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Multi-Criteria Wildfire Risk Hazard Assessment in GIS Environment: Projection for the Future and Impact on RES Projects Installation Planning

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Abstract

It is alarming for the fact that Wildfires number, severity and consequently impact have significantly increased during the last years, an aftermath of the Climate Change. One of the most affected areas worldwide is Mediterranean, due to the unique combination of its type of vegetation and demanding climatic conditions. This research is focused on the Region of Epirus in Greece, an area with significant natural vegetation and a range of geomorphological aspects. In order to estimate the Wildfire Risk Hazard, several factors have been used: geomorphological (slope, aspect, elevation, TWI, Hydrographic network), social (Settlements and landfils, roads, overhead lines and substations), environmental (land cover) and climatic (Fire Weather Index). Through a multi-criteria decision analysis (MCDA) and an analytic hierarchy process (AHP) in a GIS environment, the Wildfire Risk Hazard has been estimated not only for current conditions but also for future projections for the near future (2031-2060) and the far future (2071-2100). The selected case study includes the potential impact of the Wildfires to the installed (or targeted to be installed) RES projects in the studied region.

Keywords

RES Projects, Greece, Epirus, Analytic Hierarchy Process, Multi-Criteria Decision Analysis

1. Introduction

One of the most common natural hazards, with worldwide distribution, is Wildfires with a significant economic and social cost (e.g. Abedi et al., 2019; Antoniou et al., 2020; Arango et al., 2023, 2024; Bedia et al., 2018; Butry et al., 2001; Hysa, 2021; Lin et al., 2023; Martin et al., 2016). Their occurrence has considerably increased during the last years across the world (e.g. Iban & Sekertekin, 2022). Based on the technical report of the European Commission on forest fires in Europe, Wildfires resulted to ~66.000 ha of forest land lost between 2010 and 2019 (San-Miguel-Ayanz et al., 2021). Additionally, Lin et al. (2023) mentioned that more than 100,000 Wildfires occur around the world every year, while the burned forest area has reached more than 1 million hectares. Notably, an area which is most vulnerable in wildfires is Mediterranean region, due to its unique combination of climatological, geomorphological, and environmental conditions (Abdo et al., 2022).

Moreover, the Climate Change undeniable influences not only the severity of wildfires, but their frequency as well (Arango et al., 2023, 2024; Zumbrunnen et al., 2011). Furthermore, climate change has led to prolonged warm periods, as well as to increased and more severe heatwaves worldwide (e.g. Arango et al., 2023, 2024; Copernicus Emergency Management Service, 2019 etc.). Additionally, based on models' predictions (e.g. Amatulli et al., 2009; Giorgi & Lionello, 2008; Cubasch & Meehl, 2001), temperatures are expected to be increased, causing an intensification to the occurrence and the severity of Wildfires. Wildfires affect land cover and human activities (e.g. housing, farming, transportation etc.), but can also have severe geomorphological and environmental impacts. Moreover, it can increase the probability of major secondary post-fire occurrences (e.g. landslides, soil erosion etc.) (e.g. Alexiou et al., 2021; Deligiannakis et al., 2021) but also impacts on health due to unknown burnt materials when wildfires enter communities (e.g. Dittrich & McCallum, 2020; Jaffe et al., 2020).

Fire weather indices have been used to provide a more realistic representation of the climatic conditions amenable for fires to spread (e.g. Bedia et al., 2013, 2018). Such an index is the Canadian Fire Weather Index (e.g. Van Wagner, 1987; Taylor & Alexander, 2006; Ntinopoulos et al., 2022), which takes under consideration the precipitation and near-surface air temperature, humidity, and wind speed of an area. While the FWI is focused on climatic conditions, other crucial factors such as the geomorphology, the vegetation and the human impact have not been considered for the evaluation of the wildfire risk hazard.

Several researchers have proposed several models to quantify this risk (Mhawej et al., 2016; Abedi et al., 2019; Lin et al., 2023; Hysa & Başkaya, 2019; Adaktylou et al., 2020; Maniatis et al., 2022; Arango et al., 2023, 2024). Each model is based on several parameters, mostly focused on environmental, geomorphological, and climatological parameters. Through the spatial analysis of above data can result to detailed risk map of an examined region. The outcome of these models cannot be the same everywhere since there is a strong correlation between the followed methodology-model and the unique morphological characteristics that control each area, the different types of vegetation that might exist and the different climatological conditions. Therefore, for each region, different parameters must be considered and be evaluated with a different approach. Several researchers have proposed Wildfire hazard maps for the area of Mediterranean (e.g. Ntinopoulos et al., 2022; Hysa et al., 2022; Bedia et al., 2018; Iban & Sekertekin, 2022; Mhawej et al., 2016; Rivière et al., 2023; Tuyen et al., 2021; Gürsoy et al., 2023; Oliveira et al., 2018). The most common parameters that these researchers have considered are slope and aspect of the examined area, the vegetation coverage, temperature, and wind patterns, as well as the presence of human factor (distance form settlements, landfills etc.).

Geographical Information Systems (GIS) is a powerful tool that can examine and analyze both spatial and temporal information. Therefore, this tool can significantly assist on the analysis and the evaluation of multiple parameters (e.g. Dong et al., 2005; Abedi et al., 2019; Hysa & Başkaya, 2019; Maniatis et al., 2022; Arango et al., 2023, 2024). Moreover, a multi-criteria decision analysis (MCDA) in combination with the analytic hierarchy process, which assigns weights to the examined parameters, can be assessed. Previous researchers (e.g. Abedi et al., 2019; Maniatis et al., 2022; Abdo et al., 2022) have also performed a hierarchical analysis of the examined criteria, proposing wildfire hazards maps for the region of Mediterranean.

In this research, the Weight Analysis tool, which is included in the ArcGIS Pro software, has been applied to the examined data to create detailed wildfire hazards maps for the region of Epirus. As first step, ten major factors which can influence the wildfire susceptibility mapping based on the literature were obtained as the raster or vector data: elevation, slope, aspect, topographic wetness index (TWI), distance to roads, distance to settlements and landfills, distance to rivers, distance to power lines and substation, land cover and forest type, and FWI. Based on the international literature, the impact of each factor has been estimated and a hierarchical Weight has been proposed.

This research provides new insights in estimating the Wildfire Risk hazard, since has incorporated the Fire Weather Index (FWI) in the followed methodology, along with the other environmental, social and geomorphological parameters. As far as the researchers know, this has not been utilized before, since the most common methodology involves the simultaneous usage of different climatic factors (e.g. temperature, wind humidity etc.), instead of one cumulative factor. Moreover, this research provides new insights to the spatial planning of RES Projects, in respect not only the current, but to the future estimation of the Wildfire Risk hazard in an area incorporating clime change impacts.

