The importance of Earth Observation for monitoring cultural heritage sites affected by fire events: The Case Study of Arakapas, Cyprus using Sentinel 2 data

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ABSTRACT:

This paper presents the importance of using Earth observation to assess the impact of fire events on monitoring cultural heritage sites. The use of sensors such as Sentinel 2 can detect burnt areas in order to determine the extent of fire events on cultural heritage sites, using the fire event in Arakapas, Cyprus as a case study. Sentinel-2 is a multispectral optical sensor acquiring information in a range extending from the visible up to the short-wave infrared, which is the most sensitive spectral range for the detection of damages caused by fire. Sentinel-2 can support cultural heritage monitoring and assessment allowing rapid revisit of any site of interest using pre- and post-event images, where burned areas can be detected with change detection techniques coupled with suitable, spectral indices. Such derived products assist in quickly raising awareness on the endangerment of cultural and natural heritage sites and landscapes, emphasising the importance of Earth observation data for monitoring natural hazards for the protection of valuable cultural heritage sites.

1. INTRODUCTION

Forest fires have significant impact on both natural and anthropogenic ecosystems. Fire is an integral part of many ecosystems; however, in recent decades, there has been a significant increase in the Mediterranean area in the number of fires and the extent of the surface burned because of its distinctive climate and vegetation features. (Chergui et al., 2018). Wildland fire is a major and potentially catastrophic disturbance affecting ecosystems and their interface with urban areas, which results in loss of property, deaths, and significant environmental degradation.

Earth observation and remote sensing are a valuable and effective tool which includes a large number of systems that focus on using data from spectroradiometers, satellites, airborne and UAV platforms using visible, near and thermal infrared, microwave and other wavelengths (Santos et al., 2021). Such tools can be effectively used for fire prevention projects, assessment and monitoring purposes, as well as detecting areas affected by wildfires, estimating fire severity and burnt severity/ratio (GÜLCİ et al., 2021; Hu et al., 2021). The Sentinel 2 satellite has been used in several studies to detect burnt areas in order to determine the location and extent of fire events and to monitor environmental recovery (GÜLCİ et al., 2021; Hu et al., 2021; Pádua et al., 2020; Schroeder et al., 2016). According to the wider literature (Morresi et al., 2022) (Dindaroglu et al., 2021) (Zidane et al., 2021)(Abdikan et al., 2022) (Luo and Wu, 2022) (Putra et al., 2022)(Saulino et al., 2020), the analysis of the damage that an area suffers after a fire can be investigated using spectral indices. The most widely used index for mapping the forest fire disturbance is the Normalised Burn Ratio (NBR) (García and Caselles, 1991; Key and Benson, 2006)

The majority of cultural heritage and archaeological sites, especially in the Mediterranean region, are covered with vegetation - increasing the risk of fires – and are located near to forest regions or in abandoned areas covered with vegetation (Grammalidis et al., 2011). Several factors contribute to the increased risk of forest fires, such as prolonged drought, hot summers, strong winds, large slopes of forests and flammable dry vegetation (Prodromou et al, 2022), which have resulted in a dramatic increase in the number of wildfires in many forested areas that have become disastrous for many cultural heritage sites.

The use of Earth Observation (EO) data and remote sensing techniques has been successfully utilize for several archaeological applications, mostly for the systematic detection of CH sites (Cerra et al., 2016) as well for the Cultural Heritage Disaster Risk Management (Agapiou et al., 2020). A recent study by (Themistocleous, 2023) was focus on the monitoring cultural heritage sites affected by geohazards in Cyprus using earth observation based on the development of long-term low-impact monitoring systems as well as indirect analysis of environmental contexts to investigate changes and decay of structure, material and landscape. Also,(Cerra and Plank, 2020) in their study shows a comprehensive case of study for damage detection and monitoring in time through a series of satellite images acquired over the city of Palmyra, Syria, which suffered huge losses related to its cultural heritage in a time span longer than a year.

