cephalonia (1970-2010) (HNMS [46]).; Table S2: Climatological information from Zakynthos Airport Station in Zakynthos (1982-2010) (HNMS [46]).

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References

1. Scicchitano, G.; Scardino, G.; Monaco, C.; Piscitelli, A.; Milella, M.; De Giosa, F.; Mastronuzzi, G. Comparing impact effects of common storms and Medicanes along the coast of south-eastern Sicily. *Mar. Geol.* **2021**, *439*, 106556. [CrossRef]
2. Jansa, A.; Genoves, A.; Picornell, M.A.; Campins, J.; Riosalido, R.; Carretero, O. Western Mediterranean cyclones and heavy rain. Part 2: Statistical approach. *Meteorol. Appl.* **2001**, *8*, 43–56. [CrossRef]
3. Androulidakis, Y.; Makris, C.; Mallios, Z.; Pytharoulis, I.; Baltikas, V.; Krestenitis, Y. Storm surges during a Medicane in the Ionian Sea. In Proceedings of the Marine and Inland Waters Research Symposium, Porto Heli, Greece, 16–19 September 2022; Volume 2, pp. 9–14.
4. Valkaniotis, S.; Papathanassiou, G.; Marinos, V.; Saroglou, C.; Zekkos, D.; Kallimogiannis, V.; Karantanellis, E.; Farmakis, I.; Zalachoris, G.; Manousakis, J.; et al. Landslides Triggered by Medicane Ianos in Greece, September 2020: Rapid Satellite Mapping and Field Survey. *Appl. Sci.* **2022**, *12*, 12443. [CrossRef]
5. Rizza, U.; Canepa, E.; Miglietta, M.M.; Passerini, G.; Morichetti, M.; Mancinelli, E.; Virgili, S.; Besio, G.; De Leo, F.; Mazzino, A. Evaluation of drag coefficients under medicane conditions: Coupling waves, sea spray and surface friction. *Atmos. Res.* **2021**, *247*, 105207. [CrossRef]
6. Rizza, U.; Canepa, E.; Ricchi, A.; Bonaldo, D.; Carniel, S.; Morichetti, M.; Passerini, G.; Santiloni, L.; Puhales, F.S.; Miglietta, M.M. Influence of wave state and sea spray on the roughness length: Feedback on medicanes. *Atmosphere* **2018**, *9*, 301. [CrossRef]
7. Nastos, P.T.; Karavana Papadimou, K.; Matsangouras, I.T. Mediterranean tropical-like cyclones: Impacts and composite daily means and anomalies of synoptic patterns. *Atmos. Res.* **2018**, *208*, 156–166. [CrossRef]
8. Patlakas, P.; Stathopoulos, C.; Tsalis, C.; Kallos, G. Wind and wave extremes associated with tropical-like cyclones in the Mediterranean basin. *Int. J. Climatol.* **2021**, *41*, E1623–E1644. [CrossRef]
9. Toomey, T.; Amores, A.; Marcos, M.; Orfila, A.; Romero, R. Coastal Hazards of Tropical-Like Cyclones Over the Mediterranean Sea. *J. Geophys. Res. Ocean.* **2022**, *127*, e2021JC017964. [CrossRef]
10. Bakkensen, L.A. Estimating the Damages of Mediterranean Hurricanes. *J. Extrem. Events* **2017**, *4*, 1–23. [CrossRef]
11. Tervo, R.; Láng, I.; Jung, A.; Mäkelä, A. Predicting power outages caused by extratropical storms. *Nat. Hazards Earth Syst. Sci.* **2021**, *21*, 607–627. [CrossRef]
12. Loli, M.; Manousakis, J.; Mitoulis, S.A.; Zekkos, D. UAVs for Disaster Response: Rapid Damage Assessment and Monitoring of Bridge Recovery after a Major Flood. *Eng. Proc.* **2022**, *11*, 17011. [CrossRef]
13. Bitan, M.; Zviely, D. Lost value assessment of bathing beaches due to sea level rise: A case study of the Mediterranean coast of Israel. *J. Coast. Conserv.* **2019**, *23*, 773–783. [CrossRef]
