Remote sensing and GIS combination to evaluate the ecosystems' conditions in "Serras do Porto"

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MSc

Todas as correções determinadas
pelo júri, e só essas, foram efetuadas.

O Presidente do Júri,

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Como resultado desta tese já foram divulgados alguns dados que resultaram nas seguintes publicações científicas:

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Resumo

As florestas são ecossistemas dinâmicos, complexos e multidimensionais, desempenhando um papel insubstituível no contexto social, económico, ambiental, ecológico e cultural. O eucalipto, *Eucalyptus* sp., é a espécie exótica mais comum nas florestas de Portugal, e é o recurso fundamental para a indústria de pasta de papel e celulose. No entanto, a sua utilização em grande escala potencia os seus efeitos sobre o ecossistema terrestre. O caso de estudo deste projeto decorreu nas "Serras do Porto", uma paisagem de extrema relevância para a Área Metropolitana do Porto. Durante décadas, esta área foi amplamente explorada com plantações de eucalipto para produção de celulose para a indústria do papel. Assim, devido às características geográficas da área e à sua extensão (≈ 40 hectares), o objetivo do presente estudo foi caraterizar a zona recorrendo ao uso dos Sistemas de Informação Geográfica e Deteção Remota. A análise dos resultados da combinação destas ferramentas permitiu a caracterização do relevo do terreno, nomeadamente a análise da altimetria, hipsometria, hidrografia, a criação de índices ambientais como o Índice de Vegetação por Diferença Normalizada, Índice de Vegetação Melhorada e o Índice de Água por Diferença Normalizada e o Modelo Digital de Terreno. Da análise do mapa do uso e coberto do solo foi possível avaliar o uso do solo e comprovar a heterogeneidade da zona onde o *Eucalipto* domina toda a área. Os mapas dos índices ambientais permitiram ainda identificar a distribuição da vegetação. Foram identificadas as zonas com maior densidade de vegetação e as zonas onde a vegetação tinha uma maior atividade fotossintética. O mapa de incêndio elaborado forneceu informações sobre o risco de incêndio da zona de estudo e foi possível perceber que as zonas com maior atividade fotossintética e maior densidade de cobertura vegetal apresentam um risco de fogo mais elevado. A combinação de dados de deteção remota com técnicas de sistemas de informação geográfica permitiu a avaliação das condições do ecossistema. Através da compreensão da atividade e distribuição da vegetação e do risco de incêndio foi possível perceber que as zonas com maior presença de eucalipto têm um maior risco de incêndio associado. A fusão destas técnicas poderá permitir no futuro uma análise mais completa e possivelmente, uma melhor compreensão da influência do eucalipto esta área.

Palavras-chave: SIG, Deteção Remota, NDVI, EVI, NDWI, Eucalipto, mapas

Abstract

Forests are dynamic, complex and multidimensional ecosystems and play an irreplaceable role in social, economic, environmental, ecological and cultural context. Eucalyptus is the most common exotic species in Portugal forests. This species is fundamental in the industries related to the pulp paper production and the concern about their effects in ecosystems is growing. The study case of this project was the municipal lands included in “Serras do Porto”. The study zone considered in this work is a landscape of extreme relevance to Porto Metropolitan Area. For decades this area was extensively explored with eucalyptus plantations in order to produce cellulose for paper industry. Due to the characteristics of the area and its extension (40 hectares) the use of geographic information systems became the most accurate and reliable alternative to characterize it. The combination of geographic information systems tools and Remote Sensing data allows the characterization of terrain relief, namely the analysis of altimetry, hypsometry, hydrography, the creation of environmental indexes such as Normalized Difference Vegetation Index, Enhanced Vegetation Index and Normalized Difference Water Index, and the Digital Elevation Model. In this project through the combination of geographic information systems and remote sensing it was possible to use a sentinel-2A image to identify the land use in the area and to characterize vegetation through the production of environmental indices. A forest fire risk map was also created for the study area. From the analysis of the land use map it was possible to study the land use and to verify the expected heterogeneity of the zone and that the Eucalyptus dominates the entire area. The environmental indexes maps allowed to identify the distribution of vegetation. The areas with the highest vegetation density and the areas where the vegetation had more photosynthetic activity were identified. The fire map provided information about the fire risk of the study area and it was possible to notice that the areas with more photosynthetic activity and higher density of vegetation cover had the highest values in the symbolic forest fire risk classes assigned to the zone. In conclusion, the combination of remote sensing data with geographic information systems techniques allowed the evaluation of ecosystem conditions. The analysis of photosynthetic activity, the distribution of vegetation and the forest fire risk, allowed to perceive that the zones with higher density of eucalyptus have a higher fire risk associated. This combination was useful in this study and in the future may allow a more complete analysis and perhaps a better understanding of the influence of eucalyptus in this area.