In this paper, a first assessment for the case of the Arakapas fire in Cyprus is presented. The fire event began on Saturday, the 3rd of July 2021 in the Limassol district near the village of Arakapas and was controlled after approximately 24 hours. The area affected by the fire is designated as an area of special aesthetic value of the Troodos Mountain range and is included in the Troodos UNESCO global geo-park. According to the Department of Antiquities, there were 13 cultural heritage sites in the extended region of the fire. Indeed, several churches of significant cultural value were in danger, as they were located close to the fire.

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2. METHODOLOGY

2.1 Study Area

The fire event began on Saturday, the 3rd of July 2021 in the Limassol district near the village of Arakapas in Cyprus and was finally controlled after less than 24 hours. Cyprus is located in Eastern Mediterranean, which is an area where forest fires frequently occur, especially during the summer period. Forest fires are considered as a major and persistent threat for the forests of Cyprus. Cyprus has an increased risk of forest fires especially during the summer period, because of the high temperatures, the prolonged drought periods, the strong winds, the configuration of the ground and the extremely flammable vegetation.

The area affected by the fire is designated as an area of special aesthetic value of the Troodos Mountain range to the Southwest Shores and is included in the Troodos UNESCO global geo-park, which characterizes it as a natural heritage landscape.

The cultural heritage buildings and monuments located in the fire-affected areas comprise churches, ancient settlements as well as water and olive mills. According to the Department of Antiquities, there are 22 cultural heritage sites in the extended region of the fire which the point of them are presented in Figure 1 and some of them are accompanied with their photo and the names of them are presented on the Table 1. Although the flames reached very close to some monuments, fortunately no monuments were damaged by fire.

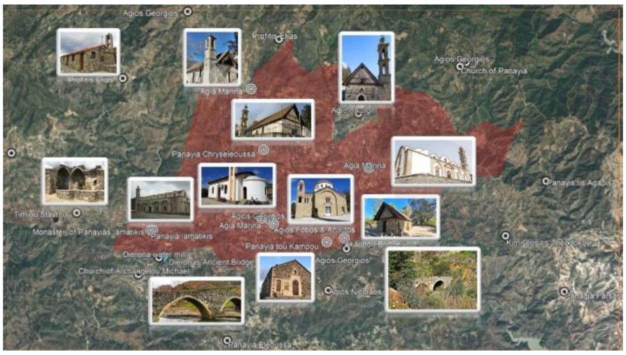

Figure 1 The 22 cultural heritage sites in the extended region of the fire event.

Table 1 The names of the CH sites near to the burned area

CH site - Village
Agia Marina - Eptagoneia
Agia Marina - Odou
Agia Marina - Ora
Agie Anargiri - Agioi Vavatsinias
Agios Fotios & Anikitos - Eptagoneia
Agios Georgios - Akapnou
Agios Georgios - Eptagoneia
Agios Georgios - Vavatsinia
Agios Nicolaos - Klonari
Akapnou Bridge - Akapnou
Church of Archangelou Michael - Dierona
Church of Panayia - Vavatsinia
Dierona water mill - Dierona
Kimiseos tis Theodokou - Lageia
Monasteri of Panayias Iamatikis - Arakapas
Panayia Chryseleoussa - Melini
Panayia Iamatikis - Arakapas
Panayia tou Kampou - Akapnou
Panayis tis Agapis - Vavla
Profitis Elias - Odou
Profitis Elias - Sykopetra
Timiou Stavrou - Arakapas

2.2 Materials and Methods

The image processing was performed using custom scripts in the Google Earth Engine (GEE) platform using the JavaScript programming interface and the spatial analysis was performed using the ArcGIS Pro. The GEE is a planetary-scale platform for scientific analysis and visualization of geospatial datasets. In this platform, the open-source images acquired by several satellites, including Sentinel-2, Landsat-7, and Landsat-8 etc are accessible and can be efficiently imported and processed in the cloud without the necessity of downloading the data to local computers. Moreover, several image-driven products and many remote sensing algorithms, including classification algorithms and cloud masking methods, are available in this platform (Gorelick et al, 2017; Kumar & Mutanga 2018). In the GEE, the Sentinel-2 SR data which are orthorectified atmospherically corrected (surface reflectance) can be directly called.

