An Integrated Environmental Monitoring Approach through the Development of *Coal Mine*, a GIS Open Source Application

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Abstract: Coal related fires may occur in un-mined outcrops, during coal mining, in abandoned mines, during storage and transportation and in coal waste deposits. The self-burning of coal mobilizes large amounts of pollutants, for instance, particulate matter, organic compounds and toxic trace elements that can be emitted, released or leached to soils, waters and air of the surrounding environment. The S. Pedro da Cova (Porto, Portugal) coal mine was exploited between 1795 and 1972 and had an important role on the economic development of the region. Nowadays a waste pile of about 28,000 m2 is still deposited in the mine, suffering from self-combustion since 2005. Geographical Information System (GIS) and spatial databases are frequently used for monitoring this type of processes. The main objective of this work was to integrate, manipulate and combine the spatial information obtained in the field with other datasets (geospatial and alphanumerical) in a GIS open source application connected to a relational database (PostGIS), in order to monitor and assess environmental conditions in the S. Pedro da Cova coal mine. This is an ongoing project where some campaigns were conducted and some spatial information was obtained (thermal images, Digital Elevation Model) and also water and soil samples.

1 INTRODUCTION

The S. Pedro da Cova coal mine was exploited between 1795 and 1972 and had an important role on the economic development of the region. Nowadays a waste pile of about 28,000 m^2 is still deposited in the mine, suffering from self-combustion since 2005. These coal waste piles can be responsible for the dissemination of pollutants through particulate matter and gases by air and water. It is thereby crucial to monitor the geochemical elements mobilization into soils and water, as well as the combustion process associated with the coal fires.

In this context, Geographical Information Systems (GIS) and relational databases are frequently used when the issue involves several data. For instance, Chen and Li (2008) developed a WebGIS-based decision support system that integrates spatial information techniques and field survey data of a coal mine waste. Also, Guo et al. (2016) created a WebGIS system to perform the information management of a coal mine. The Global Positioning System (GPS) combining with GIS techniques have also been used in this context. For instance, Mert and Dag (2018) used GPS and GIS technologies focusing in real-time monitoring of excavated coal quality.

Tama et al. (2018) used web-based GIS solutions as cloud-based WebGIS application to track changes in land surface of Miedzianka caused by historical mining of metal ores. Lee and Park (2013) also analysed the hazard to ground subsidence through a decision trees approach in a GIS environment.

Several studies use the PostgreSQL-PostGIS spatial database to manage different layers of information based on an analytical hierarchy process (Kumar et al., 2016; Kostecki, 2017; Díaz-Cuevas et al., 2018; Liu et al., 2019; Obeidavi et al., 2019).

The QGIS, an open source GIS software, has been already used in geology studies. For instance, Choudhury and Arutchelvan (2016) used QGIS to know the implementation of technology intended for the development of Neyveli mine closure planning system. Also, Tama and Malinowska (2018) used QGIS and SAGA to analyse the water hazard caused

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by ground deformations in the mining area of coal mine Kopalnia Węgla Kamienneg (KWK) Morcine.

The main objective of this work was to integrate, manipulate and combine the spatial information obtained in the field with different datasets in a GIS open source application connected to a relational database, in order to monitor and assess environmental conditions of the S. Pedro da Cova coal mine. The development of this application present several advantages in coal mining context, automatizing the procedures to integrate and analyse all the data acquired in the field, incorporating several methodologies and updating the data acquired in the field through a database created for that purpose. These possibilities implemented in the GIS application will improve time-efficiency and automatize the procedures to study the coal mine.

Under this scope, a GIS open source application (*Coal Mine*) and a PostGIS database were created and connected in order to access the data.

2 STUDY AREA

The study area is located approximately at 10 km east of Porto (in S. Pedro da Cova, Gondomar), in northern Portugal, and it is a part of the Douro Coalfield that represents the most important coal-bearing deposit in Portugal (Upper Pennsylvanian). It has a NW–SE alignment, a variable width (30–250 m) and approximately 53 km in length (Pinto de Jesus, 2001).