Keywords: GIS, remote sensing, NDVI, NDWI, EVI, eucalyptus, maps

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Abbreviation List

GIS – Geographic Information Systems

RS – Remote Sensing

QGIS – Quantum - GIS

OsGeo – Open Source Geospatial Foundation

GPL – General Public License

SAGA – System for Automated Geoscientific Analyses

SCP – Semi – automatic Classification Plugin

ESA – European Space Agency

MSI - Multi-Spectral Instrument

TOA - Top-Of-Atmosphere

UTM/WGS84 - Universal Transverse Mercator/World Geodetic System 1984

PDGS - Payload Data Ground Segment

GPS - Global Positioning System

LULC – Land Use Land Cover

NDVI - Normalized Difference Vegetation Index

EVI - Enhanced Vegetation Index

NDWI - Normalized Difference Water Index

DEM – Digital Elevation Model

TIN - Triangular Irregular Network

DOS1 - Dark Object Subtraction 1

LAI – Leaf Area Index

Introduction

Forests are fundamental for the stability and support of diverse ecosystems (Louro, 2015; Reboredo, 2014). They are important to keep the balance of geomorphological cycles being the main source for multiple ecosystem services. These ecosystems have multidisciplinary and multifunctional characteristics (Pereira et al. 2005; Madeira et al. 2007). In Portugal, as in many other countries, forests have an irreplaceable role in the social, economic, environmental, ecological and cultural context (Águas et al., 2014; Kling, 2012). However, almost all the Portuguese forests are a result of human intervention (Birot, 2004; Pereira et al., 2009). In fact, most of the forests in Portugal are considered cultivated forests and were evolutionarily altered by edaphic and climatic pressures and artificially shaped by environmental stress due to anthropogenic influence, being used for raw material to diverse economic activities (Mendes 2007; Pereira et al. 2009). The relationship between the Portuguese Government politics and the decisions of the different types of forests owners is responsible for the Portuguese forest areas constitution (Coelho, 2003; Radich and Baptista, 2005). In Portugal there are several types of forest resource owners: public owners, community owners, industrial owners and private non-industrial owners (Coelho, 2003). Radich and Baptista (2005) affirm that the evolution of the Portuguese forests is the result of the interaction and the conjugation of the interests and the strategies of management of the forest resources by the different owner's types. The management of resources is done according to the desired ecosystem services (Silva et al., 2009) and, in Portugal, the dominant type of owner is private, with about 84.2% of forest areas (Louro, 2015).

The eucalyptus is the most common exotic genus in Portuguese forests and the concern about its effects in ecosystems is growing in the last decades (Louro, 2015). According to the 6th National Forest Inventory, 26% of the Portuguese forests are formed by *Eucalyptus* sp. (ICNF, 2013). The eucalyptus is extensively used in one of the most important economic sectors in Portugal, which is the paper industry (Papajorgji and Pardalos, 2009; Reboredo, 2014). Nowadays, in Portugal the *Eucalyptus* species occurs in 812 mil ha and the tendency is increasing (Godinho-Ferreira et al., 2005; ICNF, 2013). The dominant species is the *Eucalyptus globulus* Labill. and it has attractive characteristics to economic activities. It is a species of long trunk and of straight format, with fast growth, great plasticity and adaptability to different places and climatic conditions. The distribution of eucalyptus in Portugal was in agreement with the ecophysiological needs of the species (Alves et al., 2007). This taxon is adapted to the Mediterranean regions with mild climate. Although it is a drought resistant species, it requires an average annual precipitation above 700 mm, and these conditions are more pronounced at north of the Tejo River (Pereira, 2007). The eucalyptus plantations were distributed according to these conditions and because of that the areas of the north coast have the highest proportion of eucalyptus occupancy. The geographic areas of Grande Porto, Entre Douro e Vouga, Baixo Vouga, Baixo Mondego, Pinhal interior Norte, Médio Tejo and Oeste together account for 40% of the total area of eucalyptus (Alves et al., 2007). Portugal is a special case in the European Union, the climatic, biological and ecological characteristics promote optimal conditions for the production and use of eucalyptus species with high industrial productivity (Papajorgji and Pardalos, 2009).

The productivity of eucalyptus is dependent of climatic factors, such as temperature, rainfall and edaphic factors Adequate plant growth, which is indispensable to productivity, depends on the assimilation of atmospheric carbon dioxide. Together with mineral salts and water will form the plant biomass (Pereira, 2007). Most of the eucalyptus forests are managed in an intensive way with a rotation regime of 10 to 12 years (Águas et al., 2014). At the beginning of forestry sector, the eucalyptus trees were planted on wastelands areas, however, with the evolution of society and the development of the forestry sector, other types of land use have been discontinued to give rise to these planted forests. Currently, areas that were previously associated with pasture, agriculture or pine forests, are being occupied by eucalyptus plantations. Portugal is the European Union country with the lowest percentage of public forest area, only 3% of the total forest area is managed by the Portuguese Government (ICNF, 2014). According to the update of the national strategy for forests, held in 2014, about 3,135 hectares of forest areas belong to private entities (ICNF, 2014). This means that the decisions taken in terms of land use are the responsibility of private entities and owners, although they need to comply with legal requirements (Canadas & Novais, 2014; Silva et al., 2007). Owners tend to opt for eucalyptus trees because they allow them to make profits in short periods of time (Soares et al. 2007). In addition, the frequent fires in national territory made the proprietors prefer species like *Eucalyptus* instead of the pine tree because eucalyptus forests have the capacity for rapid regeneration in cases of fire disturbance, being more compatible with fire regimes in Portugal (Reboredo, 2014).