14. Remoundou, K.; Koundouri, P.; Kontogianni, A.; Nunes, P.A.L.D.; Skourtos, M. Valuation of natural marine ecosystems: An economic perspective. *Environ. Sci. Policy* **2009**, *12*, 1040–1051. [CrossRef]
15. Thébault, H.; Scheurle, C.; Duffa, C.; Boissery, P. Valuation and sensitivity of socio-economic activities along the French mediterranean coast. *Int. J. Sustain. Dev. Plan.* **2014**, *9*, 754–768. [CrossRef]
16. Vellinga, P.; Leatherman, S.P. Sea level rise, consequences and policies. *Clim. Chang.* **1989**, *15*, 175–189. [CrossRef]
17. Klein, R.J.T.; Nicholls, R.J.; Thomalla, F. Resilience to natural hazards: How useful is this concept? *Environ. Hazards* **2003**, *5*, 35–45. [CrossRef]
18. Taussik, J. Development Plans and the Coastal Zone. *Town Plan. Rev.* **1996**, *67*, 397–420. [CrossRef]

19. Gormsen, E. The impact of tourism on coastal areas. *GeoJournal* **1997**, *42*, 39–54. [CrossRef]
20. Small, C.; Nicholls, J. A global Analysis of Human Settlement in Coastal Zones. *J. Coast. Res.* **2003**, *19*, 584–599.
21. Neumann, B.; Vafeidis, A.T.; Zimmermann, J.; Nicholls, R.J. Future coastal population growth and exposure to sea-level rise and coastal flooding—A global assessment. *PLoS ONE* **2015**, *10*, e0131375. [CrossRef]
22. Mavroulis, S.; Vassilakis, E.; Diakakis, M.; Konsolaki, A.; Kaviris, G.; Kotsi, E.; Kapetanidis, V.; Sakkas, V.; Alexopoulos, J.D.; Lekkas, E.; et al. The Use of Innovative Techniques for Management of High-Risk Coastal Areas, Mitigation of Earthquake-Triggered Landslide Risk and Responsible Coastal Development. *Appl. Sci.* **2022**, *12*, 2193. [CrossRef]
23. Hochman, A.; Marra, F.; Messori, G.; Pinto, J.G.; Raveh-Rubin, S.; Yosef, Y.; Zittis, G. Extreme weather and societal impacts in the eastern Mediterranean. *Earth Syst. Dyn.* **2022**, *13*, 749–777. [CrossRef]
24. Pinna, M.S.; Loi, M.C.; Calderisi, G.; Fenu, G. Extremes Rainfall Events on Riparian Flora and Vegetation in the Mediterranean Basin: A Challenging but Completely Unexplored Theme. *Water* **2022**, *14*, 817. [CrossRef]
25. Jansa, A.; Alpert, P.; Arbogast, P.; Buzzi, A.; Ivancan-Picek, B.; Kotroni, V.; Llasat, M.C.; Ramis, C.; Richard, E.; Romero, R.; et al. MEDEX: A general overview. *Nat. Hazards Earth Syst. Sci.* **2014**, *14*, 1965–1984. [CrossRef]
26. Ragone, F.; Mariotti, M.; Parodi, A.; von Hardenberg, J.; Pasquero, C. A climatological study of Western Mediterranean Medicanes in numerical simulations with explicit and parameterized convection. *Atmosphere* **2018**, *9*, 397. [CrossRef]
27. Cavicchia, L.; von Storch, H.; Gualdi, S. A long-term climatology of medicanes. *Clim. Dyn.* **2014**, *43*, 1183–1195. [CrossRef]
28. Emanuel, K. Genesis and maintenance of "Mediterranean hurricanes". *Adv. Geosci.* **2005**, *2*, 217–220. [CrossRef]
29. Flaounas, E.; Davolio, S.; Raveh-Rubin, S.; Pantillon, F.; Miglietta, M.M.; Gaertner, M.A.; Hatzaki, M.; Homar, V.; Khodayar, S.; Korres, G.; et al. Mediterranean cyclones: Current knowledge and open questions on dynamics, prediction, climatology and impacts. *Weather Clim. Dyn.* **2022**, *3*, 173–208. [CrossRef]
30. Zhang, Q.; Li, L.; Ebert, B.; Golding, B.; Johnston, D.; Mills, B.; Panchuk, S.; Potter, S.; Riemer, M.; Sun, J.; et al. Increasing the value of weather-related warnings. *Sci. Bull.* **2019**, *64*, 647–649. [CrossRef]