The study area is located along the border of the Valongo Anticline western flank. Stratigraphically in the study area, it is possible to identify different metasedimentary formations with ages between the Precambrian and / or Cambrian, Ordovician, Silurian, Devonian and Carboniferous (Medeiros, 1980). Figure 1 presents the study area.

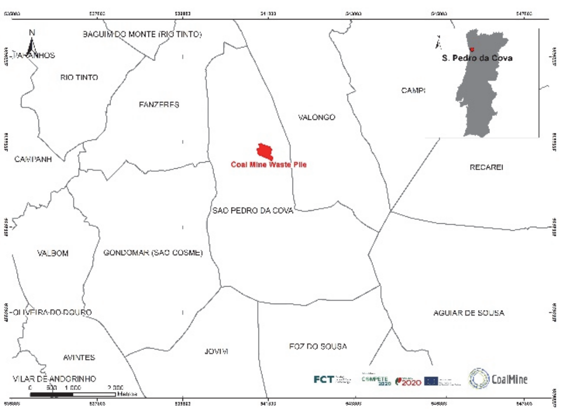

Figure 1: Study area location.

Anthracite was mined in S. Pedro da Cova for over 177 years, and, as result, a significant waste pile emerges along the landscape, with near 450 meters long, deposited along slope.

In 2001, wastes from the national steel industry were deposited along the mine waste pile northern border. These have been considered highly enriched in Lead (Pb), Zinc (Zn) e Chromium (Cr), and for this reason in 2014 the Portuguese Government started the removal process of these wastes, nowadays is estimated that 125.000 tonnes remain on site.

In 2005, after ignition caused by forest fires, a part of the coal rich waste pile started to combust, and has been burning, self-feeding, until the present days. Presently the self-combustion seems confined to one active focus, in the centre of the waste pile.

The study area is located along the western border of a sensitive natural area, the *Natura 2000* protection area, and is contiguous to the population, which enhances the environmental concerns.

2.1 Coal Mine Project

The CoalMine Project financed by the Portuguese foundation for science and technology (FCT in Portuguese) aims to characterize and quantify of the impacts on surrounding environment ecosystems and health of population living nearby S. Pedro da Cova mine waste pile. The investigation of the impacts on soil and water allows to identify organic and inorganic elements that can potentially damage the ecosystems and have negative impacts on human health. This project comprises multiple datasets referring to different periodic campaigns, that aims characterize the geochemical composition of water and soils in the vicinity of the old coal mine, and also the surface temperature. The project also monitors eventual landslide mass movements occurring in the waste piles. The spatial distribution of contamination and its extension are verified considering spatial analyses and geo-statistical algorithms.

2.2 Data Acquisition

Two soil sampling campaigns were already performed. The first was conducted in February 2019, and the second was conducted in October 2019. The soil samples of the sampling made in October are still being processed, so will not be included in this work.

A total of 50 surface (0-20cm) soil samples were collected over a regular mesh with approximately 100 m spacing between samples. The samples covered an area of about 480 000 m^2, exceeding the areas covered by the coal mine waste pile as these had been subject of previous studies (Ribeiro *et al*. 2010, 2011, 2012, 2015). The sampling was preferentially oriented NE-SW according to the development of the main drainage basin, southwest of the waste pile.

The geographic coordinates (in WGS84 coordinate system) of the sampling locations were identified using a GPS receptor.

Regarding the water quality monitoring, a total of 5 sampling points were selected, 2 in Ribeira de Silveirinhos (one upstream – A1 – and other downstream – A4 – from the mine effluents discharge), two points in mine drainage galleries (A2 and A3) and control point (A5) collected in a spring without any influence of mine drainage. The sampling plan defined for this work comprised 5 sampling campaigns at the 5 points mentioned, collected on a quarterly periodicity in November 2018, February, May, September and December 2019. Figure 2 presents the location of the soil and water quality monitoring points.