2. Study Area

The study area of this research is the Region of Epirus, located in the northwest area of Greece (**Figure 1**) approx. 9203 km^2 and exhibits a variety of different morphological aspects, from flat plains near the sea to steep slopes of Pindos Mountain range with altitude more than 2500 meters. In general, Epirus is a mountainous region and for this reason is relatively isolated both economically and technologically (e.g. Vougiouklakis et al., 2006). The total population of Epirus as recorded from the last census of The National Statistical Service Bureau

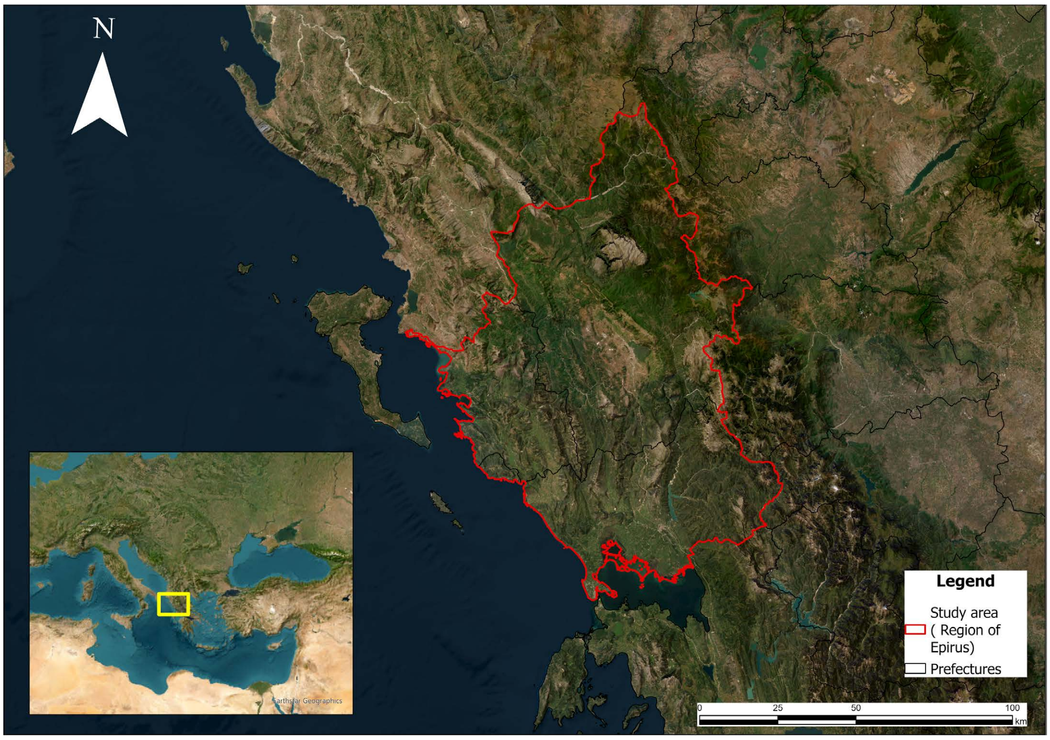

Figure 1. Location of Study area (Region of Epirus) in Greece.

in 2021 was 319,543 inhabitants, where the majority of them are located in the major urban centers of Ioannina, Arta, Preveza and Igoumenitsa.

Due to mountainous characteristics and the low population density, there are significant areas in Region of Epirus with limited human interaction. Therefore, especially towards the mountains, significant forestry area can be observed with no proper conservation activities. Moreover, several areas are protected under strict European and National environmental laws and/or have been designated as Natura 2000 Protected Zone (e.g. National Parks of Vikos Aoos and Pindus National Parks (https://natura2000.eea.europa.eu/).

3. Methodology

3.1. Considered Factors

As mentioned before, ten (10) factors have been considered for estimating the fire risk hazard in the Region of Epirus (**Figure 2**). All data have been extracted from online public sources, and/or have been modified for the purpose of this research, as presented in **Table 1** below.

As described, several researchers have performed similar multiproxy analysis for estimating fire risk hazards, based on various approaches and using different factors. In this research, the factors which have been selected are:

- the most significant, since the majority of the researchers use them as well (e.g. vegetation, climatic conditions etc.),
- their spatial data are easily accessible and free to download in online databases. In that way, a researcher can easily adapt and reproduce this methodology.

