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Executive Summary

This deliverable was conducted in the framework of Task 5.4, which is responsible to develop the data processing mechanisms (by connecting to third-party sources) and calculate important indices required by the intelligence modules of WP6.

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1. Introduction

Remote Sensing is the science that studies the physical characteristics of a phenomenon or an object without coming into physical contact via remote sensors on satellites and aircraft. It is a geophysical technology that is based on measuring the emitted and reflected electromagnetic radiation from the Earth's ecosystems (terrain, atmosphere, and water)[1]. According to the literature Remote Sensing techniques are being widely used in a large number of applications for research and monitoring such as in agriculture, forestry, geology, hydrology, land cover/land use, oceans and coastal monitoring, natural hazards, urban, safety, atmosphere, energy and many other topics and there are available observations since the 1980 [2]. Concerning the monitoring of wildfires, remote sensing is a valuable tool which includes a large range of systems that focus on using data from spectroradiometers, satellites, airborne and UAV platforms using visible, near and thermal infrared, microwave and other wavebands [3]. Specifically, the remote sensing provides the ability to produce biophysical measurements of ground conditions which are useful in several applications including the active fire detection, fuel mapping, burned area estimation, fire risk prediction, burn severity, and for the vegetation recovery monitoring [4].

This deliverable was conducted through the Task 5.4 entitled *Image Data Processing and Indices Calculation*, which aims to develop the data processing mechanisms by connecting to third-party sources and calculate important indices required by the intelligence modules of WP6**.** Specifically, in WP6 the remote sensing data, which is collected and processed through Task 5.4, will support the implementation of *Task 6.1 Fire Prevention, Detection & Reaction Module* and *Task 6.2 Detection of Illegal Logging and Hunting Module***.** Furthermore, a major part of *Task 6.3 Afforestation/Reforestation Recommendation Module* will be based on Remote Sensing data.

Section 2: Data Sources and Acquisition presents the data that according to the literature can contribute to the modules which will be developed in WP6. It’s highlighted that from these datasets we did some trials and after our analysis we chose the datasets that provide better results for the development of the modules. An expanded analysis of the selected datasets is given in the corresponding deliverable for each module.

2. Data Sources and Acquisition

2.1 Satellite data acquisition

The calculation of spectral indices was conducted using the Sentinel-1 and Sentinel-2 data due to their better spatial and temporal resolution. The description for each satellite sensor is presented below.

2.1.1 Sentinel-1

The Sentinel-1 mission is a European SAR satellite, which comprises a constellation of two polar-orbiting satellites (Sentinel-1A and -1B). Also is use a single C-band Synthetic Aperture Radar (SAR) sensor which can penetrate clouds; with a spatial resolution of 10, 25, or 40 m and a temporal resolution of 6–12 days at a central frequency of 5.405 GHz **Table *1***. Furthermore, these satellites are enabled to acquire data in four modes: strip map (SM), Interferometric Wide swath (IW), Extra-Wide swath (EW), and Wave mode (WV) [59,60].

Table 1 - Central Frequency and spatial resolution for Sentinel-1 bands.

Sentinel-1		
Band	**Central Frequency (GHz)**	**Resolution (m)**
VV	5.405	10
VH		

2.1.2 Sentinel-2

The Sentinel-2 mission is also launched by ESA and is an optical platform equipped with a multi-spectral instrument which includes two satellites (Sentinel-2A and Sentinel-2B). Furthermore, this mission enables us to acquire data in 13 spectral bands were presented in ***Table 2*****Error! Reference source not found.** in different spatial resolution (10m, 20m and 60m) every 5 days on average [5], [6]. The Sentinel-2A satellite was launched on 23 June 2015 and 2B on 7 March 2017.

Table 2 - Spatial resolution and central wavelength for Sentinel-2 bands.