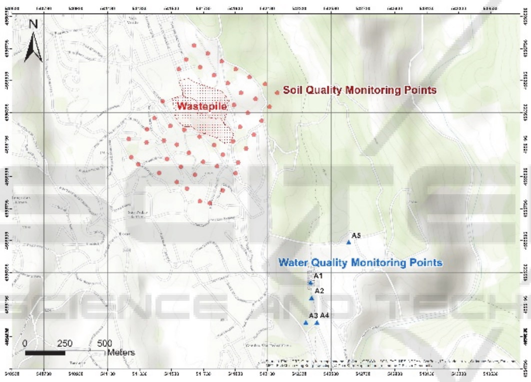

Figure 2: Location of soil and water quality monitoring points.

For the acquisition of the imagery data, 2 campaigns of flights considering an unmanned aerial vehicle (UAV) were done. The first campaign occurred on the 23 July 2019 and the second occurred on the 30 December 2019. Each flight acquired data from three different sensors, namely, a thermal infrared (TIR) sensor, an RGB camera and a multispectral sensor (blue, green, red, red edge and near infrared bands).

3 METHODOLOGY

3.1 PostGIS Database

The data acquired was stored in PostGIS 3.0 relational database, which is an extension of PostgreSQL 12.1 relational database manager. The database was stored locally (PostGIS, 2020).

The vector data, in shapefile format, was imported to the database using the *PostGIS Shapefile Import/Export Manager* 3.0.0 functionality from PostGIS 3.0 software (PostGIS, 2020). Consequently, a connection was established between the database and the QGIS 3.10 software. The *Database Manager* tool from QGIS 3.10 software was used to insert in the database the alphanumeric data, already existent (in excel format). The raster data was imported to the database through the *raster2pgsql* algorithm, included in the PostGIS 3.0 software.

As a relational database, connections between common elements must be assured, in order to reduce the computational effort of the database. For tabular data, this connection is established by the definition of one or more columns, with unique values, as the primary key and the definition, in a different table, of the identical of columns with the same data as the foreign key. The primary key uniquely identifies a line within the table, while the foreign key constraints a table to only the records that match the primary key of another table, in the process referencing and connecting the two tables (PostGIS, 2020). Figure 3 shows part of the different tabular data found in the public schema of the database and the identification of the columns and primary keys that compose it. This includes data from water and soil analysis, metadata of the raster files and the punctual temperature measurements. The aforementioned process of linking different tabular data is still ongoing, as the data acquisitions and database optimization.

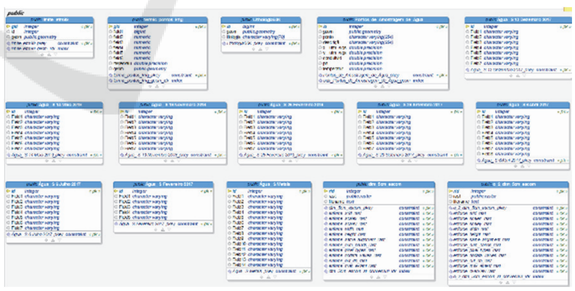

Figure 3: Tabular data of public schema of the database.

In the created database, every record is identified with the number of the sample and the date in which the sample was collected. A connection is, then, established between the table where these records are kept and the table where the location of each sample number is stored, giving not only a temporal, but also a spatial dimension to the stored data.

3.2 GIS Application

3.2.1 *Coal Mine* Implementation

The figure 4 presents a diagram containing all the procedures performed under this project, since the PostGIS database and the Coal Mine application development.

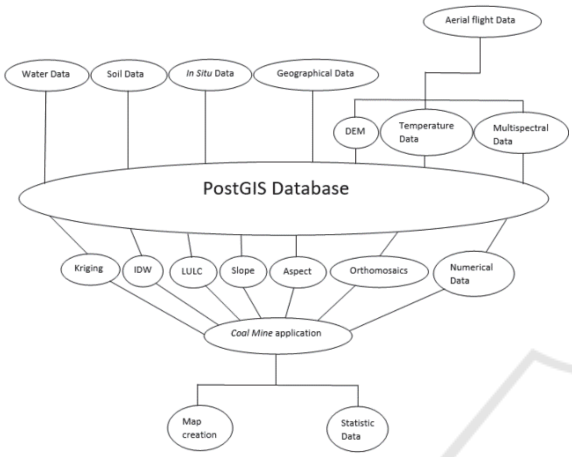

Figure 4: Diagram of Coal Mine application development.