The Sentinel-2 satellite images were selected due to the free access and the highest resolution compared to other free access data such as MODIS and Landsat satellite images. The S2 satellite's MSI (Multi-Spectral Instrument) sensor has 13 spectral bands with 10–60 m spatial resolution.

The Sentinel-2 collection in reflectance was filtered according to cloud cover, time interval, and region. Specifically, for the estimation of the fire severity, two Sentinel-2 images taken prior the fire event (2/7/2021) as shown in Figure 2 and after the fire event (27/7/2021) as shown in Figure 3 the fire incident were used due to the fact that were cloud-free and the dates were close to the fire event.

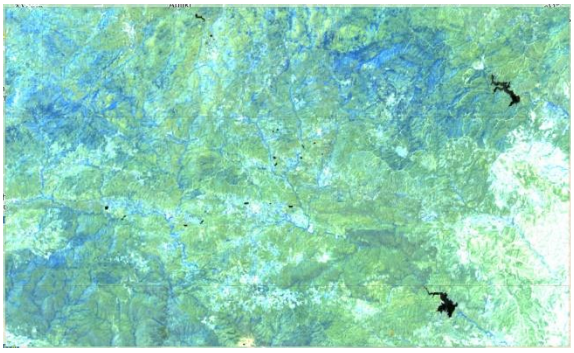

Figure 2 Sentinel-2 pseudo-color imagery (B12, B11 and B8) before the fire event 2/7/2021

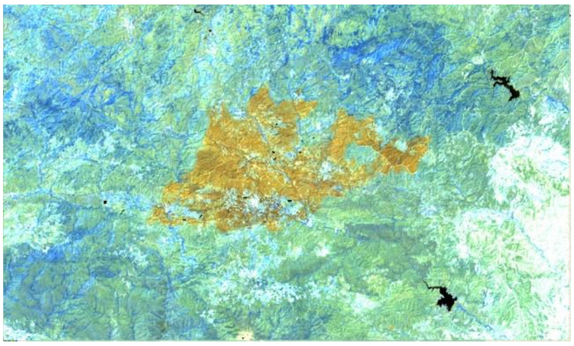

Figure 3 Sentinel-2 pseudo-color imagery (B12, B11 and B8) after the fire event 27/7/2021.

To explore and compare the spectral signal between pre- and post-fire images the reflectance values of B8 and B12 were extracted and used to create the histogram data plots for each spectral band, for each image for our study area as shown in Figure 4 and Figure 5. The histogram in green corresponds to the pre-fire satellite imagery and depicts the spectral signal of burned surfaces in B8 and B12, while the histogram in blue corresponds to the post-fire satellite imagery. Figure 4 and Figure 5 compares the histogram data plots of B8 and B12 for pre- and post-fire imagery respectively and shows that the distribution of the reflectance values of the used bands for the calculation of the dNBR spectral index is almost identical, as shown in the histograms which present a relevant overlap.

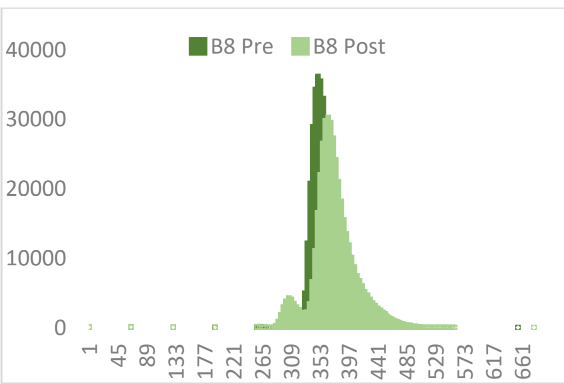

Figure 4 Histogram data plot for B8 before and after the fire event. The units on y-axes the frequency of the pixel values and the x-axis the pixel value of the reflectance scaled in 1e4.