It is known that the *Eucalyptus* has an impact on biodiversity, on soil conditions and influence the geomorphological cycles in the terrestrial ecosystems. The effects have their origin on ecophysiological needs of the eucalyptus trees and on the techniques and procedures of intensive exploitation. Changes in physical soil conditions arise from invasive mechanical practices in the soil. The aggressive practices of exploitation make the soil poorer and more vulnerable to erosive agents (Madeira et al., 2007). In addition, *Eucalyptus* produces allelopathic substances that preclude the seed germination of other species. The overused soil and the low floristic diversity and density affect the ecosystem's faunal communities, leading to a loss of biodiversity in the area (Onofre 2007; Fabião et al. 2007). Therefore, it is necessary to understand the impact and the influence of eucalyptus in the environment and biologic communities and create forest management plans of these areas.

The management of forests based on sustainability principles is fundamental whether in natural forests or in cultivated forests. Currently, the concept of sustainable forest management is the basis of forests and modern forestry practices (MCPFE, 2007). Forest management should be based on a multidisciplinary approach that considers forests areas an ecosystem and a support of other ecosystems. In addition, it is necessary that forest management and forest policies included the wide variety of dependent and independent elements of forests that produce economic and ecosystem feasible and services (Oliveira and Coelho, 2009). The industries related to the forests and products of forestry activities are growing and their importance in the European economy is increasingly important. For that reason, in 2013, The European Union elaborated a plan and a new Forestry Strategy for this type of activities and for forest management. This new plan is based on sustainable forestry exploitation practices and on ecosystem and economic level of a forest and should be applied in a national and global vision, without compromising any other ecosystem (Comissão Europeia, 2013; Reboredo, 2014).

In Portugal, the government orders are in agreement with the European norms and strategies. The National Forestry Strategies was developed and implemented according to commitments made by the Portuguese Government in the European Commission. Portugal has the commitment to implementing national policies towards sustainable forest management. Forest management practices should be made according to the national specific conditions and must be applied on locally. Besides the application of sustainable methods, it should be possible to monitor the progress of implementation, in order to be possible to identify the best practices (ICNF, 2014; Reboredo, 2014). In general, the supervision of forests should be based on the current concerns that represent our forest areas. The monitoring and evaluation of these areas should be based on recording and permanent creation of a sampling grid based on the incident points of the ICNF annual forest inventories. In these plots it should be possible to associate the representative components of biodiversity; collection of information on a regular basis at specific points with inventory records, encompassing parameters such as biomass and carbon sequestration; created areas burned maps areas and record fire occurrences (Tereso et al., 2011).

Nevertheless, assessing forest conditions and developing strategies for forest management is a complex procedure. Geographic Information Systems (GIS) provide useful tools and are commonly used in these studies (Arenas-Castro et al., 2018; Capelo et al., 2007; Pôças et al., 2014). GIS allows the manipulation, analysis, combination and generation of considerable amounts of environmental information in a short period of time (Teodoro and Duarte, 2012).Through GIS it is possible to accomplish ecological studies on different extension levels, with an accurate analysis of the environmental phenomena (ESRI, 2005). When GIS is combined with Remote Sensing (RS) data this process is optimized. Through RS data it is possible to understand the phenomena on a large scale, relating them to natural causes or connect them to anthropogenic activity. Comparatively to more conventional techniques of analysis and understanding of the phenomena, RS provides improved techniques for environmental studies (Lu et al., 2004). The advantages of this combination have already been described by several authors, through the creation of maps of the distribution of species, analysis of ecosystems and landscapes, change of climatic conditions and invasiveness issues (Rowlinson et al., 1999; Haltuch et al., 2000; Los et al., 2002). Thus, the association between RS data and GIS provides the creation of more assertive decision support plans. This association can be beneficial in assessing the conditions of an ecosystem and it is possible to assess, for instance, the land cover and the mapping of geological and biological resources (Reddy, 2008).

The main objective of this work was to characterize the ecosystem of an *Eucalyptus globulus* area in “Serras do Porto” using GIS and RS data to assess the conditions of land use, plant diversity and forest fire risk.

Methodology

Study site

The study case of this project was the municipal lands included in “Serras do Porto” and Valongo’s Natura 2000 network with an extension of 40 ha (Figure 1). It is located a few kilometers from Porto, Portugal. It is characterized by countless faunal and floristic values. For decades this area was extensively explored with plantations of eucalyptus in order to produce cellulose for paper industry. This study site it is inserted in a landscape of extreme relevance to Porto Metropolitan Area. It is characterized by a climate of Atlantic characteristics with Mediterranean influence. The mild temperatures, that occur most of the year, allow the existence of *Quercus suber* L. and improve the production of *Pinus pinaster* Aiton and *Eucalyptus globulus* Labill. The Mediterranean influence causes high summer temperatures and absence of precipitation, which enhances the existence of typically Mediterranean species as the *Arbutus unedo* L. and *Laurus nobilis* L. Although the area is inserted in a protected zone, a management plan for the areas dominated by eucalyptus is lacking. The eucalyptus dominates the majority of the area, and only exists a few small forests stands of other species. Besides that, invasive species begin to appear on the area, such as *Acacia melanoxilon* R. Br. in W. T. Aiton, *Acacia dealbata* Link., and *Hakea sericea* Schrad. & J.C. Wendl. The area is dominated by sharp slopes and most of the soil is poor and infertile (Câmara Municipal de Valongo, 2014). This study was conducted in a parcel abandoned by a pulp production company that explored this area with eucalyptus intensive plantation. The eucalyptus dominates the parcel which makes the area a homogeneous zone.