The *Coal Mine* application was developed under QGIS 3.10 software, using Python programming language (QGIS, 2020). The graphic interface was created based on the composition of *Qt Designer* framework widgets (QGIS, 2020). *Qt Designer* is a Qt tool which allows to design and build graphical user interfaces (GUI) through QWidgets. The windows and dialogs can be personalized in this framework. The application was created as a toolbar button. This button opens a main window built as a *QMainWindow* class (Figure 5; Qt API, 2020).

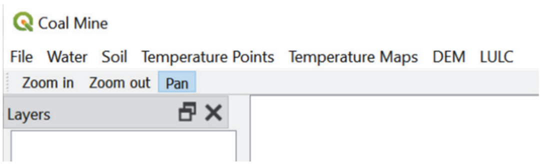

Figure 5: *Coal Mine* application main window.

The main window is composed by 7 menus: *File*, *Water*, *Soil*, *Temperature Points*, *Temperature Maps*, *Digital Elevation Model (DEM)* and *Land Use Land Cover (LULC);* basic and standard tools to manipulate the maps such as *Zoom in*, *Zoom out* and *Pan*; a table of contents named *Layers* and the canvas where the layers are spatially presented (Figure 5).

The menu *File* allows to open vector or raster files in the application canvas.

The *Water* and *Soil* menus connects to the database where the information of water and soil are saved and present options to open a specific campaign (by date) chosen by the user.

The *Temperature Points* menu also connects to the database and presents the temperature information measured in the field) and provides a functionality that incorporates Kriging algorithm and Inverse Distance Weighting (IDW) in order to automatize the procedure to create a continuous temperature surface (Figure 6). This implementation was based on a previous GIS application which allows to create temperature interpolation maps using Kriging algorithm (Duarte et al., 2017).

The IDW method was implemented based on *v.surf.idw* algorithm from GRASS library (GRASS, 2020) and the kriging method was implemented based on *Ordinary Kriging* algorithm from SAGA library (SAGA, 2020).

In this GUI, 5 fields were created based on the parameters of *v.surf.idw* algorithm: the field to input the points, the field to choose the attribute with the values to interpolate, the cell size of the final raster surface, the interpolation method (*IDW* or *Kriging*), and finally the field to the output surface (Figure 7).

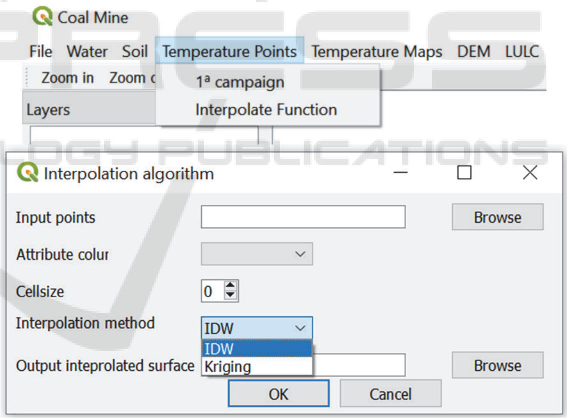

Figure 6: GUI of *Temperature Points* menu.

The *Temperature Maps* menu allows to open, in the canvas, the temperature maps already created. These maps where created combining several methods. The thermal imagery, acquired by the TIR sensor, was aligned and juxtaposed using the Agisoft Metashape 1.5.5 software (Agisoft, 2019). The images were orthorectified, based on the DEM, creating an orthomosaic of the surface temperatures. Finally, the orthomosaic was clipped to the extent of the coal mines' waste pile using *Clip raster with polygon* from SAGA library, (SAGA, 2020). This menu is connected to the PostGIS database and opens the temperature maps in raster format.