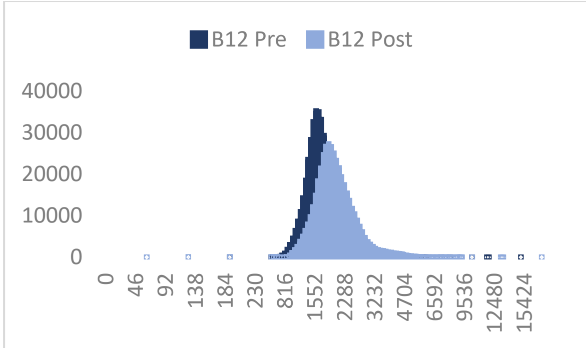

Figure 5 Histogram data plot for B12 before and after the fire event. The units on y-axes the frequency of the pixel values and the x-axis the pixel value of the reflectance scaled in 1e4.

Additionally, a cloud-masking technique relying on the assessment of the quality of each sensor's pixel was applied to minimize the chance of clouds in the analyzed region, even though images free of clouds were already selected. In this study, the Normalized Burn Ratio (NBR) indices were estimated before and after the fire event in order to estimate the burn severity using the difference of the NBR (dNBR). The Normalised Burn Ratio (NBR) was selected because is the most widely used index for mapping the forest fire disturbance and for detecting fire scars is the (García and Caselles, 1991; Key and Benson, 2006) which is given by the ratio of the difference between the near-infrared (NIR) and short-wave infrared (SWIR) bands of electromagnetic radiation and the sum of NIR and SWIR, where the NIR and SWIR refers to band 8 and band 12 of the Sentinel-2 data, respectively. The NBR spectral index takes values from -1 to +1 where the low values represent bare ground and recently burnt areas and the high values represents healthy or unburned vegetation. Also, the differenced Normalised Burn Ratio (dNBR) which is calculated by the difference of the NBR before and after the fire is an effective method for measuring burnt severity in various plant species. The low values of dNBR index refer to less burnt severity and unburned areas in contrast with high values which indicate severe damage Key & Benson (2006). The NBR and dNBR spectral indices obtained by the equations (1) and (2) respectively.

$$NBR = \frac{\mathrm{NIR-SWIR}}{\mathrm{NIR+SWIR}} \tag{1}$$

$$dNBR = NBR_{preFire} - NBR_{postFire} \tag{2}$$

Where:

NIR: near-infrared
SWIR: short-wave infrared

Moreover, in order to identify the Cultural Heritage (CH) sites that were at risk of being destroyed by fire, we considered the spatial overlap between the dNBR map derived from the Sentinel-2 satellite data and the cultural heritage sites. The CH sites were acquired from data.gov.cy, which is the central information portal of the public sector which provides access to datasets of all Cypriot government. Also, the nearest distance from each severity class was estimated in order to identify the riskiest CH site.

3. RESULTS AND DISCUSSION

The area affected by the fire was identified by the differenced Normalized Burn Ratio (dNBR) index based on Sentinel-2 satellite data where the pixel values were classified based on the thresholding technique according to the severity levels Table 2proposed by the (Key and Benson, 2006). The total burned area derived from Sentinel-2 data based on dNBR was 44,25Km2. For each fire severity class, the total area has been estimated and presented in Table 2.

Table 2: Fire severity classes and the burned area per class

Severity level	dNBR range (scaled by 1000)	Area (Km^2)
Enhanced Regrowth, High	-500 to -251	0.08726
Enhanced Regrowth, Low	-250 to -101	0.51229
Unburned	-100 to +99	387.32837
Low	+100 to +269	9.86474
Moderate-Low	+270 to +439	17.6953
Moderate-High	+440 to +659	15.72674
High	+660 to +1300	0.96959

The map regarding the spatial distribution of the dNBR based on the abovementioned thresholds, for the fire event in Arakapas village in Cyprus, is shown in the Figure 6.

