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## QGIS approach to extract fluvial terraces for archaeological purposes using remote sensing data

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## **Optional Cover Page Acknowledgements**

Acknowledge funding sources and research organizations, along with colleagues with minor support. A special thanks to the municipalities of Melgaço and Monção for sharing the altimetric data of their territory.

# QGIS approach to extract fluvial terraces for archaeological purposes using remote sensing data

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**Abstract:** Fluvial terraces, usually defining flattened surfaces, are significant geomorphic features that explains the presence of rivers at high altitudes and constitute the remains of the old river along the valley. In Iberia, many of these terraces preserve Paleolithic artifacts and document the presence of the first human communities. Nowadays, the increasing use of Free and Open Source Software (FOSS) provides the opportunity to analyze and test different approaches to study these geomorphological features. According to the literature, several algorithms from open source GIS software have been used, such as Geographic Resources Analysis Support System (GRASS) GIS. In the recent versions, QGIS, a GIS open source software, is integrated with several algorithms from other open source software, such as GRASS GIS, System for Automated Geoscientific Analyses (SAGA), Orfeo-ToolBox (OTB), among others. Therefore, the procedures used to extract and identify the fluvial terraces can be performed using QGIS software.

The objective of this work was to combine Remote Sensing (RS) data and GIS algorithms, considering QGIS software, to identify fluvial terraces in order to support archaeological prospection of Paleolithic artifacts along the Minho River (Portugal border). Different data were used such as the Digital Surface Model (DSM), the slope derived from DSM, the Normalized Difference Vegetation Index (NDVI) map derived from Sentinel-2A image (summer), the Land Use Land Cover (LULC) derived from Corine Land Cover (CLC) and hydrological data from Minho valley. The data used were in WGS84 UTM zone 29 (EPSG:32629) and the spatial resolution adopted was 10 meters.

The method proposed allowed the definition of a fluvial staircase considering several terraces levels along the Minho valley. Different scenarios were tested, and the results were

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validated considering *in situ* measurements, in order to find the best weight associated to each parameter.

## 1. Introduction

The fluvial terraces are common geomorphic features along the river valleys. They usually define flattened surfaces on bedrock, the strath terraces, or platforms made by the sediments transported and leaved by the river, the fill terraces. These terraces explain the presence of rivers at high altitudes, qualifying the river incision capacity and allows to date the age of the sediment deposition (Viveen et al., 2012).

In Iberia Peninsula, many of these fill terraces preserve Paleolithic artifacts and document the presence of the first human communities (Méndez-Quintas et al. 2018), since the age of the terraces is related with the human presence.

The recent evolution of FOSS GIS software provides several tools to process and analyze geographic information regarding the identification of the fluvial terraces. The amount of GIS open source software, such as QGIS, GRASS GIS, SAGA GIS, gvSig or other software more specific as Orfeo Toolbox (OTB), provide more possibilities and capabilities to manipulate geographic data. In general, FOSS presents several benefits as: lower (or no) cost software; more flexibility considering the code development allowing the modification, the use and distribution of developed extensions; the interoperability of the software, so it possible to interact with other software (for instance, the more recent versions of QGIS integrates algorithms from other open source software such as GRASS, SAGA and OTB); and the ethics of the use of open source software: the development and use of FOSS contributes to the evolution of human knowledge [<https://www.e-education.psu.edu/geog585/node/4>]. Besides that, the FOSS concept presents some challenges such as: the usability reflected in the user-friendly software production; the documentation availability, given the existent tutorials, cookbooks and guides for GIS software or extensions; and the support availability provided by the online forums and code repositories with the possibility to report bugs or suggestions to improve the code [<https://www.e-education.psu.edu/geog585/node/4>].

The objective of this work was the integration of different approaches combining Remote Sensing (RS) data and GIS algorithms in QGIS software in order to extract and identify the fluvial terraces. Different data were created and considered in the approaches tested such as the Digital Surface Model (DSM), the slope derived from DSM, the Normalized Difference Vegetation Index (NDVI) map derived from Sentinel-2A image, the Land Use Land Cover (LULC) derived from Corine Land Cover (CLC) and the hydrological data from Minho valley.

The methodology proposed was used to identify the fluvial terraces and to define the levels of the staircase along the river Minho valley.