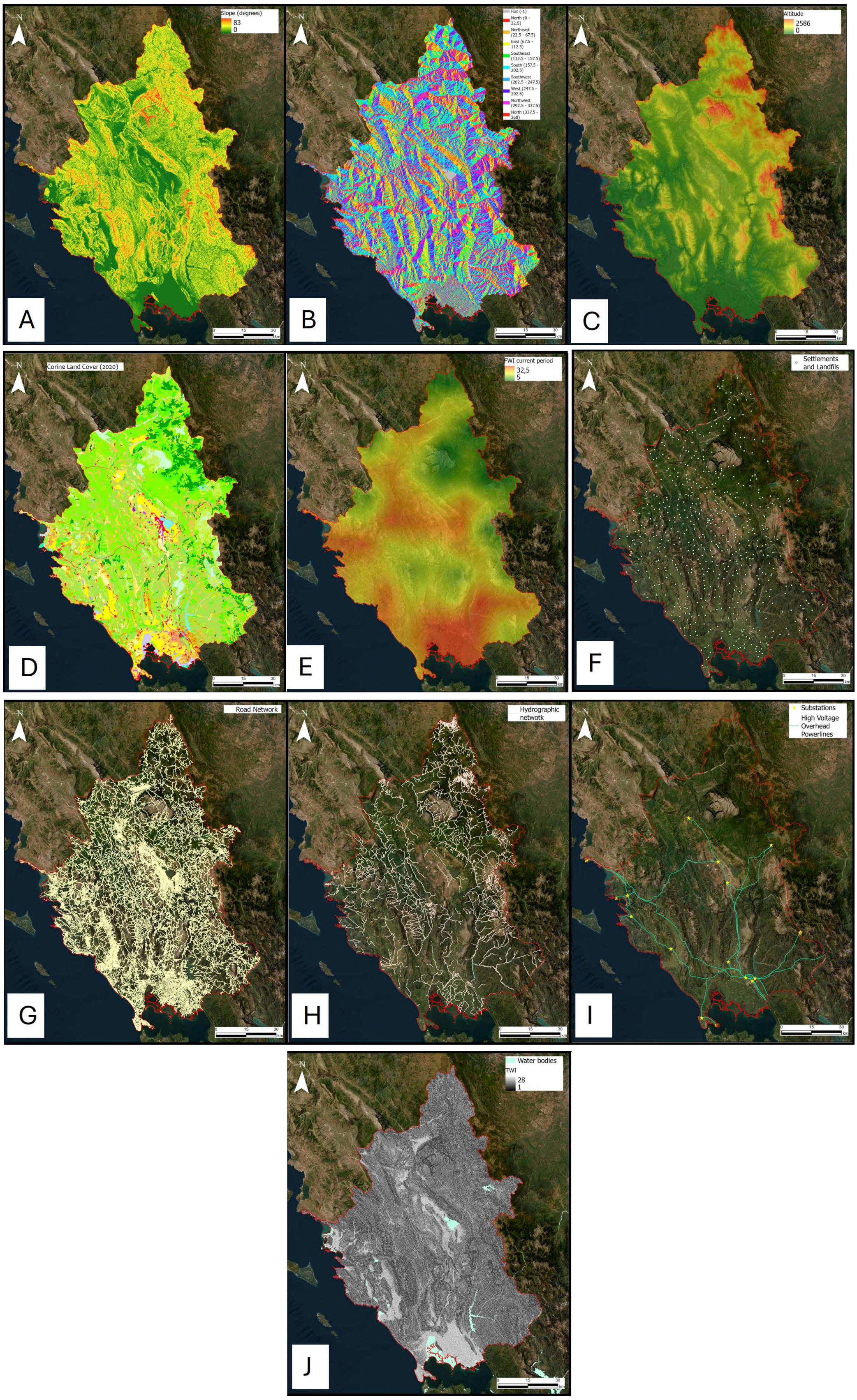

Figure 2. The factors which have been considered in this research for the estimation of the fire risk hazard.

Table 1. Data which have been used for the Wildfire Hazard Risk analyses.

Factor	Source
DEM, Slope, Aspect, TWI	European Digital Elevation Model (EU-DEM)
High voltage overhead lines, Substations	Grid Map of IPTO
Settlements, Hydrographic network	Open Data for Greece
Landfils	Landfils in Greece
FWI	LIFE-IP AdaptInGR
Land cover	Corine 2018
Streets	The Humanitarian Data Exchange (HDX)

The logic behind the factors' categorization is shown in **Table 2**. In general, the followed methodology can be described in three steps:

1) Determination of the factors and data collection,

2) Estimating their weighted rating and perform an analytic hierarchy process (AHP)

3) Through the Weight analysis tool (ArcGIS software), the estimated wildfire Risk Hazard has been extracted (in a 5-rank scale), for current and future projections incorporating climate change impacts.

Step 1

3.1.1. Slope

As several researchers mention (e.g. Erten et al., 2002; Maniatis et al., 2022), slope inclination may affect the pace that fire propagates. Wildfire may grow faster on steeper slopes since flames can reach higher vegetation easier and water runoff increases which may result less soil moisture (Maniatis et al., 2022). Consequently, steeper slopes have a higher risk of fire. Several researchers have proposed different ranges and/or different ranking for slope inclinations (Erten et al., 2002). In this research, the slope degrees were categorized into five classes (%): 0 < 5, 5 - 15, 15 - 25, 25 - 35, and >35 degrees (**Figure 3(A)**).

3.1.2. Aspect

The aspect of the slope might influence the local climatic conditions, since in the northern hemisphere the south slope aspects receive more solar radiation, and consequently vegetation has less humidity (Dillon et al., 2011; Fernandes et al., 2016). Slope aspects of the study area have been grouped into nine orientations: Flat, North, Northeast, East, Southeast, South, Southwest, West, and Northwest, each of which has a different ranking classification (**Figure 3(B)**).

3.1.3. Elevation

The elevation can influence the vegetation coverage, humidity and the temperature of an area (Dillon et al., 2011; Fernandes et al., 2016). As mentioned by several researchers, the higher the altitude, the lower the vegetation density and the inflammation risk (e.g. Maniatis et al., 2022). In this research, the elevation has been classified into five categories: 0 < 200, 200 - 400, 400 - 600, 600 - 800, and >800 m (**Figure 3(C)**).

3.1.4. Land Cover (LC)

One of the most crucial factors to estimate the fire risk hazard is the vegetaion land cover (Maniatis et al., 2022; You et al., 2017). Here, Corine Land Cover (CLC) (from 2018, as updated in 2020) has been used in order to assess the impact to forest fires. Papanikolaou et al. (2012) have proposed a classification of the existing land cover based on the land used described in the Corine database. Based on their analysis, agricultural areas are less vulnerable to wildfire fires, while oak tree forest exhibit the higher vulnerability ranking score (**Figure 3(D)**).

3.1.5. Fire Weather Index (FWI)

Fire Weather Index (FWI) focused on climatic factors has already been used to evaluate the fire risk of an area (e.g. Bedia et al., 2018; Papagiannaki et al., 2020; Ntinopoulos et al., 2022). Copernicus Emergency Management Service has adopted the Canadian Forest Fire Weather Index System as the method to assess the wildfire danger level in a harmonized way throughout Europe. As the researchers mentioned, FWI is computed from the ECMWF model (8 km), which provides 1 to 9 days forecasts, and from the MeteoFrance model (10 km), which provides up to 3 days forecasts (Copernicus Emergency Management Service). A significant benefit where this Index can provide is ability to estimate not only current but future conditions as well (e.g. Copernicus FWI). In that way, the proposed model can be adopted for the current and future projections (**Figure 4**). The Fire Weather Index is categorized in 5 classes: Negligible, Low, Moderate, Significant, High (**Figure 3(E)**).

3.1.6. Distance from Settlement and Landfills (DS)

The distance from settlement can affect the wildfire risk hazard since humans can cause accidental and deliberate fires especially during dry seasons (e.g. Dong et al., 2005; Caballero et al., 2007; Zambon et al., 2019; Maniatis et al., 2022; Abdo et al., 2022). Additionally, uncontrollable disposals of waste in some areas, may trigger a fire (e.g. from glasses etc.) as mentioned in Papanikolaou et al. (2012). Therefore, the distance from the settlements and landfills has been divided into five classes: <100, 100 - 200, 200 - 300, 300 - 400, and >400 m (**Figure 3(F)**).

3.1.7. Distance from Roads (DR)

Similarly with the distance from the settlements, distance from roads can be a contributing factor for wildfire risk hazard (e.g. Dong et al., 2005; Caballero et al., 2007; Zambon et al., 2019; Maniatis et al., 2022; Abdo et al., 2022). Both intentionally and unintentionally, a fire can be triggered due to human activities (e.g. littering, arson etc). Therefore, the distance from the roads has been divided into 2 classes, after Papanikolaou et al. (2012): <50 and >50 m (**Figure 3(G)**).