31. Taylor, A.L.; Kox, T.; Johnston, D. Communicating high impact weather: Improving warnings and decision making processes. *Int. J. Disaster Risk Reduct.* **2018**, *30*, 1–4. [CrossRef]
32. Romero, R.; Emanuel, K. Climate change and hurricane-like extratropical cyclones: Projections for North Atlantic polar lows and medicanes based on CMIP5 models. *J. Clim.* **2017**, *30*, 279–299. [CrossRef]
33. Cavicchia, L.; Von Storch, H.; Gualdi, S. Mediterranean tropical-like cyclones in present and future climate. *J. Clim.* **2014**, *27*, 7493–7501. [CrossRef]
34. Tous, M.; Zappa, G.; Romero, R.; Shaffrey, L.; Vidale, P.L. Projected changes in medicanes in the HadGEM3 N512 high-resolution global climate model. *Clim. Dyn.* **2016**, *47*, 1913–1924. [CrossRef]
35. Romera, R.; Gaertner, M.Á.; Sánchez, E.; Domínguez, M.; González-Alemán, J.J.; Miglietta, M.M. Climate change projections of medicanes with a large multi-model ensemble of regional climate models. *Glob. Planet. Chang.* **2017**, *151*, 134–143. [CrossRef]
36. Zittis, G.; Almazroui, M.; Alpert, P.; Ciais, P.; Cramer, W.; Dahdal, Y.; Fnais, M.; Francis, D.; Hadjinicolaou, P.; Howari, F.; et al. Climate Change and Weather Extremes in the Eastern Mediterranean and Middle East. *Rev. Geophys.* **2022**, *60*, e2021RG000762. [CrossRef]
37. IPCC Climate Change 2013: The Physical Science Basis. In *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2013.
38. Agulles, M.; Melo-Aguilar, C.; Jordà, G. Risk of loss of tourism attractiveness in the Western Mediterranean under climate change. *Front. Clim.* **2022**, *4*, 1–17. [CrossRef]
39. Aston Centre for Europe. *Sustainable Tourism in the Mediterranean*; Aston: Birmingham, UK, 2012; Volume 1.
40. Amelung, B.; Viner, D. Mediterranean tourism: Exploring the future with the tourism climatic index. *J. Sustain. Tour.* **2006**, *14*, 349–366. [CrossRef]
41. Perry, A.H. Will predicted climate change compromise the sustainability of Mediterranean tourism? *J. Sustain. Tour.* **2006**, *14*, 367–375. [CrossRef]
42. Bartholy, J.; Pongrácz, R.; Pattantyús-Ábrahám, M. Analyzing the genesis, intensity, and tracks of western Mediterranean cyclones. *Theor. Appl. Climatol.* **2009**, *96*, 133–144. [CrossRef]
43. Prezerakos, N.G. The northwest african depressions affecting the south balkans. *J. Climatol.* **1985**, *5*, 643–654. [CrossRef]
44. Kalimeris, A.; Founda, D.; Giannakopoulos, C.; Pierros, F. Long-term precipitation variability in the Ionian Islands, Greece (Central Mediterranean): Climatic signal analysis and future projections. *Theor. Appl. Climatol.* **2012**, *109*, 51–72. [CrossRef]
45. Flocas, A.A.; Giles, B.D. Distribution and intensity of frontal rainfall over Greece. *Int. J. Climatol.* **1991**, *11*, 429–442. [CrossRef]
46. Hellenic National Meteorological Service. *Climatic Data for Selected Stations in Greece—Argostoli*; Hellenic National Meteorological Service: Ellinikon, Greece, 2023.
47. Nastos, P.T.; Matsangouras, I.T. Composite Mean and Anomaly of Synoptic Conditions for Tornadic Days over North Ionian Sea (NW Greece). In *Advances in Meteorology, Climatology and Atmospheric Physics*; Helmis, C.G., Nastos, P.T., Eds.; Springer: Berlin/Heidelberg, Germany, 2012; pp. 639–645. ISBN 9783642291715.