## 2. Literature Review

Different techniques and methods have been used to identify the fluvial terraces using GIS. These flattened surfaces are usually identified and discriminated on topographical maps or analyzing Digital Terrain Models (DTM) with GIS software's. DTM could be generated considering different altimetric data source, such as: points and contour lines from conventional topography, Light Detection And Ranging (LIDAR) data; and more recently altimetric data provided by Unmanned Aerial Vehicles (UAVs) surveys. Among the studies related with the fluvial terraces, we highlight the works about the Atlantic Iberian Rivers. For instance, for the Minho River, Viveen et al. (2012, 2013), Pérez Alberti (2013) and Mendez-Quintas et al. (2018) performed relevant studies. Cunha et al. (2016) and Ramos et al. (2012)

considered conventional altimetric data from topographic maps to study fluvial and coastal terraces in Mondego and Tejo Rivers. Anton et al. (2014) based their terraces definition and interpretation on conventional altimetric data, Shuttle Radar Topography Mission (SRTM) and LIDAR data for the Douro River.

### 3. Methodology

To produce the maps required in order to define the best methodology to identify fluvial terraces in the study area selected for this work, the QGIS version 2.18 software was used. Several algorithms from *Processing Toolbox* framework were used to create the different maps, such as *slope*, *aspect*, *curvature* from SAGA and *rastercalculator* from *gdalgr*. Also, *Semi Automatic Classification (SCP)* plugin (Congedo 2016), a plugin from QGIS used to process the satellite image.

#### 3.1. DSM, slope and hillshade maps

The DSM with 30 meters of spatial resolution, 16-bit in GeoTiff format, was obtained from Advanced Land Observing Satellite (ALOS) World 3D [<http://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm>]. The DSM was resampled to 10 meters since it is the best spatial resolution provided by the satellite image. Slope and hillshade maps were derived from DSM using the algorithms available in the *Processing Toolbox*. The terraces are usually defined in flat surfaces, so understand the slope is relevant to identify them. According to Hopkins and Snyder (2016) and Clubb et al. (2017), hillshade map can help to in the analysis of the results obtained and to understand the relief of the zone.

#### 3.2. NDVI map

An image from Sentinel-2A (a Level-1C product acquired by Sentinel-2A on the 13<sup>th</sup> August, 2017 at 11:21:21 AM, acquired over Tile T29TNG during Relative Orbit 037, and processed with PDGS Processing Baseline 02.05) was considered. The image was processed using SCP plugin in order to perform the atmospheric correction based on *Dark Object Subtraction 1 (DOS1)* method, to convert Digital Numbers (DN) to surface reflectance (Chavez, 1996). The image was restricted to the study zone and the NDVI map was obtained applying the Equation 1 (Reed et al., 1994):

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED}) \quad (1)$$

Where NIR corresponds to near infrared reflectance band (band 8 in Sentinel-2A image) and RED corresponds to red reflectance band (band 4 in Sentinel-2A image). The NDVI map was considered in this study because terraces can be associated with vineyards fields where NDVI values are well defined and well known.

#### 3.3. LULC map and Hydrography data

The LULC map considered was based on Corine Land Cover 2012 (CLC 2012) (<https://land.copernicus.eu/pan-european/corine-land-cover>) and some of the classes (level 3) were considered: agricultural areas (complex cultivation patterns, 242), coniferous forests (312), annual crop associated with permanent crop (241) and vineyards (221).

The hydrography data (scale source 1: 25000) was also considered since the terraces are more probable to appear closest to the rivers.

### 3.4. Approaches considered

In this study were considered three approaches. The first and second approaches were based on a combination of several criteria considering different values for each factor. For that, *Raster calculator*, an algorithm from QGIS, was used. The values assigned to each map, are given in Table 1 and Table 2.

Table 1. Values assigned to each map (Approach 1).

Map	Values interval
DSM	[0, +∞ [
SLOPE	] -∞, 15]
SHADED RELIEF	]0, 150[

Table 2. Values assigned to each map (Approach 2).

Map	Values interval
DSM	[0, +∞ [
NDVI	[0.55, 0.8]
RIVER	]0, +∞[
CLC	1*
SLOPE	] -∞, 15]

\* The CLC values were restricted to the classes referred before. To the zones with that classes were assigned the value 1.

The criteria defined in Table 1 and Table 2 were applied to each map and the result obtained (a raster with values 1-True or 0-False) was multiplied by the DSM. This procedure allows to consider only the zones that comply the conditions related to the altitude values associated to them. Applying an adequate symbology it is possible to estimate the zones where the terraces could be identified. These results need to be improved in the future, considered more field data in order to validate these approaches.