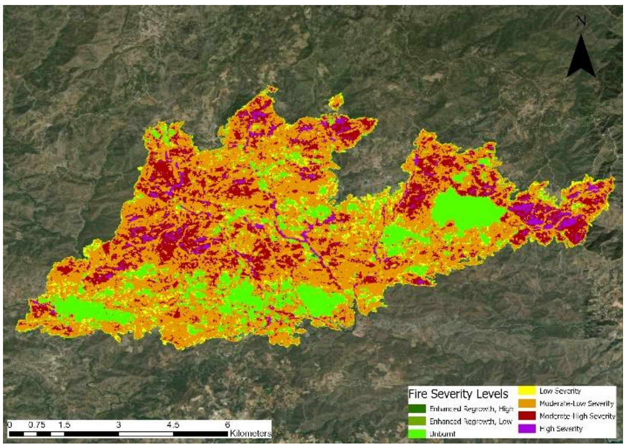

Figure 6 Map of the differenced Normalized Burn Ratio for the study area.

A total of ten villages was evacuated because of the fire: Ora, Eptagoneia, Melini, Odou, Agioi Vavatsinias, Arakapas, Vavatsinia, Akapnou, Lageia and Dierona. Furthermore, based Corine Land Cover 2018 provided by Copernicus Land Service Figure 7, in this area, the vegetation is characterized by shrubs and other types of Mediterranean vegetation, pines and olive trees.

The estimation of total burned area and the fire severity shown that the process can be done rapidly thanks to the power of the Google Earth Engine.

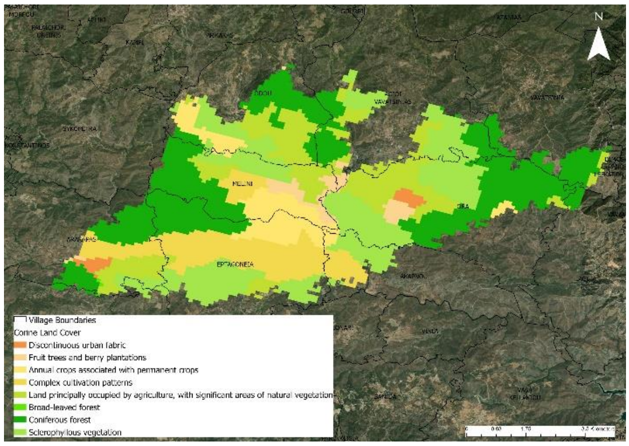

Figure 7 Vegetation type based on Corine land Cover data (2018)

In order to define and geographically locate cultural heritage assets with which to perform the assessment, we used https://www.data.gov.cy/ , that is the central information portal of the public sector which provides access to datasets of all Cypriot government.

Based on a 3Km buffer zone out of the burned area as shown in Figure 8, there are 22 cultural heritage sites inside and outside of the burned area. The list of cultural heritage sites potentially affected by the fire event in July 2021 near to Arakapas village was obtained by performing a spatial overlap between the dNBR map derived from the Sentinel-2 satellite data and the cultural heritage sites as shown in Table 3. The points which are overlapping with the burned area maps were selected.