48. Lagouvardos, K.; Karagiannidis, A.; Dafis, S.; Kalimeris, A.; Kotroni, V. Ianos-A Hurricane in the Mediterranean. *Bull. Am. Meteorol. Soc.* **2022**, *103*, E1621–E1636. [CrossRef]

49. Spyrou, E.; Triantaphyllou, M.V.; Tsourou, T.; Vassilakis, E.; Asimakopoulos, C.; Konsolaki, A.; Markakis, D.; Marketou-Galari, D.; Skentos, A. Assessment of Geological Heritage Sites and Their Significance for Geotouristic Exploitation: The Case of Lefkas, Meganisi, Kefalonia and Ithaki Islands, Ionian Sea, Greece. *Geosciences* **2022**, *12*, 55. [CrossRef]
50. Kotsi, E.; Vassilakis, E.; Diakakis, M.; Mavroulis, S.; Konsolaki, A.; Filis, C.; Lozios, S.; Lekkas, E. Using UAS-Aided Photogrammetry to Monitor and Quantify the Geomorphic Effects of Extreme Weather Events in Tectonically Active Mass Waste-Prone Areas: The Case of Medicane Ianos. *Appl. Sci.* **2023**, *13*, 812. [CrossRef]
51. Mavroulis, S.; Diakakis, M.; Kranis, H.; Vassilakis, E.; Kapetanidis, V.; Spingos, I.; Kaviris, G.; Skourtsos, E.; Voulgaris, N.; Lekkas, E. Inventory of Historical and Recent Earthquake-Triggered Landslides and Assessment of Related Susceptibility by GIS-Based Analytic Hierarchy Process: The Case of Cephalonia (Ionian Islands, Western Greece). *Appl. Sci.* **2022**, *12*, 2895. [CrossRef]
52. Papanikolaou, D.I. *The Geology of Greece*; Springer: Berlin/Heidelberg, Germany, 2021; ISBN 9783030607302.
53. Lekkas, E.; Danamos, G.D.; Lozios, S. Neotectonic structure and evolution of Lefkada island. *Bull. Geol. Soc. Greece* **2001**, *34*, 157–163. [CrossRef]
54. Lekkas, E.L.; Danamos, G.D.; Georgios, M. Geological structure and evolution of Kefallonia and Ithaki Islands. *Bull. Geol. Soc. Greece* **2001**, *34*, 11–17. [CrossRef]
55. Scordilis, E.M.; Karakaisis, G.F.; Karacostas, B.G.; Panagiotopoulos, D.G.; Comninakis, P.E.; Papazachos, B.C. Evidence for transform faulting in the Ionian sea: The Cephalonia island earthquake sequence of 1983. *Pure Appl. Geophys. Pageoph.* **1985**, *123*, 388–397. [CrossRef]
56. Louvari, E.; Kiratzi, A.A.; Papazachos, B.C. The Cephalonia Transform Fault and its extension to western Lefkada Island (Greece). *Tectonophysics* **1999**, *308*, 223–236. [CrossRef]
57. Sachpazi, M.; Hirn, A.; Clément, C.; Haslinger, F.; Laigle, M.; Kissling, E.; Charvis, P.; Hello, Y.; Lépine, J.C.; Sapin, M.; et al. Western Hellenic subduction and Cephalonia Transform: Local earthquakes and plate transport and strain. *Tectonophysics* **2000**, *319*, 301–319. [CrossRef]
58. Sakkas, V.; Kapetanidis, V.; Kaviris, G.; Spingos, I.; Mavroulis, S.; Diakakis, M.; Alexopoulos, J.D.; Kazantzidou-Firtinidou, D.; Kassaras, I.; Dilalos, S.; et al. Seismological and ground Deformation Study of the Ionian Islands (W. Greece) during 2014–2018, a Period of Intense Seismic Activity. *Appl. Sci.* **2022**, *12*, 2331. [CrossRef]
59. Lekkas, E.; Mavroulis, S.; Carydis, P.; Alexoudi, V. *The 17 November 2015 Mw 6.4 Lefkas (Ionian Sea, Western Greece) Earthquake: Impact on Environment and Buildings*; Springer: Berlin/Heidelberg, Germany, 2018; Volume 36, ISBN 1070601804528.