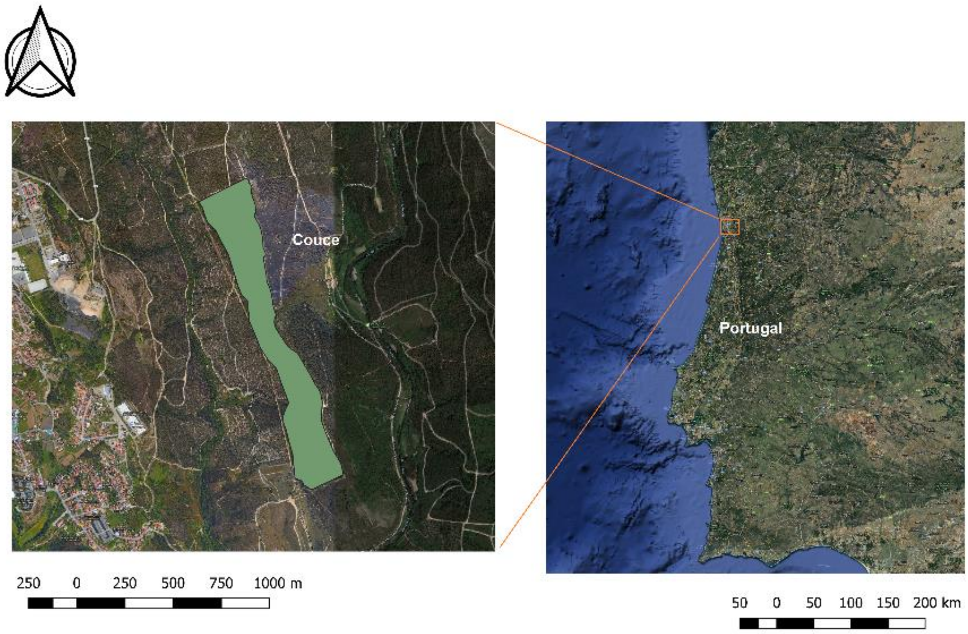

FIGURE 1 - AERIAL VIEW OF STUDY ZONE LOCATED IN "SERRA DA SANTA JUSTA", VALONGO, PORTO, PORTUGAL

Open source GIS software

QGIS is a free and open source GIS software desktop. It is owned by the Open Source Geospatial Foundation (OSGeo), an official project, licensed by GNU General Public License (GPL) (Steiniger and Bocher, 2009). Initially, this program was created for Linux users but now it is a multiplatform software, available in Windows, Mac OSX, Unix, Linux, and Android. Due to core functions and addable plugins added through Python language, this software provides a growing number of capacities. QGIS is developed in C++ programming language and has an integration with Python language, which allows adapt or automate GIS functions. In addition to the incorporation of Python, QGIS integrates a processing framework, Processing Toolbox, which allows the inclusion of external applications such as System for Automated Geoscientific Analyses (SAGA), Geographic Resources Analysis Support System (GRASS), Orfeo ToolBox (OTB) and other command-line applications that provide spatial data analysis functionalities (Teodoro and Duarte, 2013). Also, several image processing algorithms can be assessed using the QGIS Semi-Automatic Classification Plugin (SCP) (Congedo, 2016).

Data Acquisition

The Sentinel-2 mission was developed by European Space Agency (ESA) and it is included on the Copernicus environmental monitoring program (Fernández-Manso et. al 2016). Sentinel-2 is composed of two satellites with the same polar-orbiting with 180º of difference. Those satellites are Sentinel-2A, launched in June 2015, and the Sentinel-2B, launched in March 2017. Sentinel-2 is integrated with a Multi-Spectral Instrument (MSI) that produces images 2 (Wang et al., 2016). The Sentinel-2 constellation permits global coverage of the Earth's surface, every 5 days with a swath of 290 km. Sentinel-2A at level 1C images, radiometrically and geometrically corrected were used in this work (Top-Of-Atmosphere (TOA) product). Level-1C product is a 100 km x 100 km tile with a Universal Transverse Mercator/World Geodetic System 1984 (UTM/WGS84) projection (Skakun et al., 2017). Level 1C product was acquired by Sentinel-2A in November 2017 by the Earth Explorer website (https://earthexplorer.usgs.gov/) over title T29TNF during Relative Orbit 080 and processed with Payload Data Ground Segment (PDGS) Processing Baseline 02.06.

Processing steps

The field points were randomly collected through the study area using a Global Positioning System (GPS) Trimble receptor with 2 meters of planimetric accuracy. The points were collected according to the two classes predefined: bare soil and eucalyptus. Twenty-five points were collected to each class. 70% of the collected points were used to training, i.e. to obtain the Land Use Land Cover (LULC) training areas in SCP plugin. The remaining 30% were used for validation.

