

# GIS APPLICATION TO DETECT INVASIVE SPECIES IN AQUATIC ECOSYSTEMS

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## ABSTRACT

The detection of invasive plant species in aquatic ecosystems is important to help in the control or to mitigate its spread and impacts. Remote sensing (RS) can be explored in this context, helping to monitor this type of plants. This study intends to present a free to use and open-source software application that, through a graphical user interface, can process remote sensed data to monitor the spread of invasive plant species in aquatic environments, enabling a multi-temporal monitoring. Both unmanned aerial vehicle and satellite-based data were used to validate the potential of the proposed application. A site containing water hyacinth (*Eichhornia crassipes*) was selected as case study. Both RS platforms provided effective data to detect the areas containing water hyacinth. Thus, this tool provides an alternative and user-friendly way to include RS-based data in ecological studies allowing the detection of invasive plants in water channels.

**Index Terms**— unmanned aerial vehicles, Sentinel-2, vegetation indices, QGIS, water hyacinth

## 1. INTRODUCTION

Invasive aquatic plants take possession of aquatic ecosystems, changing their dynamics and biodiversity [1] with high socio-economic impacts in different sectors [2], [3]. Water hyacinth (*Eichhornia crassipes*) is originated from the Brazilian Amazon basin and it is one of the most dangerous invasive species in the world [1], [4], [5]. Once it is within the perfect conditions, this invasive species colonize watercourses and water bodies forming a dense green mat, modifying habitats, preventing the sunlight and oxygen in aquatic environment and causing a loss of water by evapotranspiration [1].

Water hyacinth is a major environmental threat to water quality and scarcity. Several countries in the world are

affected by this invasive species [1], [6]. In Portugal, since the beginning of the 1980's, the spread of water hyacinth has been obvious, affecting irrigation channels, mostly in Mondego, Tagus and Sado Valleys [7].

Geographical Information Systems (GIS) and remote sensing (RS) have been used to monitor and detect the infestation of water hyacinth [8]. Satellite imagery obtained from different sensors such as Sentinel-2 MultiSpectral Instrument (MSI), Moderate-Resolution Imaging Spectroradiometer (MODIS) and Landsat, among others, have been used to retrieve vegetation indices, such as Normalized Difference Vegetation Index (NDVI), that are used to detect aquatic vegetation [1], [4], [9]. Some studies used machine learning techniques [8], [10], [11] which requires a previous knowledge of the areas with presence of invasive aquatic species for training the classifiers. Other techniques, such as Object-Based Image Analysis (OBIA) have been also used to map invasive plants along roads using very high-resolution aerial imagery [12].

The main objective of this article is to present a free and open-source GIS application developed for QGIS software, designed for users with few GIS expertise, that can help in the detection of invasive species in aquatic ecosystems, relying in computer-aided photo interpretation of vegetation indices. To demonstrate the effectiveness of the developed tool, an area containing water hyacinth was used as case study. Multispectral data acquired by an unmanned aerial vehicle (UAV) and by satellite (Sentinel-2) were used.

## 2. DATA AND METHODOLOGY

### 2.1. Study zone

The data used in this work is from the Mondego river basin (40°8'55" N, 8°44'12" W), Portugal. The area is composed of two hydrographic canals that outlet into the Mondego River main channel. The surveyed area has a total area of 9.8 ha from which 2 ha are water, with an incidence of

approximately 0.6 ha of water hyacinth within the water channels.

## 2.2. UAV data

The UAV-based data was acquired using a Matrice 300 RTK (DJI, Shenzhen, China). This multi-rotor UAV has real time kinematic (RTK) navigation capabilities, an approximate weight of 6.3 kg and 2.7 kg of maximum payload capacity. Onboard of the UAV the MicaSense RedEdge-MX (MicaSense, Inc.; Seattle, Washington, USA) was mounted. This sensor is able to capture multispectral data in the blue, green, red, red edge, and near infra-red (NIR) parts of the electromagnetic spectrum with a resolution of 1.2 MP. A sensor to measure solar radiation and to provide Global Positioning System (GPS) data during flight is positioned on the top of the UAV.

Data was acquired on 21 July 2021 at 10:35 a.m., in a 100 m flight height (7 cm spatial resolution), with a longitudinal overlap of 80% and a lateral overlap of 70%. Before the flight, a target formed by different predetermined levels of gray tones, providing well-defined reflections, was used for the radiometric calibration. A total of 1955 images were acquired in 391 different captures, covering a total area of 23 ha.

The UAV-based imagery was subjected to photogrammetric processing using Pix4Dmapper Pro (Pix4D SA, Lausanne, Switzerland). After the computation of the dense point cloud and orthorectification, the five bands were radiometrically calibrated and NDVI was also computed.