60. Lekkas, E.L.; Mavroulis, S.D. Earthquake environmental effects and ESI 2007 seismic intensities of the early 2014 Cephalonia (Ionian Sea, western Greece) earthquakes (January 26 and February 3, Mw 6.0). *Nat. Hazards* **2015**, *78*, 1517–1544. [CrossRef]
61. Mavroulis, S.; Stanota, E.S.; Lekkas, E. Evaluation of environmental seismic intensities of all known historical and recent earthquakes felt in Zakynthos Island, Greece using the Environmental Seismic Intensity (ESI 2007) scale. *Quat. Int.* **2019**, *532*, 1–22. [CrossRef]
62. IGUR. *The Devastating Earthquakes of the Ionian Islands in August 1953: Proposal for the Reconstruction of Cities, Towns and Villages of the Earthquake-Affected Islands*; Institute of Geology and Underground Research (IGUR): Athens, Greece, 1954.
63. Mavroulis, S.; Carydis, P.; Alexoudi, V.; Grambas, A.; Lekkas, E. The January-February 2014 Cephalonia (Ionian Sea, Western Greece) Earthquakes: Tectonic and Seismological Aspects. In Proceedings of the 16th World Conference on Earthquake, 16WCEE, Santiago, Chile, 9–13 January 2017.
64. Mavroulis, S.; Diakakis, M.; Kotsi, E.; Vassilakis, E.; Lekkas, E. Susceptibility and hazard assessment in the Ionian Islands for highlighting sites of significant earthquake-related hazards. In Proceedings of the Safe Corfu 2019 Proceedings, SafeGreece, Corfu, Greece, 6–9 November 2019; Volume 1, pp. 13–16.
65. ELSTAT. *Census Results of Population and Housing 2021*; ELSTAT: Athens, Greece, 2021.
66. Lekkas, E.; Nastos, P.; Cartalis, C.; Diakakis, M.; Gogou, M.; Mavroulis, S.; Spyrou, N.-I.; Kotsi, E.; Vassilakis, E.; Katsetsiadou, K.-N.; et al. Impact of Medicane "IANOS" (September 2020). *Newsletter of Environmental, Disaster and Crisis Management Strategies*, 28 October 2020.
67. Velesioti, A. *NewMoney*; Athens, Greece November 2020; pp. 1–7.
68. Prat, A.C.; Federico, S.; Torcasio, R.C.; D'adderio, L.P.; Dietrich, S.; Panegrossi, G. Evaluation of the sensitivity of medicane ianos to model microphysics and initial conditions using satellite measurements. *Remote Sens.* **2021**, *13*, 4984. [CrossRef]
69. Lagouvardos, K.; Kotroni, V.; Bezes, A.; Koletsis, I.; Kopania, T.; Lykoudis, S.; Mazarakis, N.; Papagiannaki, K.; Vougioukas, S. The automatic weather stations NOANN network of the National Observatory of Athens: Operation and database. *Geosci. Data J.* **2017**, *4*, 4–16. [CrossRef]
70. *Special Secretariat for Water Flood Risk Management Plans of the Hydrological Basins of North Peloponnese-Intensity-Duration-Frequency Curves*; Greek Ministry of Environment and Energy: Athens, Greece, 2018.
71. Diakakis, M.; Deligiannakis, G.; Antoniadis, Z.; Melaki, M.; Katsetsiadou, N.K.; Andreadakis, E.; Spyrou, N.I.; Gogou, M. Proposal of a flash flood impact severity scale for the classification and mapping of flash flood impacts. *J. Hydrol.* **2020**, *590*, 125452. [CrossRef]
72. Lekkas, E.L.; Andreadakis, E.; Kostaki, I.; Kapourani, E. A proposal for a new integrated Tsunami intensity scale (ITIS-2012). *Bull. Seismol. Soc. Am.* **2013**, *103*, 1493–1502. [CrossRef]
73. Koujianos, J.; Danezis, E.; Koujianos, P.; Charitonidis, A.; Efthimiou, A. *Consulting Services for Updating the Agia Efimia Anti-Flood Pipeline Studies*; Regional Authorities of Kefallinia and Ithaki: Argostoli, Greece, 2020.