The third approach includes a weighted criteria analysis. Considering the conditions presented in Table 2, each map was multiplied by the original data and then normalized (0-100%) using *Raster normalization*. A weight was assigned to each map, according to the importance degree, and in the end all the maps were summed. The weights considered in the approach 3 are presented in Table 3.

Table 3. Weights - Approach 3.

Map	Weight
RIVER	1
NDVI	2
DSM	3
CLC	4
SLOPE	5

#### 4. Study Area

The three approaches considered were tested in Minho River located in NW Iberia (Figure 1). This area is dominated by Palaeozoic crystalline rock and Palaeozoic metasedimentary rocks (Viveen et al., 2013). During the Mesozoic, this bedrock was affected by deeply erosion and the formation of flat surfaces at the end. The Cenozoic is marked by the uplift of tectonic blocks, the individualization of several tectonic depressions and the mountain relief with flat surfaces on the mountains top, which is affected by the quaternary fluvial incision (Viveen et al., 2013).

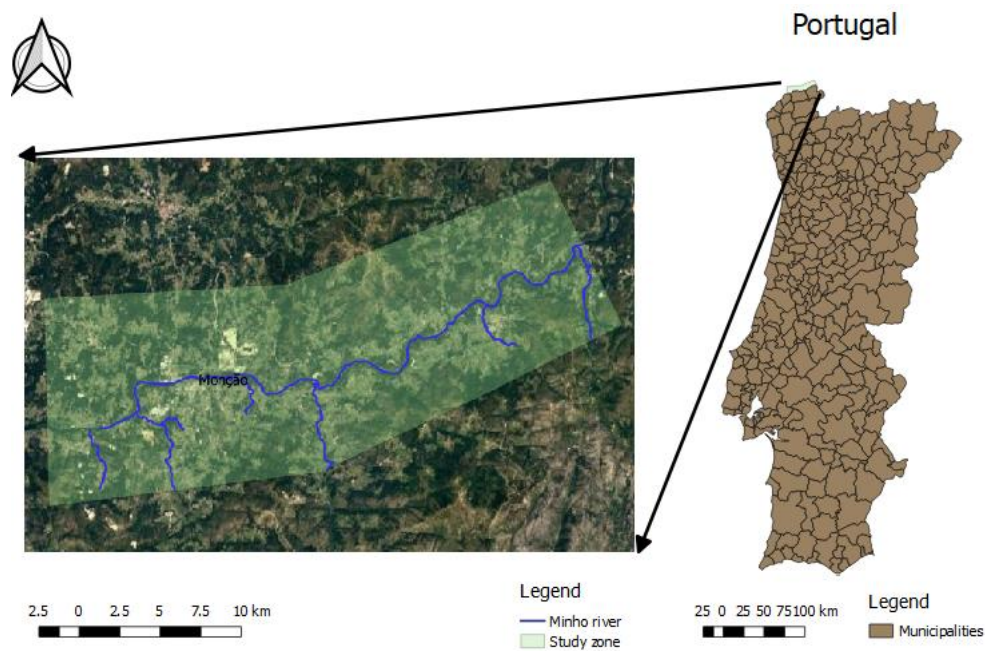


Figure 1: Study zone.

All the data generated and used in this work were in World Geodetic System 1984 Universal Transverse Mercator (WGS84 UTM) zone 29 (EPSG:32629) and the spatial resolution adopted was 10 meters, since it is the best spatial resolution of satellite images.

#### 5. Results and Discussion

A prospection was performed in the field in order to validate the different approaches presented in this work.

The first approach considered the combination presented in Table 1 and the result is showed in Figure 2.

Assigning the raster values to the prospection points in the field, the minimum altitude value founded was 0 meters and the maximum was 44.2 meters. The mean value of the 13 points was 33.1 meters and the median 34.6 meters.