The Sentinel-2A image was used to produce the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), and Normalized Difference Water Index (NDWI), to generate the LULC map and Forest Fire Risk map. The LULC was produced on QGIS through the SCP Dock tool using the Sentinel-2A image. The generated LULC was then validated with field points collected in the study area with a GPS Trimble receptor. The training areas were created through Classification Dock and ROI tool and the two classes were identified according to the points collected. For this the Minimum Distance algorithm was used (Wacker and Landgrebe, 1972). The DEM (Digital Elevation Model) was created from quoted points and contour lines provided by city council of "Valongo" and the Interpolation tool from module Raster was used. The inputs were quoted points and contour lines and the elevation was used as an attribute for both. The DEM was created through Triangular Irregular Network (TIN). The cell size was defined as 10 meters in accordance with the spatial resolution of the Sentinel-2A image. The DEM was used to create the slope and the aspect map as an input to the algorithms of the processing tool box. The algorithm used to create the slope map was "r.slope- Generates raster maps of slope from an elevation raster map" and the algorithm used to create the aspect map was "r.slope- Generates raster maps of aspect from an elevation raster map".Both algorithms were included on Grass GIS 7. The forest fire risk map was based on mathematical equations between different data. The first setp was the creation of Hazard map. The Hazard map was generated through the multiplication of Probability map and Susceptibility Map. The Probability map was created based on the shapefiles with the burned areas between 2000 and 2017 (available on ICNF website). Those shapefiles were clipped to the study zone and all of them were rasterized. The Susceptibility map was the result of the multiplication of Slope map and land-cover information. The next sept was the creation of Potential loss map, which results from the mathematical product of Vulnerability Map and the Economic Value Map. The Vulnerability map contains the information about the vulnerability value of the elements at risk. The Economic Value map is composed by the information of the price of the land, in euros. The final step was the multiplication of Hazard Map and Potential Loss map, resulting in the Forest Fire Risk Map.

The pre-processing of Sentinel-2A image on SCP includes the following steps: atmospheric correction, a clip of the study area from the Sentinel image; and the creation of RGB composites (Congedo, 2016). The atmospheric correction was performed through the Dark Object Subtraction 1 (DOS1) method available SCP plugin (Congedo, 2016). The DOS1 method is an image-based atmospheric correction with the "basic assumption that within the image some pixels are in complete shadow and their radiances received at the satellite are due to atmospheric scattering (path radiance)(Chavez, 1996). The next step was the clipping of the image with a shapefile provided by the city council of "Valongo". For that, it was necessary to create a virtual raster.

The NDVI environmental index uses the visible (RED) and near-infrared (NIR) bands of the electromagnetic spectrum. The active green vegetation is characterized by positive NDVI values because it has a high visible light absorption and high NIR reflectance (Neigh et al., 2008). The NDVI values are represented as a ratio ranging between -1 and 1. The negative values indicate water and values around zero indicate bare soil and buildings, for instance (le Maire et al., 2011). In this work, the NDVI index was estimated through Band calc tool from SCP plugin, using the band's band 8 (NIR) and band 4 (RED) of Sentinel-2A (Reed et al., 1994):

NDVI = (NIR-RED)/(NIR+RED)

The EVI index was also computed. This index was developed to "correct" some distortions in the reflected light caused by the particles in the air as well as the ground cover below the vegetation. The EVI data product also does not become saturated as easily as the NDVI when viewing rainforests and other areas of the Earth with large amounts of chlorophyll (Huete et al., 2002). While NDVI is more sensitive to chlorophyll, the EVI is more sensitive to canopy structural variations, including Leaf Area Index (LAI), canopy type, plant physiognomy, and canopy architecture (Matsushita et al., 2007). The procedure to estimate the EVI was similar to the calculation of NDVI and the bands required from Sentinel-2A were band 8 (NIR), band 4 (RED) and band 2 (BLUE) (Didan et al., 2015):

EVI = 2.5*(NIR-RED)/(NIR + 6*RED – 7.5*BLUE +1)

The NDWI is an environmental index relative to liquid water and, as the values of NDVI, the NDWI varies from -1 to 1. The negatives values and close to zero represent no water or vegetation. The positive values indicate water presence (Xu, 2006). The Sentinel-2A bands required to estimate this index were band 3 (GREEN) and band 8 (NIR) and the process was the same as for the two-previous indices (McFeeters, 1996) :

NDWI = (GREEN-NIR)/(GREEN+NIR)

Results and Discussion

In this work, the combination of GIS tools and RS data allows the characterization of terrain relief, namely the analysis of altimetry, hypsometry, hydrography, the creation of environmental indices and the DEM creation.

All the collected data were projected in WSG84/UTM zone 29N (EPSG:32629) and processed on QGIS through the SCP plugin. In order to obtain the LULC map, a supervised classification was performed considering the Minimum Distance algorithm and an overall accuracy of 92.98% and a kappa statistic of 0.842 was obtained (Figure 2(A)). The validation performed through the field points had a result of 65% coherence between the scaled data and the classes assigned by SCP plugin. The environmental indices NDVI, EVI, NDWI, and Forest Fire Risk map were also obtained (Figure 3).