3.1.8. Distance from Rivers (DRi)

The proximity to the hydrographic network might increase the wildfire hazard

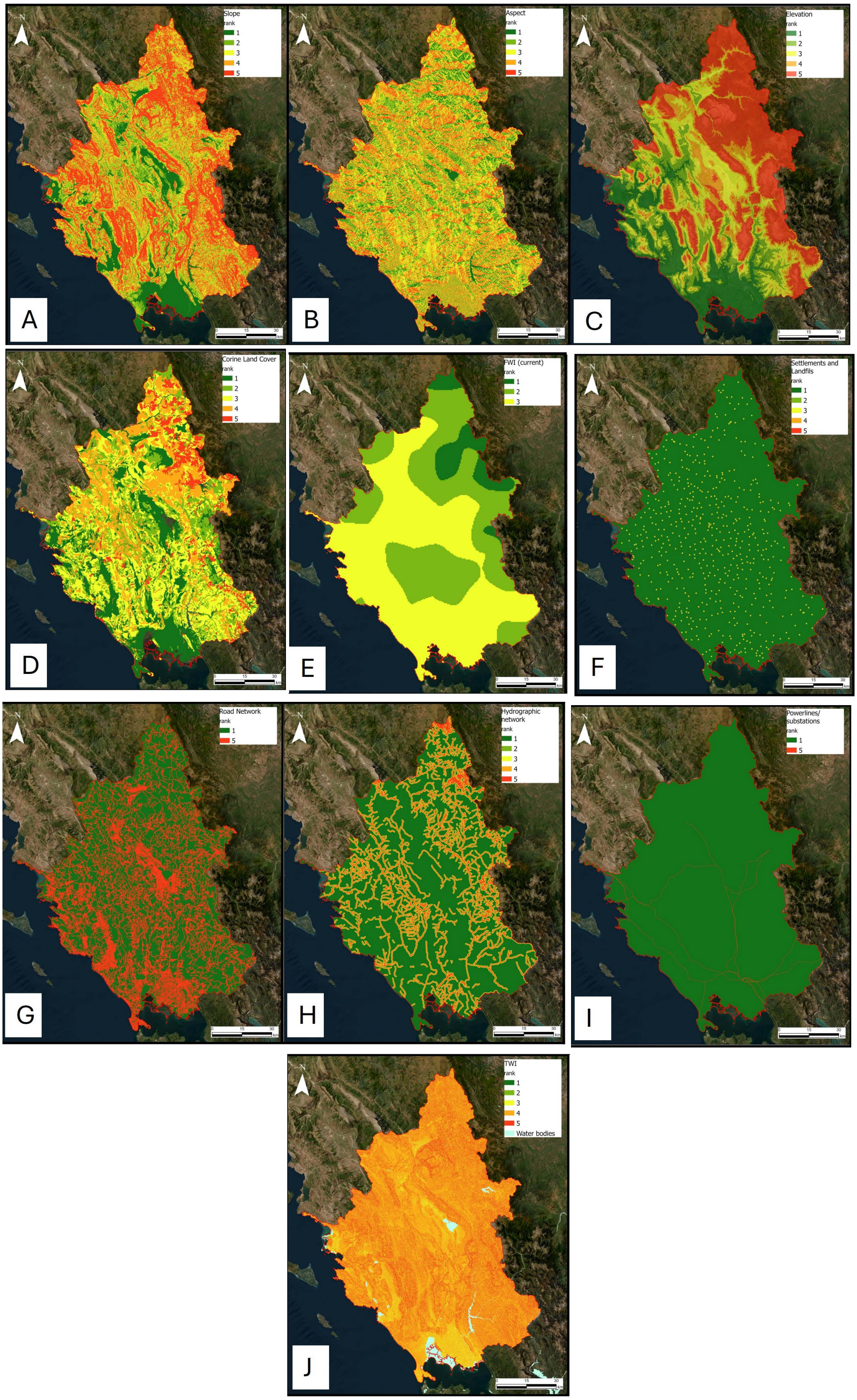

Figure 3. View of the classification of the considered factors.

as mentioned in Chuvieco and Salas (1996) and in Iban & Sekertekin (2022). Therefore, the distance from the roads has been divided into five classes: <100, 100 - 200, 200 - 300, 300 - 400, and >400 m (**Figure 3(H)**).

3.1.9. Distance from High-Voltage Overhead Powerlines and Substations (DPS)

One of most common triggering factor that can cause a wildfire worldwide are powerlines, especially Overhead High-voltage Lines (OHL) and Substations, provoked by hot particles produced by OHL clashing (e.g. Sayarshad, 2023; Guan et al., 2021; Syphard & Keeley, 2015). The distance from Powerlines and Substations has been divided into 2 classes: <50 and >50 m (**Figure 3(I)**).

3.1.10. Topographic Wetness Index (TWI)

The topographic wetness index (TWI) is another factor that can influence the behaviour of wildfire since controls the impact of topography to soil and fuel moisture (e.g. Lee et al., 2014; Maniatis et al., 2022). The risk classification of the TWI is split in five categories (**Figure 3(J)**).

As mentioned above, **Table 2**, **Figure 3** and **Figure 4** below, provides the weighted ranking of the considered factors.

Table 2. The considered factors used in this research and their weighted rating.

No.	Considered Factor	Values	Rating	Risk Classification
1		0 - 5	1	Negligible
		5 - 10	2	Low
		10 - 20	3	Moderate
		20 - 30	4	Significant
		>30	5	High
2		Flat - North	1	Negligible
		Northwest - Northeast	2	Low
		East - West	3	Moderate
		Southwest - Southeast	4	Significant
		South	5	High
3		>800	1	Negligible
		800 - 600	2	Low
		600 - 400	3	Moderate
		400 - 200	4	Significant
		0 - 200	5	High
4		Various agricultural types	1	Negligible
		Sparse bushes & vegetation	2	Low
		Dense bushes & vegetation	3	Moderate

Continued

	Broad-leaved & mixed forest	4	Significant
	Coniferous forest	5	High
5	<11.2	1	Negligible
	11.2 - 21.3	2	Low
	21.3 - 38.0	3	Moderate
	38.0 - 50	4	Significant
	≥50	5	High
6	>400	1	Negligible
	300 - 400	2	Low
	200 - 300	3	Moderate
	100 - 200	4	Significant
	0 - 100	5	High
7	>50	1	Negligible
	0 - 50	5	High
8	>400	1	Negligible
	300 - 400	2	Low
	200 - 300	3	Moderate
	100 - 200	4	Significant
	0 - 100	5	High
9	>50	1	Negligible
	0 - 50	5	High
10	>20	1	Negligible
	20 - 15	2	Low
	15 - 10	3	Moderate
	10 - 5	4	Significant
	<5	5	High

Step 2

3.2. Weight Analysis

The factors which have been described above can influence the ignition and/or the behaviour of a wildfire while each one has a different significance and consequently a different impact in order to estimate the fire risk assessment of an area. Notably, a factor may have a different impact (and therefore ranked differently during the analysis) in one area compared with another area. For example, it is not safe to copy the exact methodology used to estimate the fire hazard in Canada and apply it for estimating wildfire hazard in more arid and less vegetated