## 2.3. Satellite data

Satellite data from the Sentinel-2 (MSI), with 10 m spatial resolution, acquired on 28 July 2021 was used in this study. It corresponded to cloud-free bottom-of-atmosphere data (Level-2A). Among the 13 available spectral bands, only bands 4 (red) and 8 (NIR) were used, since they are the ones required for the NDVI computation. For visual purposes, the true colour image (TCI) representation was also downloaded.

## 2.4. Methodology

The GIS application was developed under QGIS 3.18 software [13]. QGIS is a free and open source GIS software, that started in 2002 by Gary Sherman and respects the four freedoms of Stallman: it is free to run and use, the code is freely accessible and can be modified, the program can be distributed, and freedom to distribute the modified version of the software [14]. Python programming language was used to develop the code. Thus, the GIS application, named QIASdetection (QGIS Invasive Aquatic Species detection) was developed to detect invasive species in aquatic systems, by analyzing the NDVI.

Qt Designer framework was used to create the Graphical User Interface (GUI) and several functions from QGIS Application Programming Interface (API) and Qt API, were used. The application development was initialized with Plugin Builder. Several algorithms from GDAL, GRASS and native QGIS algorithms, such as `gdal:cliprasterbymasklayer`, `grass7:r.mapcalc.simple`, and `native:zonalstatisticsfb`, were also used.

The application, presented in Fig. 1, consists of a dialog window composed of three main sections: i) the input section, where the user defines the input files; ii) the parameters definition section, where the fields related with the NDVI threshold values are defined; and iii) the output section.

The input section allows to import the red and NIR bands, if the user has the original bands; or NDVI raster, already computed. These two options are chosen through a radio button. The red and NIR input fields were created as combo boxes, where the user can access the files from the map canvas, or through the directories. The NDVI raster can be one or multiple maps (depending on the user requirements to perform a time series data analysis). In this case, the user can access through a button that opens a new window (Fig. 2). This window, automatically loads the multiple raster opened in the map canvas, if available; if not, the user can point out the file path through the Add files button. The Select all button allows the selection of all maps in the list; the Clear selection allows to clear the selection performed; Remove file allows to remove a specific/selected file; the Ok button allows to accept the selected files and close the window; and the Cancel button cancels the operation and closes the window. To create this window, the `QListWidget` class was used [18]. The study zone option allows to use a shapefile, and all available vector files loaded into the map canvas are listed in a combo box.

The parameters definition section is also composed of two radio buttons: i) the Threshold, a horizontal slider widget, that allows to define a threshold (between 0 and 1, according to NDVI), values above this threshold are kept; and ii) the definition of a Minimum and Maximum values, created as double spin boxes (defined to display double values) when the user intends to define an interval for NDVI, being the selected range of values kept to the analysis.

The output section allows to define a folder where the output files are saved. The application generates two output files for the area of interest, defined by an input mask shapefile: a raster with the areas where invasive species can be detected (marked with the value 1); and a shapefile, with descriptive statistics derived from native QGIS algorithms (zonal statistical aggregation functions and field calculator).

In the end of the process, a message appears with the information that the process is complete.

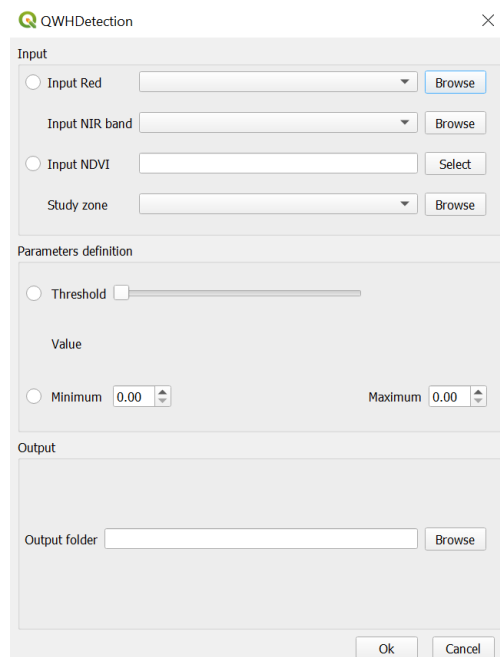


Fig. 1. QIASdetection main window.

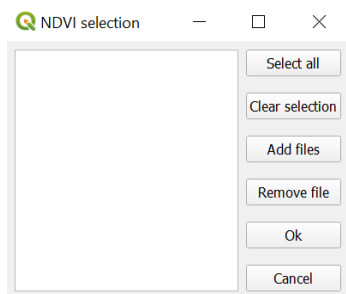


Fig. 2. NDVI selection window that allows multiple raster files to be selected.