The area is characterized, in geographic terms, by an elevation variation between 136 meters (blue zones) and 243 meters (red zones) (Figure 2(A)), with a slope range between 6.03% and 23.7% (Figure 2(B)). The dominant direction of solar exposure on this area is west (red zones) (Figure 2(C)).

The study zone is very homogeneous, and only two types of land cover are present: bare soil and eucalyptus. Given the results obtained, the dominant class in LULC map are the eucalyptus (green areas) (Figure 2(A)). The eucalyptus dominates the majority of the area, existing only a few square meters of the bare soil zones. The zones identified as bare soil correspond to pathways, burnt areas (2017 summer) and mechanical deforestation zones.

The values obtained in the NDVI map were expected (Figure 3(B)). The NDVI is more sensitive to chlorophyll and other pigments that are responsible for the absorption of radiation in the red zone of electromagnetic spectrum. The eucalyptus trees have a great number of green leaves and consequently a great intensity of chlorophyll, which means more absorption of radiation resulting in higher NDVI values. The opposite occurs in bare soil areas, sandy soil and rocky soil, with lower NDVI values (red areas – Figure 3(B)). The NDVI map obtained ranges between 0.241 and 0.603. The lowest values, presented with red color, corresponding to bare soil areas. The highest values, the green ones, correspond to eucalyptus zones. The zones with values close to 0.603 correspond to zones where the eucalyptus was completely developed and with large dimensions (or dense plantations). The zones with intermediate values correspond to zones where the eucalyptus was in development, with small dimensions. The difference between the two zones of eucalyptus developed eucalyptus and eucalyptus in development, happens because the NDVI presented higher values in zones with major densification and vegetative vigor. The here-obtained values of NDVI were slightly lower than the values obtained in previously published studies in zones with high presence of eucalyptus (Boratto & Gomide, 2013; Santos et al., 2015; Sartori et al., 2009). A possible explanation of the values obtained in this work is that the area used to be a forestry exploitation with [i]industrial aims. The eucalyptus was planted with a distance between them and this created an area of bare soil between them. The influence of intercalated bare soil zones made the NDVI values lower than the expected in eucalyptus zones.