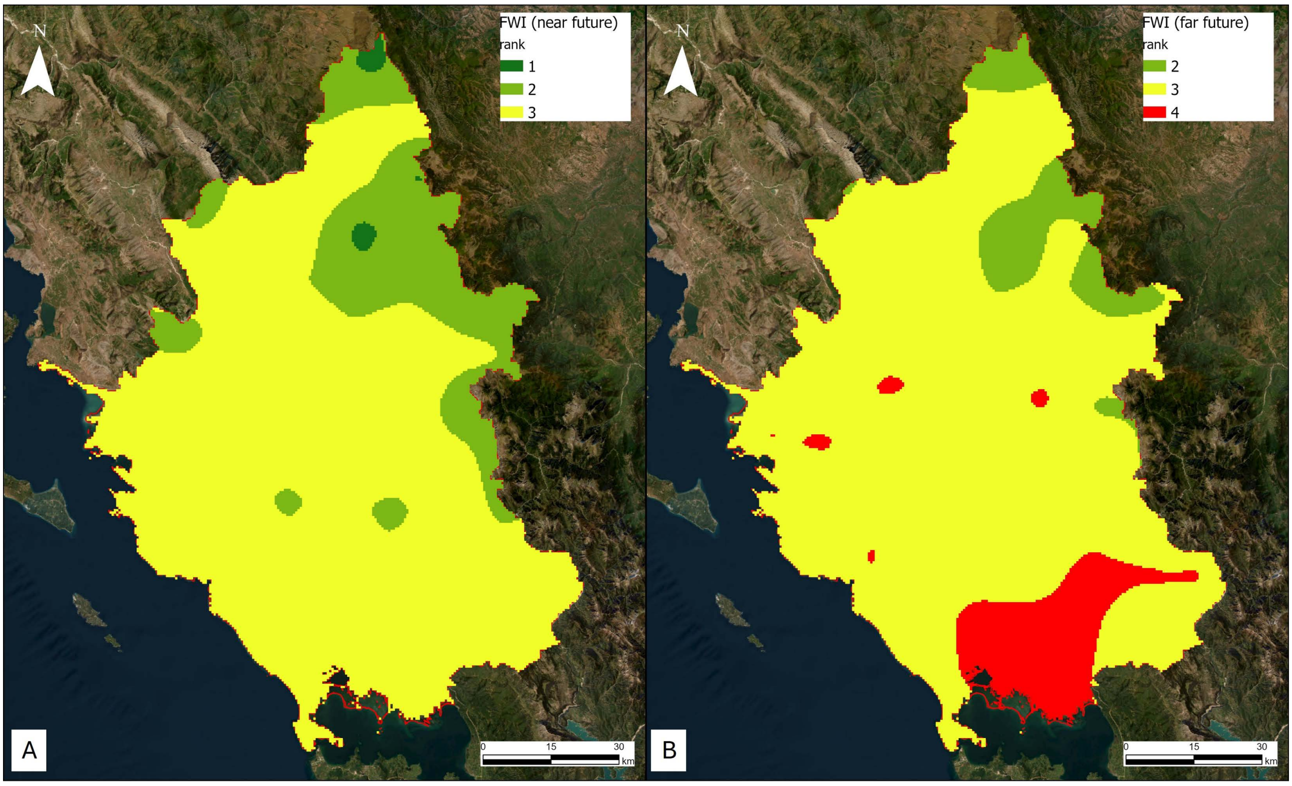

Figure 4. (A) FWI for near future (2031-2060) and (B) FWI for far future (2071-2100).

areas such as Greece.

Several researchers have analysed and have proposed different weights of the used values for estimating Wildfire hazard in the region of Mediterranean. Maniatis et al. (2022) has used seven factors while Land Cover, Distance from roads and Distance from Settlements are considered to have the most contributing factor. The significance of the Vegetation has been highlighted by Papanikolaou et al. (2012) while the importance of Powerlines and landfills is also mentioned. Here, vegetation is considered to be the most important factor. Abdo et al. (2022) highlighted the strong significance of the geomorphology to the behaviour of a wildfire (slope aspect, curvature, elevation) and into a lesser degree the climatic conditions of an area. Iban & Sekertekin (2022) mention that the most important factors that can influence the behaviour of wildfires are elevation, temperature and the slope of an area. Hysa et al. (2022) and Hysa (2021) has also mentioned the significance of climate impact to wildfire hazard both regarding ignition probability and spreading capacity. Strong correlation between the climatic conditions and the fire hazard is also suggested by other researchers (e.g. Amatulli et al., 2013). Climate conditions impact is also considered during the estimation of Fire Weather Index (FWI). This index considers the influence of temperature, wind, humidity and precipitation patterns for the calculation of FWI (e.g. Ntinopoulos et al., 2022).

An analytic hierarchy process (AHP) has been used to estimate the significance of each factor (e.g. Nuthammachot & Stratoulias, 2021). As mentioned above, the factors that have been considered in our model are the following: Slope, Aspect, Elevation, Land Cover, Distance form Settlements and landfills, Distance from Roads, Distance from Rivers, Distance from Powerlines and Substations, FWI and TWI. Considering the analysis and the methodologies described in the international bibliography, the significance of the above factors has been estimated and ranked (FWI > Land Cover > Slope > Elevation > Distance from Roads > Distance form Settlements and landfills > Distance from Powerlines and Substations > Aspect >TWI > Distance from Rivers). The results of the pairwise method (Analytic Hierarchy Process (AHP)) are presented in Table 3.

Step 3

Based on the previous steps (factor ranking, the correlated weight and the support of the ArcGIS PRO software and more specifically with the usage of Weight analysis tool (e.g. Rivière et al., 2023; You et al., 2017; Maniatis et al., 2022; Abdo et al., 2022), the wildfire risk hazard has been estimated. The results are shown below, where the map of the Wildfire Risk Hazard is presented.

Table 3. Pairwise comparison, along with the final weight of the considered factors.

	FWI	land cover	slope	elevation	aspect	Distance from road	Distance from village/ landfills	Cables	Distance from rivers	TWI	Weight
FWI	0.319149	0.402685	0.360902	0.311688	0.27907	0.266667	0.272727	0.243902	0.171429	0.208333	0.283655
Land cover	0.159574	0.201342	0.270677	0.233766	0.139535	0.266667	0.272727	0.243902	0.171429	0.208333	0.216795
Slope	0.079787	0.067114	0.090226	0.155844	0.046512	0.16	0.109091	0.146341	0.171429	0.166667	0.119301
Elevation	0.079787	0.067114	0.045113	0.077922	0.093023	0.106667	0.109091	0.097561	0.085714	0.083333	0.084533
Aspect	0.053191	0.067114	0.090226	0.038961	0.046512	0.026667	0.027273	0.02439	0.057143	0.020833	0.045231
Distance from road	0.06383	0.040268	0.030075	0.038961	0.093023	0.053333	0.054545	0.097561	0.114286	0.083333	0.066922
Distance from village/landfills	0.06383	0.040268	0.045113	0.038961	0.093023	0.053333	0.054545	0.04878	0.085714	0.083333	0.06069
Cables	0.06383	0.040268	0.030075	0.038961	0.093023	0.026667	0.054545	0.04878	0.057143	0.083333	0.053663
Distance from rivers	0.053191	0.033557	0.015038	0.025974	0.023256	0.013333	0.018182	0.02439	0.028571	0.020833	0.025633
TWI	0.06383	0.040268	0.022556	0.038961	0.093023	0.026667	0.027273	0.02439	0.057143	0.041667	0.043578

3.3. Limitations

The most significant limitation of the proposed methodology is related to the future projection of Fire Weather Index. Any future projection has to be under the assumption that the remaining factors will not change in the following years. For several considered factors this can be easily implied, since Slope, Aspect, Elevation, Distance from Rivers, Distance from Settlements and TWI, are not likely to change. Landfills though may close or be relocated, new roads and new High Voltage lines may be constructed. However, the most significant factor that is expected to change considerably is the land cover. It is possible that agriculture areas may be abandoned while forested areas may be changed to other uses or destroyed etc. Any major change will have a significant impact to the future projection of Wildfire Risk hazard as estimated before, therefore, the assumption has to be made that all above factors, especially land cover, will remain more or less the same in the studied area.