Sentinel-2 MSI		
Band	**Wavelength(mm)**	**Resolution (m)**
1 Coastal aerosol	433-453	60
2 Blue (B)	458-523	10
3 Green (G)	543-578	10
4 Red (R)	650-680	10
5 Red edge 1 (RE1)	698-713	20
6 Red edge 2 (RE2)	733-748	20
7 Red edge 3 (RE3)	773-793	20
8 Near Infrared (NIR)	785-900	10
8a Near Infrared narrow (NIRn)	855-875	20
9 Water vapour	935-955	60
10 Shortwave infrared / cirrus	1360-1390	60

11 Shortwave infrared 1 (SWIR1)	1565-1655	20
12 Shortwave infrared 2 (SWIR2)	2100-2280	20

2.2 Terrain

The DEM for the purposes of this study was retrieved from EU-DEM, which is provided by the Copernicus Program. This product is a hybrid one, based on SRTM and ASTER GDEM data fused by a weighted averaging approach with a spatial resolution at 25m (https://land.copernicus.eu/imagery-in-situ/eu-dem). DEM was used to obtain the elevation, slope, and aspect **Figure *1***. These topographic features were selected because they are widely recognized as key variables that are closely linked to fire-related phenomena. Aspect: a key factor in igniting forest fires since it also plays a key role in the growth of vegetation types species. Elevation: DEM (Digital Elevation Model) used to create the relief of the area (altitude affects the climatic conditions and consequently the fire events.) Slope: Steep slopes lead to a greater rate of fire spread due to the convective ignition and pre-heating. It is also affected by water loss and more efficient convective preheating.

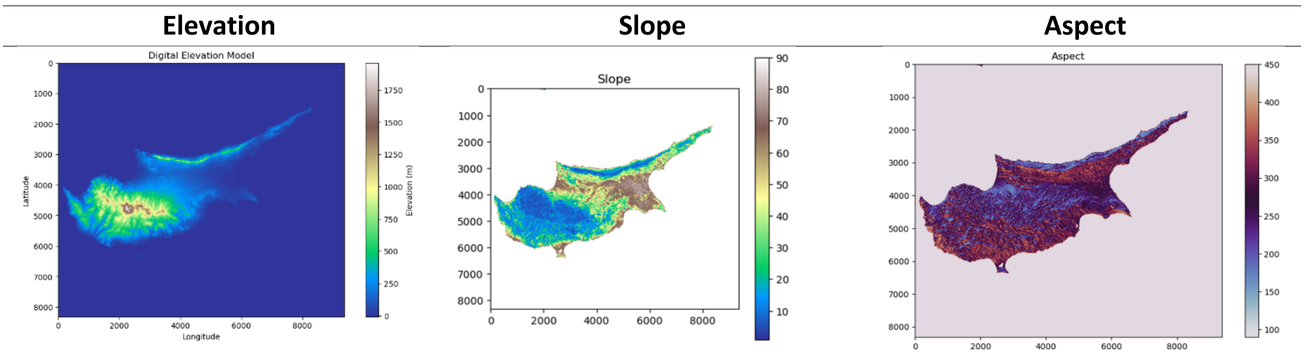

Figure 1 - Terrain characteristics derived from EU-DEM.

2.3 Land Cover

ESA WorldCover provides the first global land cover products for 2020 and 2021 at 10 m resolution. This data was developed and validated in near-real time based on Sentinel-1 and Sentinel-2 data. The land cover map contains 11 land cover classes and independently validated with a global overall accuracy of about 75%. The Corine Land Cover (https://land.copernicus.eu/pan-european/corine-land-cover), coordinated by the European Environment Agency, was also used.

2.4 Meteorological data

2.4.1 Precipitation - Ready Products

CHIRPS: Climate Hazards Group InfraRed Precipitation with Station data is a 30+ year quasi-global rainfall dataset. CHIRPS incorporates 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring.

2.4.2 Temperature - Ready Products

MODIS: The MOD11A1 V6.1 product provides daily land surface temperature (LST) and emissivity values in a 1200 x 1200 Km grid. The temperature value is derived from the MOD11_L2 swath product. Above 30 degrees latitude, some pixels may have multiple observations where the criteria for clear-sky are met. When this occurs, the pixel value is the average of all qualifying observations. Provided along with both the day-time and night-time surface temperature bands and their quality indicator layers are MODIS bands 31 and 32 and six observation layers.