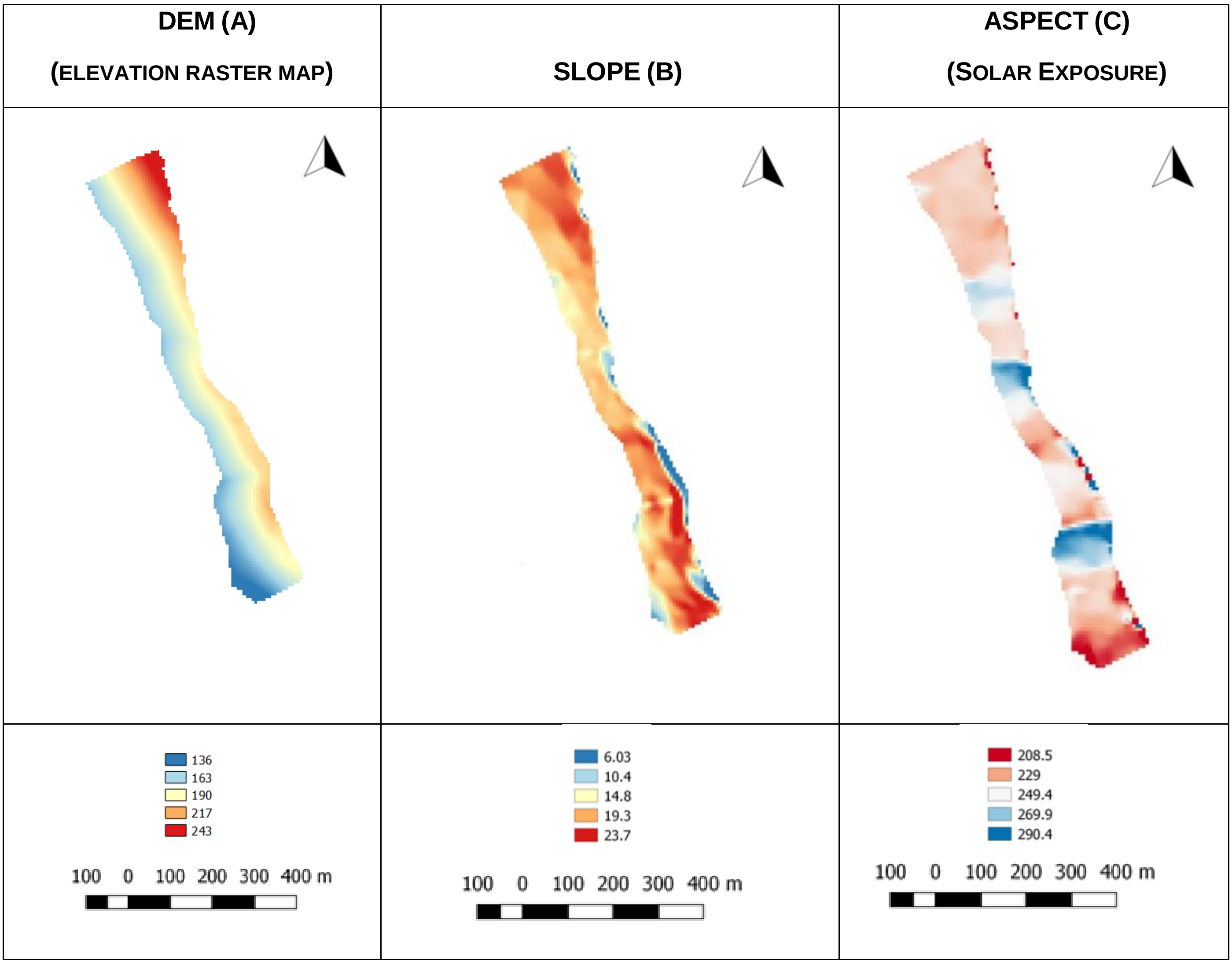

FIGURE 2 - GEOGRAPHICAL CHARACTERIZATION OF THE STUDY AREA

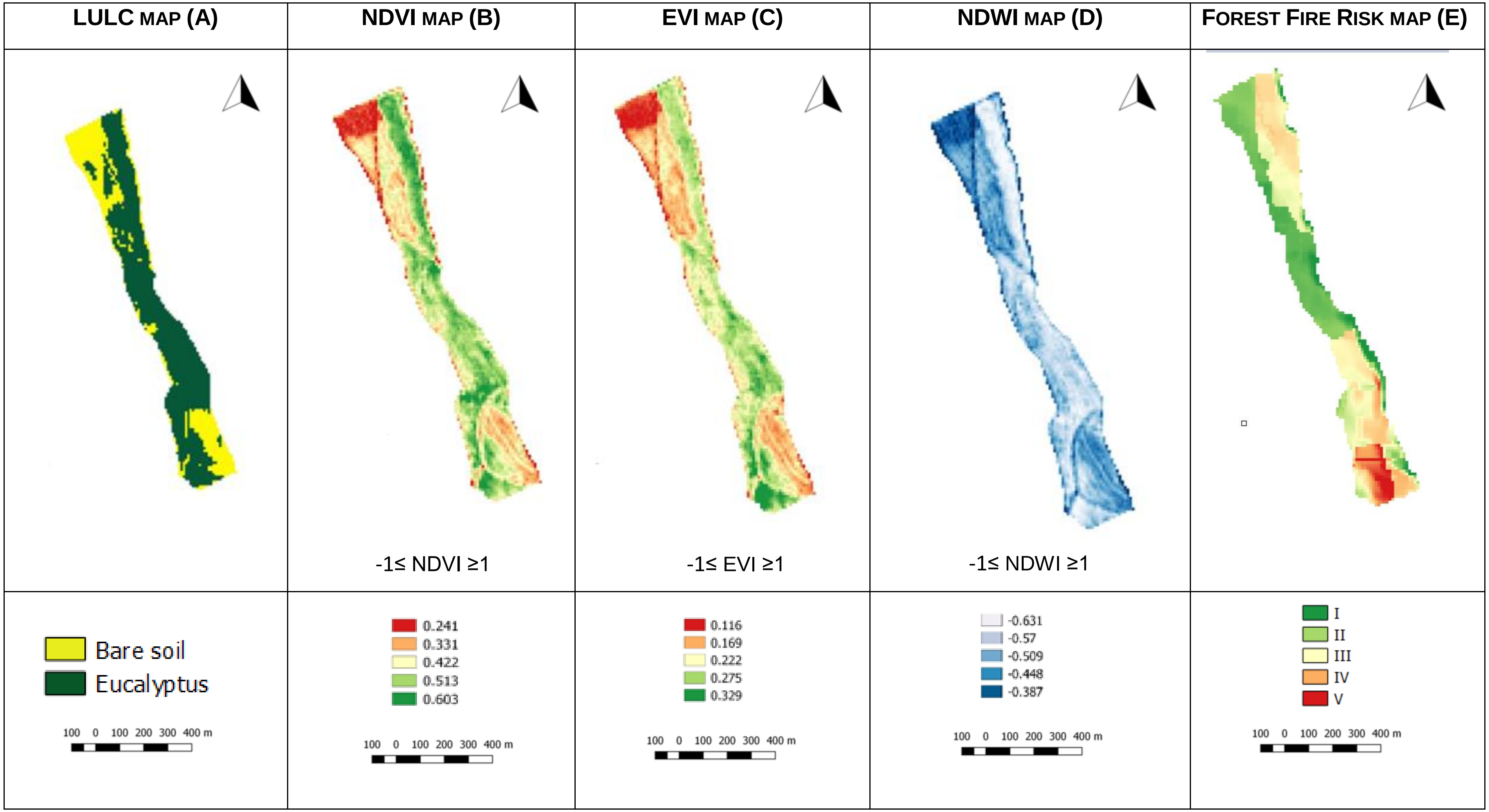

FIGURE 3 – LULC MAP, ENVIRONMENTAL INDEXES MAPS AND FOREST FIRE RISK MAP

The EVI map (Figure 3(C)) was similar to NDVI map (Figure 3(B)). However, the EVI map presents lower values. This occurs due to the fast NDVI saturation caused by the high absorption, in the red zone of electromagnetic spectrum, from the chlorophyll and the carotenes in the leaves. The EVI map of the study zone has minimum values of 0.116 and maximum values of 0.329. Such as NDVI, the lowest values correspond to bare soil zones, the highest values correspond to completely developed eucalyptus and the intermedium values correspond to zones with eucalyptus in development.