4. Results

The results of the above work have led to the production of a Wildfire Risk map for the studied area, as presented in **Figure 5**. Five classes have been used for the description of the Wildfire Hazard Risk (**Table 4**) ranging from Negligible (lower scale) to High (upper scale). As it shown in **Figure 3**, the highest rate (5-High Fire Risk) is not observed in the area while two risk classes cover almost the 99% of the studied area: moderate risk (class 3) for the majority of the studied area (approx. 68.5%) and low risk (class 2) for the 30.8 % of the Region of Epirus. The lowest Risk (1-Negligible) can be barely observed (~0.008%) while the highest risk that can be observed in the area is class 4-Significant, covering approximately 0.74% of the area.

Moreover, the lower risk is generally observed at the central and west part of the studied area (towards the sea), while the highest at the eastern part of the studied area (towards the Pindus Mountain range). The latter is in agreement with the Land cover and Slope data used for the model. As it has been shown in **Figure 5**, towards the eastern part of the studied area, coniferous forest areas and high slopes prevail. On the contrary, the central and western part is characterized mainly by more gentle slopes and other type of vegetation (e.g. agriculture).

Notably, Fire Weather Index for the current reference period (1971-2000) exhibits the lowest values (rank 1) to the northern and eastern areas. This is not in agreement with the outcome of the model, since FWI has the highest Weight as mentioned in **Table 2**. This can be explained though, since the other major factors (CLC, Slope) have higher ranking (up to class 5) in these areas.

Table 4. The Wildfire Risk hazard for the current reference period (1971-2000).

Risk	Wildfire Hazard Risk classes	Approximate total area (km^2)	Approximate total area (%)
1	Negligible	0.07	0,0008
2	Low	2.761	30,8
3	Moderate	6.123	68,5
4	Significant	67	0,74
5	High	-	-

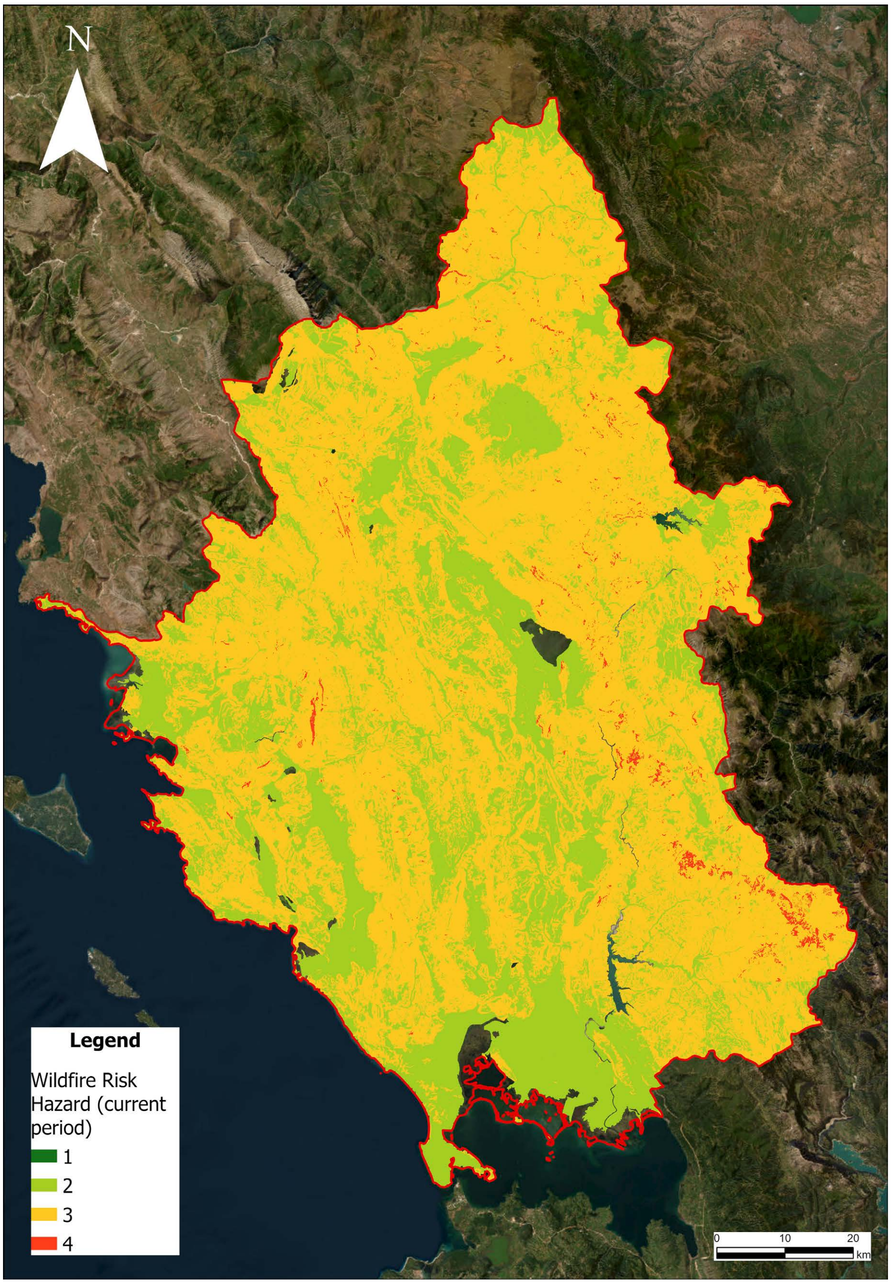

Figure 5. The Wildfire Risk hazard for the current reference period (1971-2000).

5. Discussion

5.1. Future Projections

The ongoing Climate Change is considered to have a key role in wildfires, as mentioned in the Introduction. Several researchers have proposed different approaches in order to estimate how will the wildfire risk change the near and far future. Busico et al., 2019, have performed an analytic hierarchy process for modeling wildfire risk, including as well climatic factors (temperature and precipitation). Based on future projections of these values, the researchers propose an approach on how the Wildfire risk will change in 2040 for Campania Region in southern Italy. Other researchers (e.g. Amatulli et al., 2009; Moriondo et al., 2006) have also estimated future fire risk linked with climatic conditions.