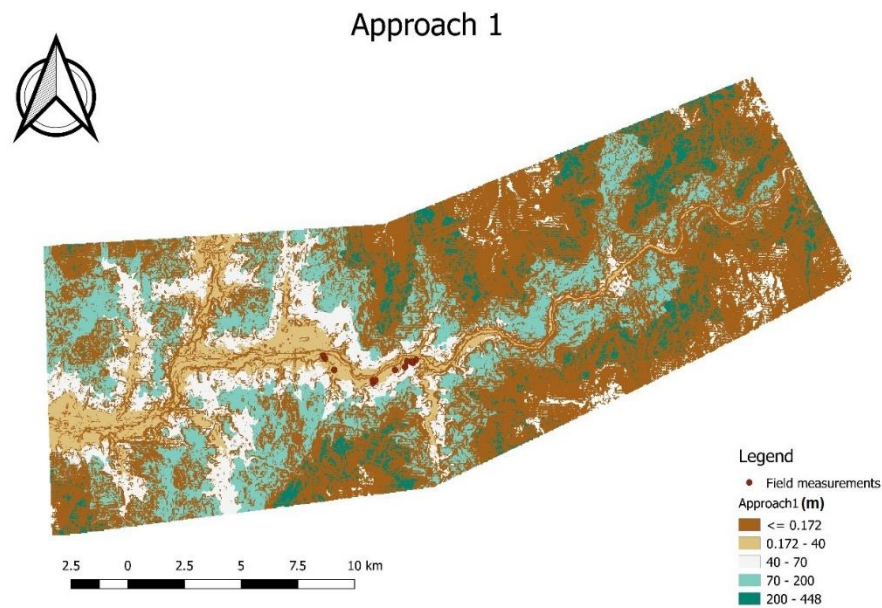


Figure 2: Result of first approach.

Considering the second approach (values presented in the Table 2), the result obtained is presented in the map of Figure 3. In this case, the NDVI values (typical from vineyards) were considered, the distance to the river and also the CLC classes where it is more plausible to find terraces.

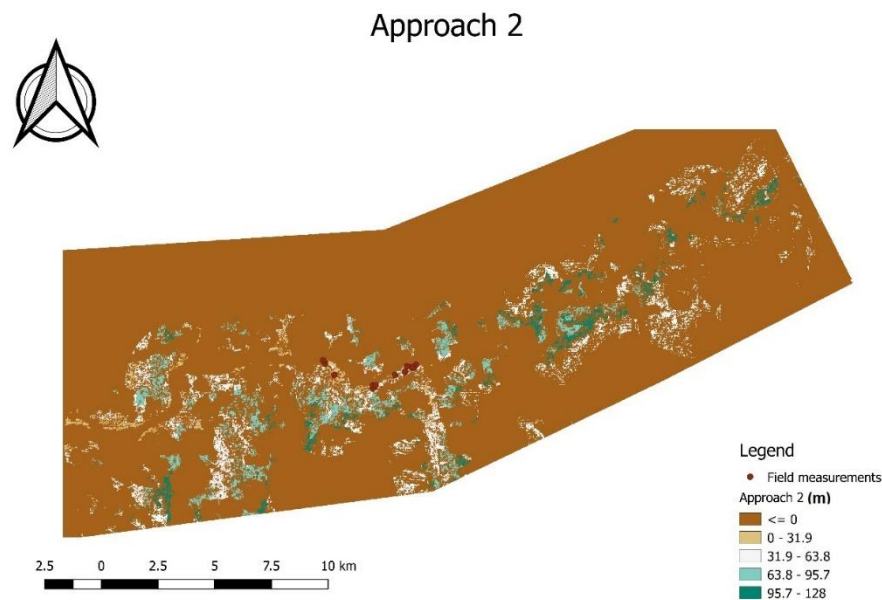


Figure 3: Result of second approach.

Assigning the raster values to the prospection points obtained in the field, the minimum altitude value founded was 0 meters and the maximum was 44.0 meters. The mean value of the 13 points was 7.7 meters and the median 0.0 meters. In this case, the majority of the points had 0 meters assigned, which means that they don't respect the conditions proposed. However, in a general way the points are representative of a terrace (Figure 2 with some zoom).