The NDVI and EVI maps help in the overall classification of the vegetation. The analysis of these maps with the LULC map data allows to deduce ecological and environmental variability and the characterization of vegetation biophysical parameters such as phytomass and density. It was possible to identify areas where vegetation is more photosynthetically active and where the *Eucalyptus* density is higher. Thus, it was possible to perceive the vegetation distribution, its density and its photosynthetic activity on the entire area. The southern zone of the study area is the zone with the more presence and higher density of vegetation. The areas with more presence and density of *Eucalyptus* are the zones where it is possible that the described above effects of intensive plantation have more impact. However, further researches are needed to comprove this hypothesis.

The NDWI map (Figure 3(D)) was used to identify inland water areas and, as the process of identifying them unfolded, it became clear that the study zone does not have inland water areas. Therefore, the values of NDWI map were all negative, corresponding to non-water features as bare soil and eucalyptus. The NDWI map of the study zone has a range of negative values between -0.631 and -0.387. The lowest negatives values correspond to zones with completely developed eucalyptus, the intermedium values correspond to eucalyptus in development and the highest values correspond to bare soil zones. Indeed, there are not water bodies in the study zone, so this result was already expected.

The forest fire risk map (Figure 3 (D)) was divided in 5 qualitative classes and that classes were calculated and identified for each specific location and there is no quantitative scale where each class can be inserted (Direcção de Unidade de Defesa da Floresta, 2012). The lowest values or class I (green zones) correspond to the areas with lower risk of fire, and the highest values or class V (red zones) correspond to the areas with higher risk of fire. The distribution of the different classes of the Forest Fire Risk map was similar to the distribution of the soil occupation on the LULC map (Figure 3(A)).

The areas with the presence of *Eucalyptus* correspond to most of the highest values of the Forest Fire Risk map. Furthermore, the values of NDVI and EVI maps and Forest Fire Risk map indicated the same thing. The zones with highest values of NDVI and EVI correspond to the zones with highest values on Forest Fire Risk map, and the same happened to the lowest values. Previous researches have studied the relation between NDVI values and fire hazard concluding that NDVI values higher than 0.5 correspond to a high fire hazard and the NDVI values between 0. 2 – 0. 5 correspond to a moderate fire hazard (Sakellariou, 2018). The highest values of NDVI or EVI correspond to the zones with more presence of eucalyptus. The fire risk map is a product between the fire hazard and the potential loss associated to a specific location (Bachmann and Allgower, 1998), and in this work it seems that the zones with more density of *Eucalyptus* (highest values of NDVI e EVI) were associated with the zones with the highest risk of fire. This means that these zones have the highest associated fire hazard and are the areas where the monetary losses will be highest in case of forest fire.

Without RS and GIS combined it would be very difficult to analyze all the study area, due to the extension and geomorphological characteristics. The creation of these maps and the information obtained make possible the comprehension and a better analysis of the area. The Forest fire risk map, the environmental indexes maps and LULC map provided information for entire area and was possible to correlate the data from the all maps. In addition, it was possible to map the geographical information of the zone, such as elevation range, slopes and solar exposure.

Conclusion

Thought the GIS and RS data analysis it´s possible to have quick access to information with great precision and utility to programs of conservation and biodiversity, namely in terms of realistic and targeted decisions. That information allows news studies and new perspectives of the phenomena, make possible different studies ways and conclusions. Conventional inventories and studies just make possible the analysis small-scale information, but with the development of this work it was possible to characterize the ecosystem conditions of the eucalyptus parcel. The approach used in this work allows to map the geographic conditions of the parcel, describing the elevation range, the slope variation and the solar exposure angles. The knowledge of geographic characterization of the study zone was important to understand the ecosystem dynamics. The combination of RS data e GIS allows the global analysis of the land use and the confirmation that the eucalyptus dominates all the area, perceive the zones where eucalyptus trees have more photosynthetic activity and the zones with more eucalyptus density. Also, it was possible the creation of the Forest Fire Risk map and a possible correlation between eucalyptus density and the higher values of fire risk. As in previous studies, it was possible to perceive that the zones with higher values of vegetation indexes such as EVI and NDVI are associated to areas with higher fire risk.

GIS techniques and remote sensing data have reduced the effort to gather information in situ. The simplicity and ease of other techniques for characterizing ecosystem conditions were extremely important in this case study. With the existing conditions in the area and the available means would be of great difficulty the type of multidisciplinary approach carried out in this project. Without the tools and methods used to characterize the area in the parameters discussed, a longer time of action and the use of more means would have been necessary.

The combination of RS data e GIS was useful in this study and in the future will allow a more complete analysis and maybe will make possible better understand the eucalyptus influence on this area.

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