FWI that has been used in this study, offers not only the ability to include fire weather in estimating Wildfire Risk Hazard along with other factors, but offers the opportunity to include future projections as well. Indeed, based on the available data retrieved online (LIFE-IP AdaptInGR) FWI projections for the near future (2031-2060) and for the far future (2071-2100), can be found. Consequently, having the remaining considered factors as constant, Wildfire Risk Hazard for these periods can be assessed.

As is shown in **Figure 4** before, the future fire weather conditions are expected to worsen, following the global Climate Change trend. This will undeniably influence the future Wildfire Risk hazard as shown in **Figure 6** and in **Table 5**.

Both **Table 5** and **Figure 6** clearly show that higher risk areas will be significant more in the near and in the far future. Specifically, during the near future (2031-2060, **Figure 6(B)**) areas categorized as class 1 (Negligible) trend to zero, while areas categorized as class 2 (Low), are expected to be significantly fewer. On the contrary, areas characterized as class 3 (Moderate) are expected to increase and areas characterized as class 4 (significant) are expected to be approximately 3 times more. Similarly, during the far future (2071-2100, **Figure 6(C)**) classes 1 and 2 lower, class 3 is increased, while class 4 is approximately 5 times more. Notably, the highest class (5 High), has not been described even in the far future. The areas where the highest risk is expected is mostly described towards the eastern part of the studied area, as it is shown in **Figure 6** with light blue.

5.2. RES Projects

Renewable energy is considered to be a powerful tool for mitigating Climate Change and minimizing the dependence of fossil fuels (IRENA, 2018; Solaun & Cerda, 2019). During the last years, RES Projects have increased worldwide (Palladino & Calabrese, 2023; International Energy Agency, 2023). In Greece where

Table 5. The Wildfire Risk hazard for the current reference period (1971-2000), the near future (2031-2060) and the far future (2071-2100).

Risk	Wildfire Hazard Risk classes	Current reference period (1971-2000)		Near Future (2031-2060)		Far future (2071-2100)	
		Approximate total area (km^2)	Approximate total area (%)	Approximate total area (km^2)	Approximate total area (%)	Approximate total area (km^2)	Approximate total area (%)
1	Negligible	0.07	0.0008	0.018	0.0002	-	-
2	Low	2.761	30.8	2.175	24.3	1.905	21.2
3	Moderate	6.123	68.5	6.584	73.5	6.732	75.2
4	Significant	67	0.74	191	2.1	313	3.5
5	High	-	-	-	-	-	-

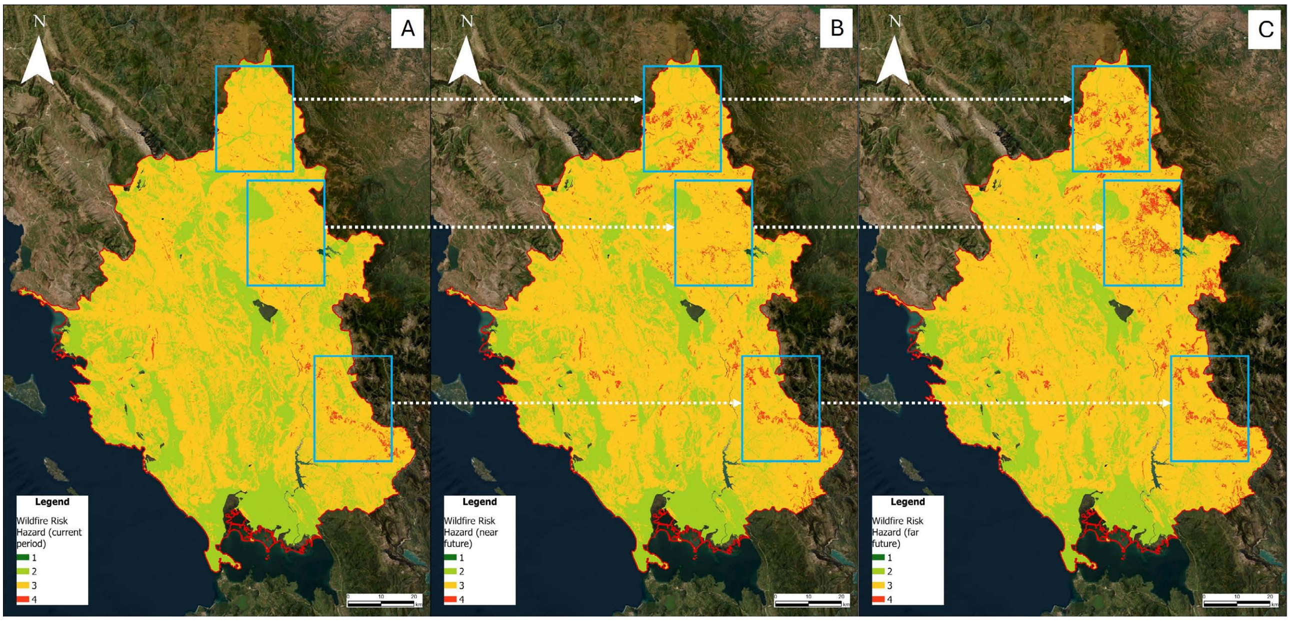

Figure 6. Wildfire Risk Hazard for current reference period (A) and projections for near future (B) and far future (C).

climatic conditions favour the installation of RES projects, their number as well as the total produced MW has significantly increased. The latter has led to the necessity of including Battery Storage Systems, for absorbing and storing the produced electricity (RAEWW). Regulatory Authority for Energy, Waste and Water (RAEWW) supervises the domestic energy market and provides online data regarding the location of operating and planned RES Projects in Greece. Wildfires can be evaluated in respect with RES projects in two different ways. Firstly, as a common infrastructure under a certain risk and secondly as a potential triggering factor.

Several researchers mention that RES projects are vulnerable to wildfires especially the Photovoltaic Panels (e.g. Cai et al., 2023). Wildfires can completely destroy any type of RES installation, as well as any accompanying infrastructure (e.g. powerlines, inverters etc.). Additionally, the smoke may temporarily reduce the sunlight and therefore reduce its operation and the produced energy (e.g. Cai et al., 2023).

On the other hand, RES projects may trigger a wildfire event. As mentioned by several researchers (e.g. Perera et al., 2023, Sayarshad, 2023), a failure of powerlines system or an electrical failure to the accompanying infrastructure such as inverters may start a wildfire. Moreover, Battery Storage systems often contain highly flammable and explosive liquids (e.g. Jin et al., 2021; Zalosh et al., 2021). Since wildfires may influence RES and vice versa, the assessment of this hazard is proved to be a valuable tool for reducing the wildfire hazard risk and consequently the economic and environmental cost.