2.5 Fire History

The burned areas were collected by EFFIS - European Forest Fire Information System, which supports the services in charge of the protection of forests against fires in the EU and neighbour countries and enriched with data from Forest Department in Cyprus. Specifically, EEFIS data provides the burned area perimeters which are produced from the daily processing of MODIS satellite imagery at 250 m ground spatial resolution and Sentinel-2 imagery at 20 m spatial resolution.

3. Data Processing and Analysis

3.1 Spectral Indices Calculation

Spectral indices are formulas that primarily focus on band ratios or feature scaling techniques such as normalized or standardized algorithms which rely on the combination of pixel values from two or more spectral bands. Their use relies on the sensitivity they offer in identifying certain features more effectively than individual spectral bands for spectral signature detection [7]. They are designed to highlight pixels in an image that shows a relative presence of a specific land cover as well as to emphasize the aspects of an ecosystem's functionality and they have contributed significantly to a more comprehensive understanding of environments and ecosystems in space and time [8], [9]. Depending on the type of platform utilized for acquired data, spectral indices are divided into two main categories airborne and satellite-based system indices. Focusing on passive satellite remote sensing the spectral indices can be subdivided to indices that utilize:

1. Simple ratio
2. Visible and near-infrared (VNIR) bands
3. Visible and red edge bands
4. Visible and mid-infrared bands
5. Visible and shortwave infrared (SWIR) bands [8]

Spectral indices were developed for several application domains. For the purposes of Green-HIT project were calculated spectral indices for vegetation condition, moisture and burned areas. In **Table *3*** were presented all the spectral indices were calculated in the framework of D5.4. We used the spectral indices because each index can provide additional information for our analysis, an example is the use of NDVI which is one of the most widely used vegetation index that highlights the condition of the vegetation [10] and the SAVI, which considers the terrain and in cases with low vegetation cover corrects the effects of soil brightness. For the water content of the leaves, we used the NDMI index which is based on the ratio of NIR and SWIR [11]. We used also the NDRE index which is based on the NDVI formula but uses Red Edge instead the Red [12]. About the spectral indices which were estimated using the Sentinel-1 data, the RVI was selected because is more beneficial for monitoring vegetation since is less affected by changes in environmental conditions like soil moisture [13]. The NDPI was also used because gives information for the surface roughness [14]. The formulas for the spectral indices were used in this study are presented at Table 3. It's highlighted that all indices ere normalized to take values from 0 to 1. The visualization of some of the indices is presented in Figure 2.