74. Koujianos, J.; Danezis, E.; Koujianos, P.; Charitonidis, A.; Efthimiou, A. *Master Plan for the Flood Protection of Pylaros River Basin*; Regional authorities of Kefallinia and Ithaki: Argostoli, Greece, 2020.
75. *Regional Authorities of Kefallinia and Ithaki Managing Issues Caused by the 17th and 18th September 2020 Weather Event*; Regional Authorities of Kefallinia and Ithaki: Argostoli, Greece, 2020.
76. Naoum, G. Impacts of Mediterranean Cyclones in the Ionian Islands: The Case of "Ianos". MSc Thesis, National and Kapodistrian University of Athens, Athens, Greece, 2023.
77. Zekkos, D.; Zalachoris, G.; Alvertos, A.E.; Amatya, P.M.; Blunts, P.; Clark, M.; Dafis, S.; Farmakis, I.; Ganas, A.; Hille, M.; et al. *The September 18–20 2020 Medicane Ianos Impact on Greece—Phase I Reconnaissance Report. Geotechnical Extreme Events Reconnaissance Report, GEER-068*; Geotechnical Extreme Events Reconnaissance Association: Alameda County, CA, USA, 2020.
78. Greek National Newspapers Archive. *National Newspapers Microfilm Database of the Library of the Hellenic Parliament*; Hellenic Parliament: Athens, Greece, 2019.
79. National Library Newspapers Collection. *E-efimeris: Digital Newspapers Collection of the Greek National Library*; Greek National Library: Athens, Greece, 2022.
80. Komar, P.D.; Moore, J.R. *Handbook of Coastal Processes and Erosion*; Komar, P.D., Moore, J.R., Eds.; CRC Press: London, UK, 2018; ISBN 9781315893808.
81. Clarke, B.J.; Otto, F.E.L.; Jones, R.G. Inventories of extreme weather events and impacts: Implications for loss and damage from and adaptation to climate extremes. *Clim. Risk Manag.* **2021**, *32*, 100285. [CrossRef]
82. Mastrandrea, M.D.; Tebaldi, C.; Snyder, C.W.; Schneider, S.H. Current and future impacts of extreme events in California. *Clim. Chang.* **2011**, *109*, 43–70. [CrossRef]
83. Marinos, P.G.; Hoek, E. A geologically friendly tool for rock mass strength estimation. In Proceedings of the GeoEng2000 at the International Conference on Geotechnical and Geological Engineering; Technomic Publishers: Lancaster, PA, USA, 2000; Volume 1, pp. 1422–1446.
84. Douglass, S.L.; Webb, B.M. *Highways in the Coastal Environment*, 3rd ed.; U.S. Department of Transportation: Washington, DC, USA, 2020.