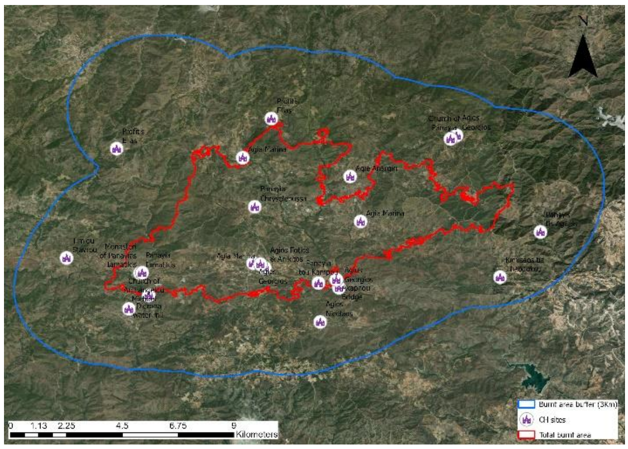

Figure 8 3Km buffer zone around the burnt area- and the included CH sites

Despite the great destruction that occurred in the area of Arakapa, which burned approximately ~42 Km^2, the 22 points of interest fall into the "unburned" according to the Figure 9 and the dNBR pixel values.

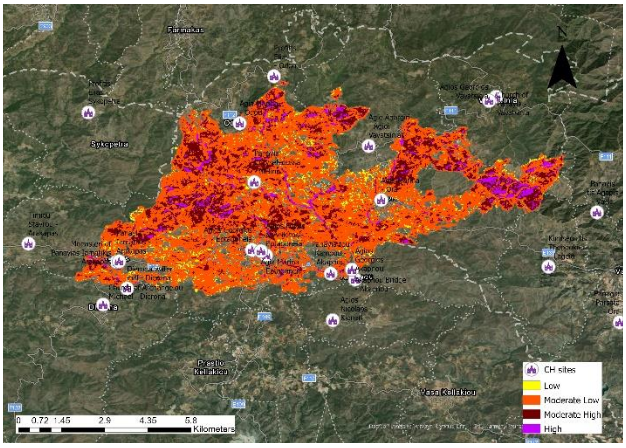

Figure 9 Map of the differenced Normalized Burn Ratio and the distribution of cultural heritage sites

Table 3 CH sites and the average distance from the burned area

CH site - Village	Average Distance from the Burned area (Km)
Agios Georgios - Eptagoneia	0.16
Agios Fotios & Anikitos - Eptagoneia	0.18
Panayia tou Kampou - Akapnou	0.23
Agia Marina - Eptagoneia	0.23
Profitis Elias - Odou	0.25
Agia Marina - Odou	0.29
Panayia Iamatikis - Arakapas	0.30
Monasteri of Panayias Iamatikis - Arakapas	0.31
Dierona water mill - Dierona	0.38
Akapnou Bridge - Akapnou	0.48
Agie Anargiri - Agioi Vavatsinias	0.52
Panayia Chryseleoussa - Melini	0.62
Agia Marina - Ora	0.64
Agios Georgios - Akapnou	0.67
Church of Archangelou Michael - Dierona	0.96
Timiou Stavrou - Arakapas	0.96
Church of Panayia - Vavatsinia	1.09
Agios Georgios - Vavatsinia	1.31
Agios Nicolaos - Klonari	1.38
Panayis tis Agapis - Vavla	1.73
Kimiseos tis Theodokou - Lageia	1.91
Profitis Elias - Sykopetra	2.56

Also buffers zones for CH site were created at 0,5Km, 1Km and 2Km in order to identify the nearest severity classes an example for the buffer zones was presented in the Figure 10.

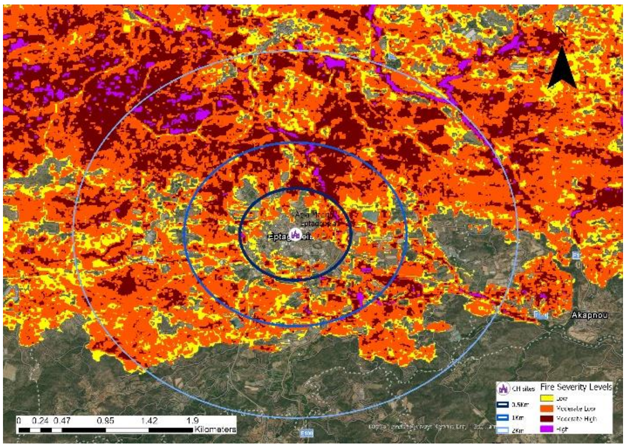

Figure 10 An example at Agia Marina (Eptagoneia) for buffer zones in 0.5Km, 1Km and 2Km for the identification of the neighbour severity classes.