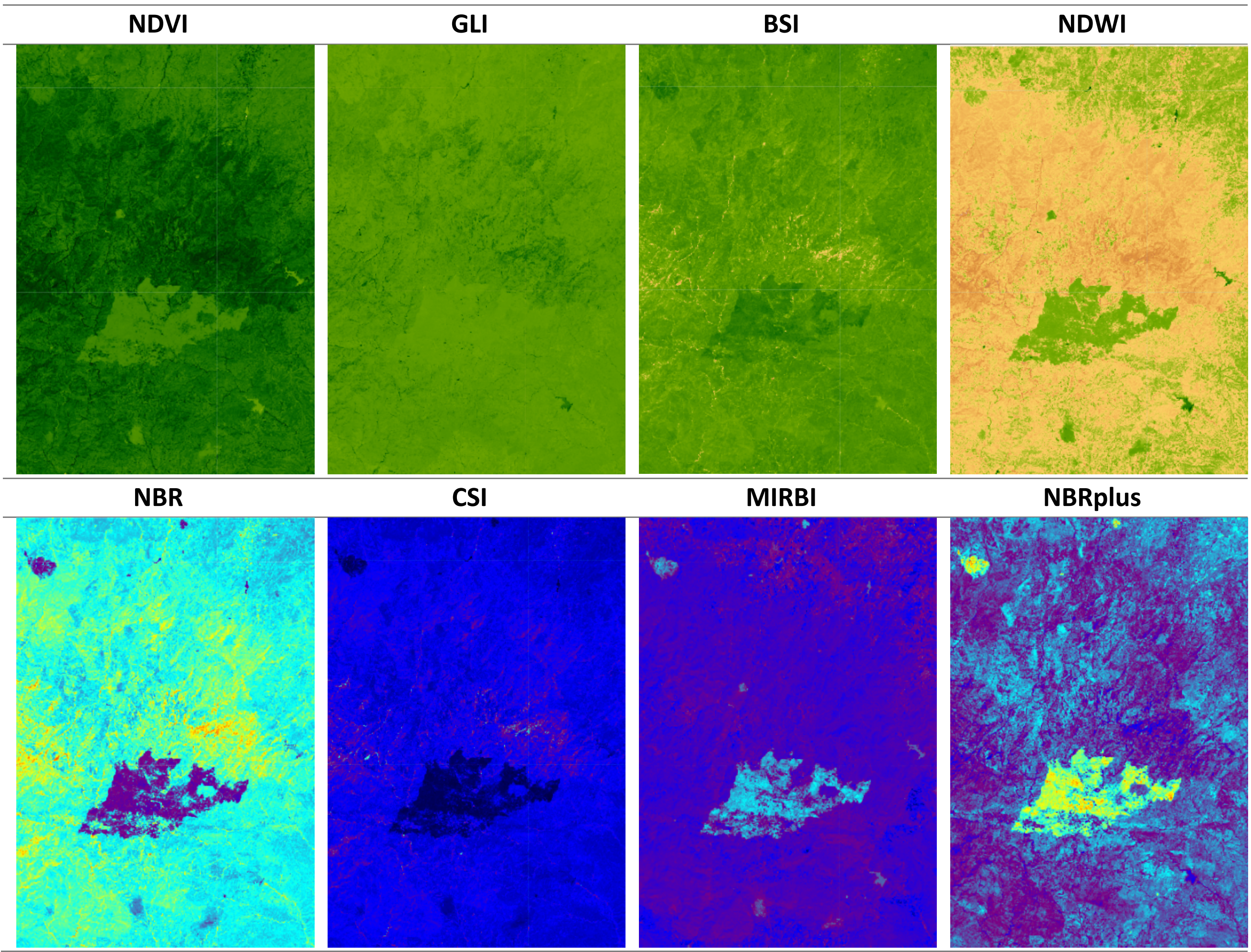

Figure 2 - Visualization of spectral indices.

The Normalised Burn Ratio (NBR) is the most widely used index for mapping the forest fire disturbance and for detecting fire scars [15], [16] 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. The NBRSWIR is similar with NBR index but in this case is utilized the SWIR1 and SWIR2 bands. Additionally, the formula incorporates two constants a subtraction of 0.02 which helps to to normalize the water changes near to zero or negative values, and an addition of 0.1 to avoid the unusual water changes [17]. The NBRplus is designed to consider the reflectance of water and can vary in a range between -1 and +1 where the burned areas are represented by higher values [18]. The BAI is designed to highlight burned areas, focusing on the charcoal spectral signature in post-fire images within the red to near-infrared spectrum. Specifically, the index is determined using the red to near-infrared spectrum. Specifically, the index is determined by calculating the spectral distance of each pixel in relation to a reference point as a result burned areas to represented by brighter pixels [20]. Furthermore, the BAIS2 is a modification of the BAI to suit the S2 bands including the visible, Red-edge, NIR and SWIR bands. Regarding the values of the BAIS2 are ranged from -1 to +1 for the identification of burn scars and from 1 to 6 in cases of active fires. The CSI is designed to detect the signals of black carbon to estimate the fire severity and is determined by the ratio of NIR and SWIR2 spectral bands[21]. The MIRBI index demonstrates significant effectiveness in distinguishing between burned and unburned areas [22].