85. Fortelli, A.; Fedele, A.; De Natale, G.; Matano, F.; Sacchi, M.; Troise, C.; Somma, R. Analysis of sea storm events in the mediterranean sea: The case study of 28 december 2020 sea storm in the gulf of Naples, Italy. *Appl. Sci.* **2021**, *11*, 11460. [CrossRef]
86. Link, O.; Mignot, E.; Roux, S.; Camenen, B.; Escauriaza, C.; Chauchat, J.; Brevis, W.; Manfreda, S. Scour at bridge foundations in supercritical flows: An analysis of knowledge gaps. *Water* **2019**, *11*, 1656. [CrossRef]
87. Diakakis, M.; Lekkas, E.; Stamos, I.; Mitsakis, E. Vulnerability of transport infrastructure to extreme weather events in small rural catchments. *Eur. J. Transp. Infrastruct. Res.* **2016**, *16*, 114–127. [CrossRef]
88. Chen, H.; Zhang, G.; Chang, Z.; Wen, L.; Gao, W. Failure Analysis of a Highway Cut Slope with Anti-Slide Piles. *Geofluids* **2021**, *2021*, 6622214. [CrossRef]
89. Oh, S.; Lu, N. Slope stability analysis under unsaturated conditions: Case studies of rainfall-induced failure of cut slopes. *Eng. Geol.* **2015**, *184*, 96–103. [CrossRef]
90. Scicchitano, G.; Scardino, G.; Tarascio, S.; Monaco, C.; Barracane, G.; Locuratolo, G.; Milella, M.; Piscitelli, A.; Mazza, G.; Mastronuzzi, G. The first video witness of coastal boulder displacements recorded during the impact of medicane "Zorbas" on Southeastern Sicily. *Water* **2020**, *12*, 1497. [CrossRef]
91. Foti, E.; Musumeci, R.E.; Stagnitti, M. Coastal defence techniques and climate change: A review. *Rend. Lincei* **2020**, *31*, 123–138. [CrossRef]
92. Ghionis, G.; Poulos, S.E.; Verykiou, E.; Karditsa, A.; Alexandrakis, G.; Andris, P. The impact of an extreme storm event on the barrier beach of the Lefkada lagoon, NE Ionian Sea (Greece). *Mediterr. Mar. Sci.* **2015**, *16*, 562–572. [CrossRef]
93. Diakakis, M.; Deligiannakis, G.; Katsetsiadou, K.; Lekkas, E. Hurricane Sandy mortality in the Caribbean and continental North America. *Disaster Prev. Manag.* **2015**, *24*, 132–148. [CrossRef]
94. Phillips, J.D. Geomorphic impacts of flash flooding in a forested headwater basin. *J. Hydrol.* **2002**, *269*, 236–250. [CrossRef]
95. Petterson, J.S.; Stanley, L.D.; Glazier, E.; Philipp, J. A Preliminary Assessment of Social and Economic Impacts Associated with Hurricane Katrina. *Am. Anthropol.* **2006**, *108*, 643–670. [CrossRef]
96. Delrieu, G.; Ducrocq, V.; Gaume, E.; Nicol, J.; Payrastre, O.; Yates, E.; Kirstetter, P.E.; Andrieu, H.; Ayral, P.A.; Bouvier, C.; et al. The catastrophic flash-flood event of 8–9 September 2002 in the Gard Region, France: A first case study for the Cévennes-Vivarais Mediterranean Hydrometeorological Observatory. *J. Hydrometeorol.* **2005**, *6*, 34–52. [CrossRef]
97. Diakakis, M.; Andreadakis, E.; Nikolopoulos, E.I.; Spyrou, N.I.; Gogou, M.E.; Deligiannakis, G.; Katsetsiadou, N.K.; Antoniadis, Z.; Melaki, M.; Georgakopoulos, A.; et al. An integrated approach of ground and aerial observations in flash flood disaster investigations. The case of the 2017 Mandra flash flood in Greece. *Int. J. Disaster Risk Reduct.* **2019**, *33*, 290–309. [CrossRef]
98. Lekkas, E.; Diakakis, M.; Mavroulis, S.D.; Katsetsiadou, K.-N.; Gogou, M.E.; Spyrou, N.I.; Mavrouli, M.; Antoniadis, K.; Stamati, E. The October 15, 2022 Flash Flood of Agia Pelagia (Crete, southern Greece). *Newsletter of Environmental, Disaster and Crisis Management Strategies*, 28 October 2022; 1–37.
99. Nucera, A.; Foti, G.; Canale, C.; Puntorieri, P.; Minniti, F. Coastal Flooding: Damage classification and Case Studies in Calabria, Italy. In Proceedings of the WIT Transactions on Engineering Sciences, Rome, Italy, 12–14 October 2022; Volume 121, pp. 93–103.

100. Amores, A.; Marcos, M.; Carrió, D.S.; Gómez-pujol, L. Coastal impacts of Storm Gloria (January 2020) over the north-western Mediterranean. *Nat. Hazards Earth Syst. Sci.* **2020**, *20*, 1955–1968. [CrossRef]
101. Lagouvardos, K.; Dafis, S.; Giannaros, C.; Karagiannidis, A.; Kotroni, V. Investigating the role of extreme synoptic patterns and complex topography during two heavy rainfall events in Crete in February 2019. *Climate* **2020**, *8*, 87. [CrossRef]