The *DEM* menu also provides two options: the DEM generated in a specific campaign (generated from UAV imagery) and the *Terrain Analysis* functionality which allows to create slope and aspect maps from DEM. The algorithm implemented, *r.slope.aspect* belongs to GRASS library (GRASS, 2020). This GUI is composed by 3 fields: an input field to DEM, and 2 output fields to slope and aspect, respectively.

The *LULC* menu also connects to the database to access the LULC map already created. The LULC map was obtained based on *K-Means Cluster Analysis Operator* 1.0 algorithm from SNAP 7.0 software (SNAP, 2019). Also, this menu provides a functionality to derive the LULC using the *K-Means unsupervised classification method* algorithm from SAGA (SAGA, 2020). The GUI that allows to create the classification is composed by 3 fields: an input field, a spin box widget to define the number of clusters and an output field.

All the data provided in this application is hosted in the PostGIS database. The application connects automatically to the database, filters the request and allowed to access to the information.

The table of contents also provides some functionalities when a layer is opened, such as: *Show extent* which provides the extent of the layer; *Remove layer* which allows to remove the layer from canvas; *Zoom to Layer* and access to the *Attribute Table* (Figure 7).

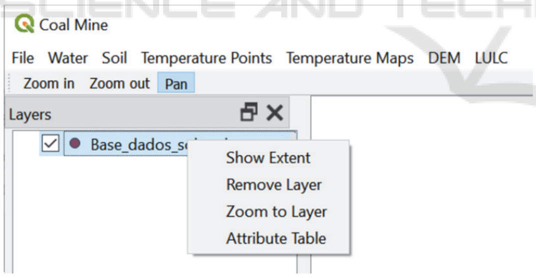

Figure 7: Basic standard tools of table of contents.

In order to create the application canvas to visualize the data, a *QWidget* was built in *Qt Designer* and it was promoted to *QgsMapCanvas*.

3.2.2 PostGIS Connection

As explained in the previous section, the data acquired in the field campaigns are available to visualize and analyse in *Coal Mine* application. This visualization is only possible through the connection to a local PostGIS database where the data is hosted (see section 3.1). The connection to the PostGIS database under the application and using Python functions were performed with the following code lines:

```
uri = QgsDataSourceUri()
uri.setConnection("localhost", "5432",
"Database", "postgres", "postgres")
uri.setDataSource("public",
"distritos2", "geom", '', "gid")

db = QSqlDatabase.addDatabase("QPSQL");
db.setDatabaseName(uri.database())
db.setPort(int(uri.port()))
db.setUserName(uri.username())
db.setPassword(uri.password())
db.open()
```

4 RESULTS AND DISCUSSION

The application was tested with the data connected to PostGIS database. This possibility allows to evaluate and analyse multiple layers which are opened and can be overlapped. Also, the new functionalities were tested, and some results are showed, such as slope and aspect maps (Figure 8), the interpolation of temperature values using kriging algorithm (Figure 9) and the LULC using K-Means algorithm (Figure 10).

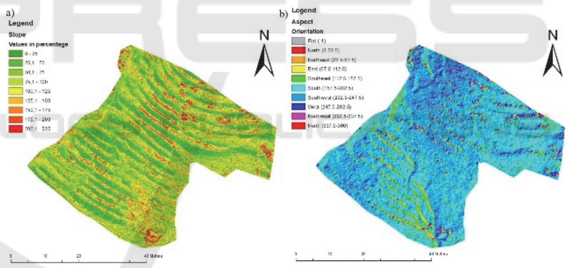

Figure 8: Slope map (left) and aspect map (right).

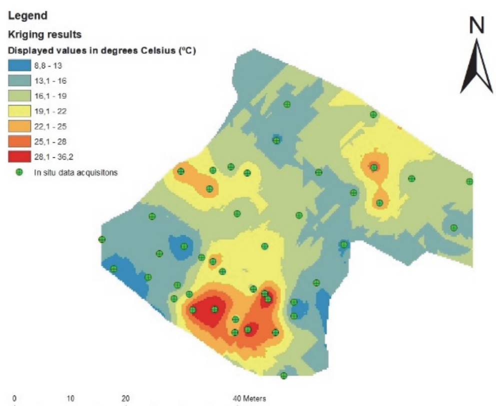

Figure 9: LULC map.