### 3. EXPERIMENTAL RESULTS

To test the developed GIS application, data acquired from UAV and Sentinel-2 were used as described in Sections 2.2 and 2.3. In the application, two inputs were defined: a NDVI raster already estimated (Fig. 3.) and the study area (mask shapefile). The data were in Universal Transverse Mercator (UTM) World Geodetic System 1984 (WGS84), Zone 29N (EPSG:32629). After a visual data inspection, the threshold considered was  $NDVI > 0.75$ . Thus, in this case, the option Threshold was selected with the manual definition of 0.75.

The result obtained for the NDVI raster generated from UAV data is presented in Fig. 4a. A total area of 5988 m<sup>2</sup> was identified as having water hyacinth. When using Sentinel-2 data, the results (Fig. 4b.) shown an area of 7000 m<sup>2</sup> containing water hyacinth.

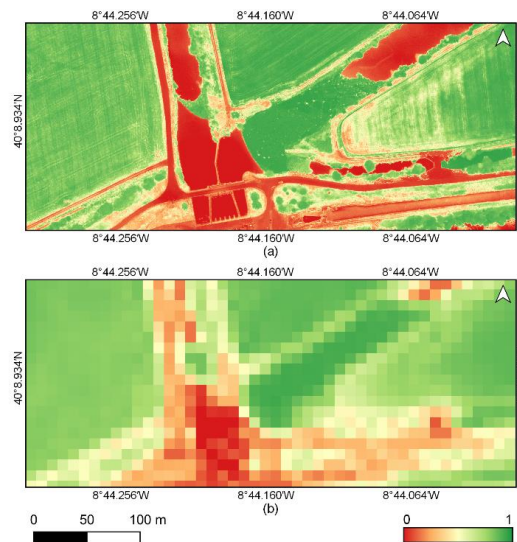


Fig. 3. NDVI computed from the UAV data (a) and from Sentinel-2 data (b).

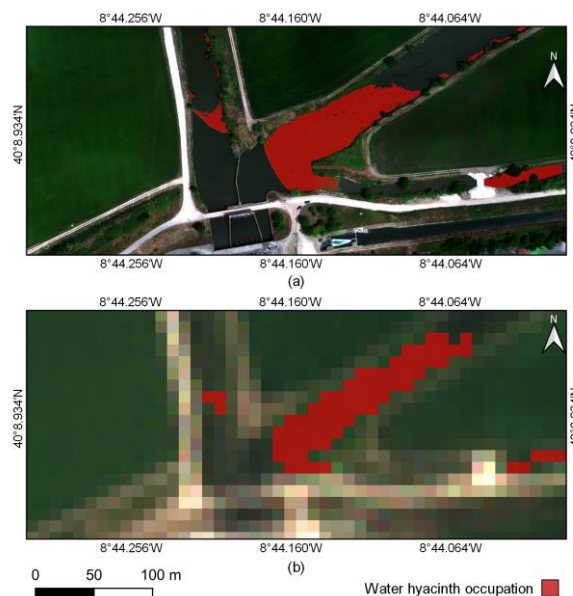


Fig. 4. Estimated water hyacinth using UAV data (a) and by using data from Sentinel-2 (b).

Since the data used in this study are from the same area with seven days apart from each other, it is possible to monitor the changes in from the first epoch (UAV data, at 21 July 2021) to the second (Sentinel-2 data, at 28 July 2021). Despite the spatial resolution differences, a growth of approximately 20% was verified. Moreover, the UAV data showed an almost perfect agreement with the data observed in the orthophoto mosaic of the area. This way, it is demonstrated the effectiveness of the developed application for monitoring water hyacinth using both UAV and Sentinel-2 data along with the potential for conducting multi-temporal analysis when using data from different epochs.

#### 4. DISCUSSION AND CONCLUSIONS

In this study a methodology involving the use of NDVI for detection of invasive plants was presented. It was developed for QGIS in a form of a plugin that can be freely used in this open-source GIS, providing the possibility for other researchers and entities to make use of the offered capabilities to perform an easier detection of invasive species in aquatic environments. Moreover, allied to the fact that Sentinel-2 data are widely available with no costs to the user, this type of analysis can be performed with a high spatio-temporal coverage. A potential constraint factor can be the presence of other plant species with a similar spectral behavior. However, the application can be improved to support the classification of other species, data types (e.g. thermal infrared or hyperspectral), vegetation indices or methodologies. Moreover, the study area addressed in this study will be analyzed by using available Sentinel-2 data to evaluate the spread of water hyacinth along time.

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