As shown in **Figure 7(A)**, according to the current projections of the Wildfire risk Hazard, only a few RES projects (both photovoltaic and wind parks) have been installed or are proposed to be installed in the future in areas with moderate

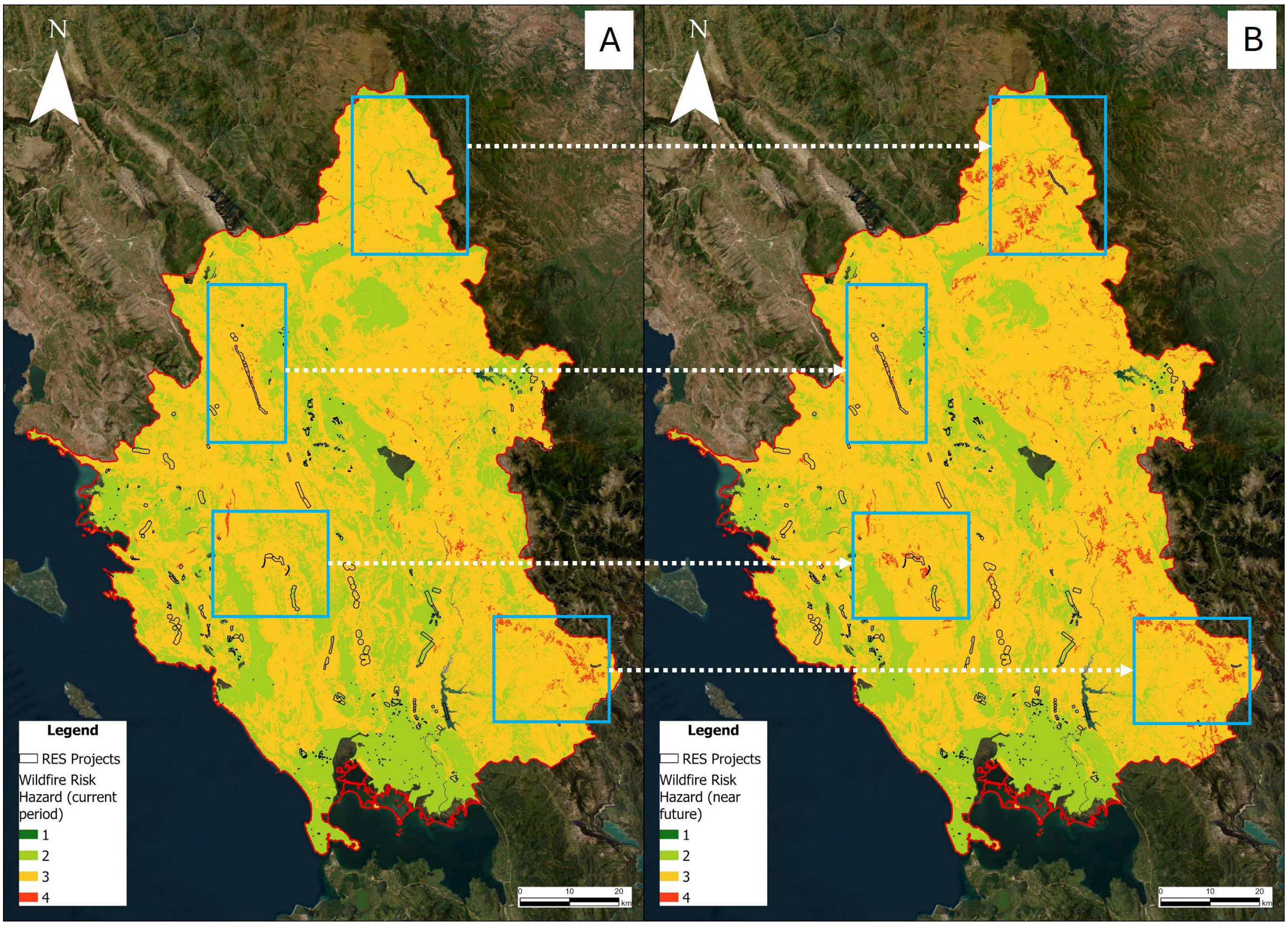

Figure 7. RES Projects (Operational and proposed to be installed) in the studied area in correlation with the expected Wildfire Risk Hazard for current reference period (A) and projections for near future (B).

risk or above. Based on the near future projections (**Figure 7(B)**), the areas with higher risk are significantly more. Therefore, more installed or proposed to be installed projects, can be affected by Wildfires during this period.

5.3. Summary and Further Examination

The research findings presented here contribute significantly to environmental management, ecosystem protection, and sustainable development. By integrating multi-criteria analysis (MCA) within a GIS framework, our understanding of wildfire risk and its implications can be improved. Regarding Multi-Criteria Analysis (MCA):

1) Instead of relying on a single factor, our approach integrates diverse aspects, including geomorphological, social, and ecological factors.

2) MCA allows us to weigh and prioritize factors based on their relevance, such as geomorphological, social and ecological factors.

3) The goal is to create a comprehensive assessment that considers the multidimensional nature of wildfire risk.

Moreover, unlike traditional methods that rely on separate climatic conditions (temperature, wind etc.), this research employs the Fire Weather Index (FWI).

The FWI integrates weather variables (temperature, humidity, wind speed) into a single metric. This simplifies the model and ensures adaptability across different environments.

The Wildfire Hazard Risk model presented here can significantly assist on:

1) Ecosystem Protection since can identify high-risk areas which help to prioritize conservation efforts. Consequently, preserving biodiversity and sensitive habitats becomes more effective.

2) Infrastructure Resilience since mapping wildfire-prone zones, can aid in spatial development of solar farms, wind parks, and other renewable energy installations.

3) The link between academia research and industrial infrastructure presented here can improve disaster risk reduction and community well-being. Stakeholders include local government, companies, residents etc.

In summary, multi-criteria wildfire risk hazard assessment in a GIS environment is pivotal for safeguarding communities, ecosystems, and infrastructure. By bridging research and practical applications, we contribute to a more resilient and sustainable future.

The proposed methodology is based on ten major factors which have been considered for the final outcome. Possible alternative methodologies that could offer new insights or more robust answers to the research question include but not limited to:

The usage of separate climatic factors, both for the current and the future reference, instead the use of FWI which has been used here;

The implementation of additional factors such as the curvature of the examined area etc.

More detailed results can be extracted if the vegetation of the examined area will be mapped.

It has to be mentioned though that the above propositions may offer a more robust and accurate result but have a significant drawback since the proposed model will be more complex and time-consuming.

6. Conclusion

It is undeniable that Wildfires is one of the major threats for the environment and the human well-being and a new model that includes climate change impacts is required. Here, based on ten different criteria that influence the behaviour of Wildfires, a model is proposed to estimate the Wildfire Risk Hazard in the region of Epirus in Greece for the current conditions, the near future and the far future. The model clearly suggests that the risk is expected to be increased in several areas while more areas will be characterised by Significant Wildfire Risk Hazard based on current climate change projections.

This model is expected to identify potential wildfire risk hazards for infrastructure projects but also to identify the raised risk of wildfire risk hazards in areas that RES projects and battery storage areas are proposed to be installed. Researchers understand that areas that provide the lowest risk and thus better potential for vulnerable and sustainable infrastructure are the essential key for spatial development of the RES projects in the area.

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No life science threat was practiced in this research.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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