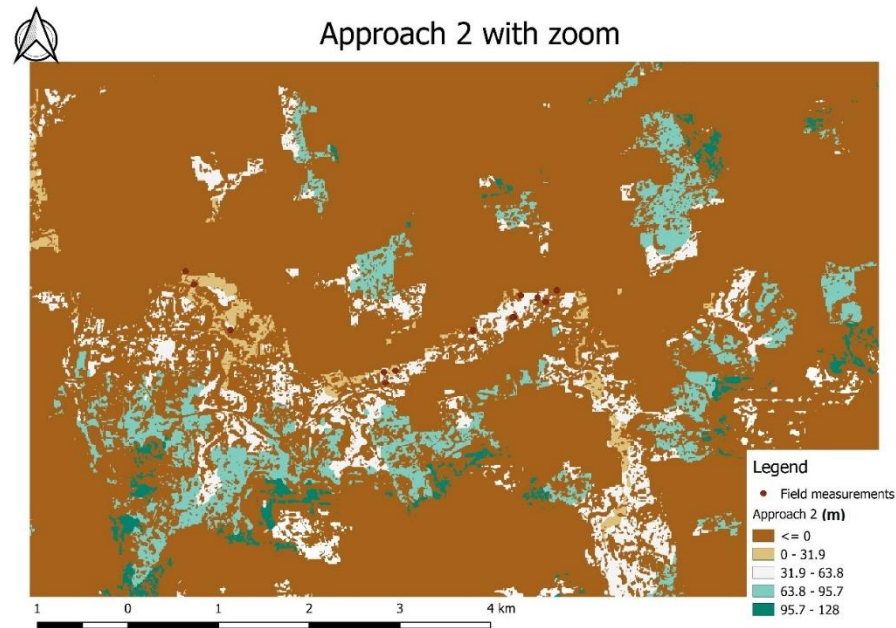


Figure 4: Result of second approach with zoom.

The result obtained regarding the third approach is presented in Figure 5.

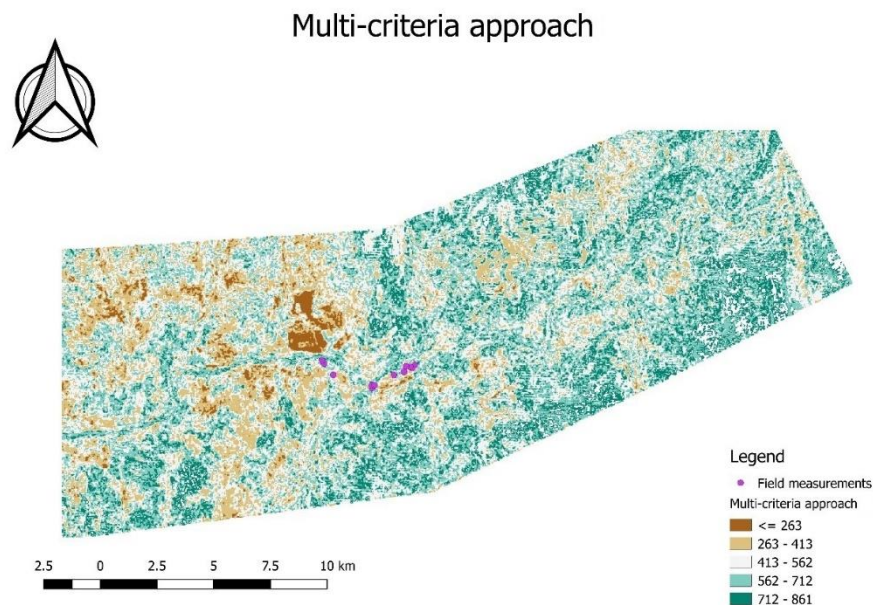


Figure 5: Result of third approach.

The values range between 263 and 861. Considering that the suitable places to have terraces are sectors of plane relief, i.e., with low values of slope, the lowest values of the sum define the areas with the highest probability of existing a terrace. These good results are illustrated by the extensive brown areas (Figure 5) near the Minho river and more abundant in western sector.

## 6. Conclusion

The first approach described is a simplistic method considering only the DSM, the slope and the shaded relief. Considering the result obtained (Figure 2) and the prospection performed in the field, the results are quite interesting, since it's possible to discriminate several levels of terrace and define a good staircase similar to the one defined in the work of Méndez-Quintas et al. (2018). In the first approach, the mean value of the 13 points was 33.1 meters of altitude, which indicated that the prospection points can be directed to the fluvial terraces that are assigned to this level.

The second approach considers more variables derived from different maps, including NDVI map, CLC classes more representative and the distance to the Minho River. In this case, the areas founded were reduced comparing to the approach 1.

The third approach considers a weight analysis e give the best results since the areas with low results define large and continuous areas with low slope, and show a distribution that defines a staircase, which corresponds to the expected geomorphological model of a normal fluvial staircase.

This is an ongoing work and more tests will be performed in the future considering new field data and new methods.

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