Table 3 - Equations of Spectral indices

Satellite	Spectral Indices	Abbreviation	Equation	Ref.
S2	Normalized Difference Vegetation Index	NDVI	$\frac{NIR-RED}{NIR+RED}$	[10]
	Normalized Difference Red Edge Index	NDRE	$\frac{NIR-RED}{NIR+RED}$	[23]
	Enhanced Vegetation Index	EVI	$\frac{2.5(NIR-RED)}{NIR+6RED-7.5BLUE+1}$	[24]
	Green Leaf Index	GLI	$\frac{2*GREEN-RED-BLUE}{2*GREEN+RED+BLUE}$	[25]
	SAVI	SAVI	$\frac{1.5(NIR-RED)}{NIR+RED+0.5}$	
	Structure Insensitive Pigment Index	SIPI	$\frac{NIR-BLUE}{NIR-RED}$	[26]
	Atmospherically Resistant Vegetation Index	ARVI	$\frac{NIR-(2*RED)+BLUE}{NIR+(2*RED)+BLUE}$	[27]
	Bare Soil Index	BSI	$\frac{(SWIR1+RED)-(NIR+BLUE)}{(SWIR1+RED)+(NIR+BLUE)}$	[28]
	Normalized Difference Water Index	NDWI	$\frac{GREEN-NIR}{GREEN+NIR}$	[29]
	Advanced Vegetation Index	AVI	$\sqrt[3]{NIR*(1-RED)*(NIR-RED)}$	[30]
	Green Normalized Difference Vegetation Index	GNDVI	$\frac{NIR-GREEN}{NIR+GREEN}$	[23]
	Normalized Difference Moisture Index	NDMI	$\frac{SWIR-NIR}{SWIR+NIR}$	[11]
	Normalized Burn Ratio	NBR	$\frac{NIR-SWIR2}{NIR+SWIR2}$	[19]
	Burned Area Index	BAI	$\frac{1}{((0.1-RED)^2+(0.06-NIR)^2)}$	[20]
	Burned Area Index for Sentinel 2	BAIS2	$\left(1-\sqrt{\frac{RE2*RE3*NIRn-GREEN}{B4}}\right)*(\frac{SWIR2-NIRn}{\sqrt{SWIR2+NIRn}}+1)$	[31]
	Char Soil Index	CSI	$\frac{NIR}{SWIR2}$	[21]

	Mid-Infrared Burn Index	MIRBI	$10*SWIR2 - 9.8 * SWIR1 + 2$	[22]
	Normalized Burn Ratio SWIR	NBRSWIR	$\frac{SWIR2 - SWIR1 - 0.02}{SWIR2 + SWIR1 + 0.1}$	[17]
	Normalized Burn Ratio Plus	NBRplus	$\frac{SWIR2 - NIRn - GREEN - BLUE}{SWIR2 + NIRn + GREEN + BLUE}$	[18]
S1	Radar Vegetation Index	RVI	$\frac{4VH}{VH + VV}$	[32]
	Normalized Difference Polarization Index	NDPI	$\frac{VV - VH}{VV + VH}$	[33]

3.2 Revised Universal Soil Loss Equation (RUSLE)

The RUSLE model was developed for the estimation of soil erosion which is a major environmental problem. The RUSLE equation incorporates five different factors concerning rainfall (R), soil erodibility (K), slope length and steepness (LS), cover management (C) and support practice (P).

A = R*K*L*S*C*P

R: Rainfall R factor

K: Soil Erodibility

LS: Topographic Factor

P: Practise factor

C: Cover management factor

A detailed analysis will be provided to **D6.3 – Afforestation/Reforestation Recommendation Module.**

3.3 Analytic Hierarchy Process (AHP)

The multi-criteria analysis is a decision-making tool which helps in the environmental system analysis. Specifically assist in evaluating a problem by giving an order of preferences based on a range of criteria that might process different units as described by Carver 1991 [34]. The AHP is one of the widely used multi criteria decision -making method proposed by Saty el., 1977 [35]. Is a useful tool for decision-makers to the evaluation of various relative important elements utilizing pairwise comparison [36].

A detailed analysis will be provided to **D6.3 – Afforestation/Reforestation Recommendation Module.**

4. Conclusions

This Deliverable was conducted in the framework of Task 5.4. Through this task useful data were collected and some of the most widely used spectral indices were calculated, which are beneficial for the development of the tools that described in the WP6. The data collection primarily focused on data derived from third-party missions. It's highlighted that this data it will be tested and based on its performance, selected for the finalization of the corresponding tools. Furthermore, a script has been prepared to calculate these indices enabling the implementation of these indices in various locations across Cyprus and not only. This script, initially prepared for Sentinel-2 but is also compatible with other satellite data including Landsat and MODIS depending on their spectral characteristics.