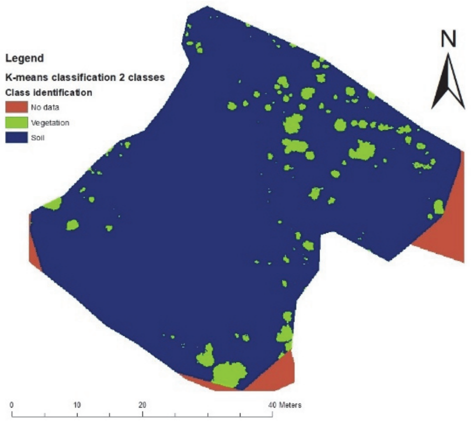

Figure 10: Unsupervised classification with 2 clusters defined.

The developed application allowed to create several maps such as: slope and aspect maps, LULC map and temperature map. An analysis was performed considering the referred variables. The temperature values are independent of the slope values. However, based on the aspect map, the waste pile is facing a southerly direction, receiving direct sunlight for most of the daylight. Despite this, the heat dispersed on the surface by the sun cannot explain the presence of the verified high temperatures. This conclusion stems from the fact that the results attained, so far, were very similar, despite the significantly different conditions of both flights. One campaign was conducted during summer and the second during winter, under substantially different air temperature conditions. The winter flight recorded a maximum surface temperature of 50,9 ºC, while, during the flight that took place in the summer the highest surface temperature detected was 57,8 ºC. It was also observed that high temperatures seem to be a deterrent for vegetation growth, regarding the LULC map and the temperature map. The areas with the higher temperatures featured little or no vegetation.

The development of Coal Mine application present several advantages in coal mine environmental monitoring context: i) it automatize several procedures that allows to integrate and analyse all the data acquired in the field; ii) it is composed by several methodologies such as the creation of interpolation surfaces for punctual data, the creation of slope and aspect maps from DEM and the automatic land cover classification through unsupervised classification and; iii) to update the data acquired in the field through the database. These possibilities implemented in the GIS application will improve time-efficiency and automatize the procedures to study the coal mine environmental legacy.

Given the periodic nature of these monitoring campaigns, the Coal Mine application should help to minimize the potential input errors, automatizing the data procedures. The results will contribute to support decision making.

5 CONCLUSIONS

The Coal Mine Project aims the characterization and quantification of the impacts on surrounding environment ecosystems and have negative impacts on human health of population living nearby S. Pedro da Cova mine waste pile. Under this project, the *Coal Mine* application was created in a GIS open source software in order storage all the data obtained in the field and generates useful information. The application allows to visualize, manipulate and create relevant data. The *Coal Mine* application can be used as a decision support tool to help to mitigate and minimize the severe impacts in the environment nearby S. Pedro da Cova. The main advantage of the *Coal Mine* application is to improve and optimize the manipulation of the data obtained *in situ* and using geo-processing algorithms which will help in the future to perform the management of the coal mine, to improve the safety and the automatization of several processes.

This is an ongoing project where some campaigns were conducted and different spatial information was obtained, such as water and soil samples in the field. Through the UAV flights, several maps were also obtained such as LULC maps and thermal images. A lot of information has been collected until now and with future campaigns this volume tends to grow, so a spatial and open source database was crucial to integrate all the data.

In the future, this application will incorporate other functionalities to provide other maps such as fire risk maps, groundwater vulnerability to pollution maps and soil erosion maps. Also, it will provide the possibility to perform statistical analysis providing results in the format of histograms, plots and variograms. The results will also allow the analysis of the dynamics of the combustion process in the coal waste pile as well as predict evolution scenarios. The GIS application is free and open and available to any user.

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