Furthermore, in APPENDIX the Figure 11 presents the nearest distance from each severity class by CH site. Based on the CH site's average distance from the total burned area in the range of the 0 to 0,5Km radius the nearest CH sites which has the highest risk to be destroyed were the Agios Georgios – Eptagoneia (0,16Km), Agios Fotios & Anikitos – Eptagoneia (0,18Km), Panayia tou Kampou – Akapnou (0.23Km), Agia Marina – Eptagoneia (0.23Km), Profitis Elias – Odou (0.25Km), Agia Marina – Odou (0.29Km), Panayia Iamatikis – Arakapas (0.30Km), Monastery of Panayias Iamatikis – Arakapas (0.31Km), Dierona water mill – Dierona (0.38Km), Akapnou Bridge – Akapnou (0.48Km), Agie Anargiri - Agioi Vavatsinias (0.52Km). Furthermore, in the range of 0.5 to 1Km radius included the Panayia Chryseleoussa- Melini (0.62Km), Agia Marina – Ora (0.64 Km), Agios Georgios – Akapnou (0.67Km), Church of Archangelou Michael – Dierona (0.96 Km), Timiou Stavrou – Arakapas (0.96Km) and in the radius of the 1 to 2Km included the Church of Panayia – Vavatsinia (1.09 Km), Agios Georgios – Vavatsinia (1.31Km), Agios Nicolaos – Klonari (1.38Km), Panayis tis Agapis – Vavla (1.73Km), Kimiseos tis Theodokou – Lageia (1.91Km) and Profitis Elias – Sykopetra (2.56Km). In the range of 1 to2Km based on the distance values the CH sites are nearest to the lower severity classes and are further away from the higher severity classes.
This approach shows the risk of CH sites based on their proximity to the burned area as well as based on the degree of severity. In our future plans in order to have a more integrated estimation of the destruction risk of the CH sites, a risk map will be created which will combine other parameters, such as vegetation conditions (distribution, type, density), elevation and slope, soil moisture, fuel map, wind speed and direction statistics.

4. CONCLUSIONS

This paper provided the methodology of the monitoring and assessment of the fire event in Arakapas village. This study identified a set of potentially affected cultural heritage assets based on remote sensing techniques, using maps derived from Sentinel-2 satellite data in order to estimate the total burned area and the fire severity. The methodology was able to determine that the fire event occurred in an area with 22 cultural heritage sites, several of which were located near the site of the fire and in danger of being damaged. Decision-makers do not recognize heritage as a priority. The global Disaster Risk Reduction sector is currently not concerned with cultural heritage. To guide the decision-making process where safety and resource values are evaluated in terms of fire risk and appropriate fire management, response strategies are identified for wildland fires. There is a need to provide a framework for fire management strategies through the use of specific fire mitigation actions as well as a platform to cooperate more fully in planning and implementing wildland fire programs across the natural and cultural monuments. The proposed methodology shows very promising results for the assessment of fire severity and the estimation of the burned area to assess the impacts on the environment and especially the cultural heritage sites with a very quick way thanks to the computational power of the Google Earth Engine platform.

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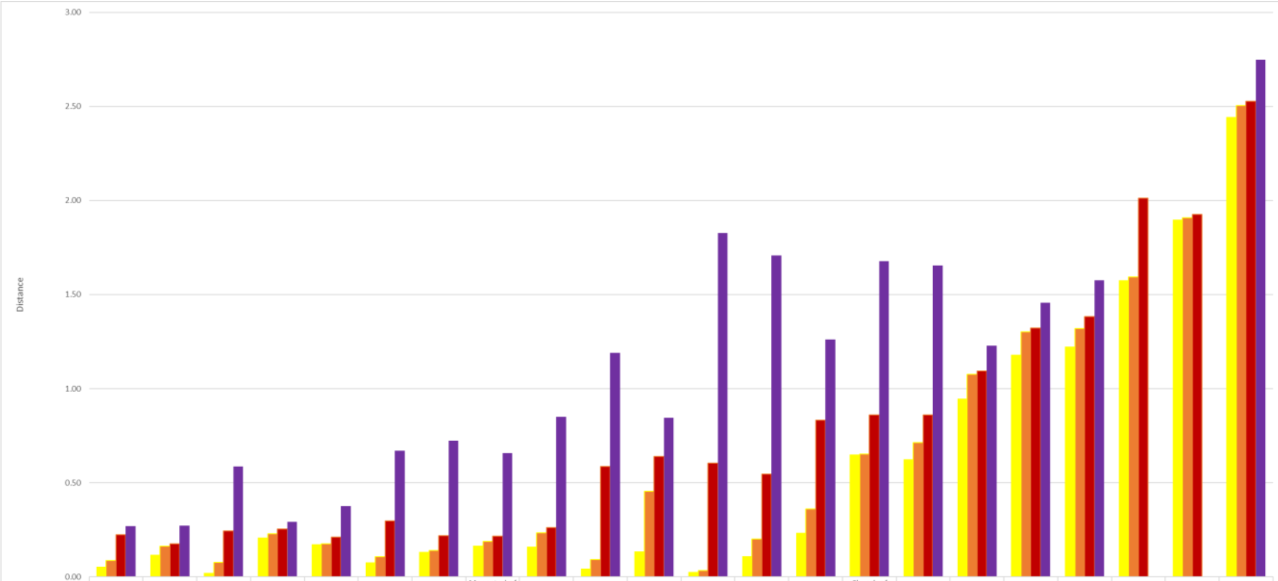
APPENDIX



	Agios Georgios - Eptagoneia	Agios Fotios & Anikitos - Eptagoneia	Panayia tou Kampou - Akapnou	Profitis Elias - Odou	Agia Marina - Eptagoneia	Agia Marina - Odou	Panayia Iamatikis - Arakapas	Monasteri of Panayias Iamatikis - Arakapas	Dierona water mill - Dierona	Akapnou Bridge - Akapnou
Low	0.05	0.12	0.02	0.21	0.17	0.08	0.13	0.16	0.16	0.04
Moderate-Low	0.09	0.16	0.08	0.23	0.17	0.11	0.14	0.19	0.23	0.09
Moderate-High	0.22	0.18	0.24	0.25	0.21	0.30	0.22	0.22	0.26	0.59
High	0.27	0.27	0.59	0.29	0.38	0.67	0.72	0.66	0.85	1.19

	Agie Anargiri - Agioi Vavatsinias	Panayia Chryseleoussa - Melini	Agia Marina - Ora	Agios Georgios - Akapnou	Church of Archangelou Michael - Dierona	Timiou Stavrou - Arakapas	Church of Panayia - Vavatsinia	Agios Georgios - Vavatsinia	Agios Nicolaos - Klonari	Panayis tis Agapis - Vavla	Kimiseos tis Theodokou - Lageia	Profitis Elias - Sykopetra
Low	0.14	0.03	0.11	0.23	0.65	0.62	0.95	1.18	1.22	1.58	1.90	2.44
Moderate-Low	0.46	0.03	0.20	0.36	0.65	0.71	1.08	1.30	1.32	1.59	1.91	2.50
Moderate-High	0.64	0.60	0.55	0.83	0.86	0.86	1.09	1.32	1.38	2.01	1.93	2.53
High	0.84	1.83	1.71	1.26	1.68	1.65	1.23	1.46	1.57			2.75

Figure 11 CH distance from the severity classes