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Development of an application for the estimation of vegetation indices using SENTINEL remote sensing data

Desarrollo de una aplicación para la estimación de índices de vegetación en imágenes del sensor SENTINEL

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Abstract

Geomatics is an application that covers various topics; sustainable land use, identification and monitoring of crops, production estimation, marketing, evaluation of other lands, environmental impact analysis, among. It groups techniques related to data collection using remote and proximal sensors which allow determining wavelengths and spectral responses to estimate variables that allow quantification of statistical data. Vegetation indices are combinations of spectral bands recorded by the different remote sensing satellites, their basic function is to enhance the vegetation based on its spectral response and thus attenuate the details. The objective of this research was to provide the user with a tool developed by means of GIS that allows to execute complex processes in an automated way and with optimal results whose impact is mainly focused on optimizing production time and obtaining variables whose application can have an impact on the optimal use of fertilizers in agricultural activities. The results obtained are a total of 21 automated vegetation indices having as input the scenes obtained through the SENTINEL 2A and 2B sensor.

SENTINEL, Vegetation index, Python

Resumen

La geomática es una aplicación que comprende temas diversos; el uso sostenible de la tierra, la identificación y monitoreo de cultivos, estimación de la producción, el mercadeo, la evaluación de tierras, análisis de impacto ambiental, entre otros. Agrupa técnicas relacionadas con el levantamiento de datos mediante sensores remotos y proximales los cuales que permiten determinar longitudes de onda y respuestas espectrales para estimar variables que permitan la cuantificación de datos estadísticos. Los índices de vegetación son combinaciones de bandas espectrales registradas por los diferentes satélites de teledetección, su función básica es realzar la vegetación en función de su respuesta espectral y así atenuar los detalles. El objetivo de esta investigación fue el de facilitar al usuario una herramienta desarrollada mediante programación SIG que permite ejecutar procesos complejos de manera automatizada y con resultados óptimos cuyo impacto principalmente va enfocado a la optimización de tiempo de producción y la obtención de variables cuya aplicación puede repercutir en el uso óptimo de fertilizantes en actividades agrícolas. Los resultados obtenidos son un total de 21 índices de vegetación automatizados teniendo como insumo las escenas obtenidas mediante el sensor SENTINEL 2A y 2B.

SENTINEL, Índice de vegetación, Python

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Introduction

In recent years, Geographic Information Systems (GIS) have undergone significant development since their origins. The popularity of these technologies and the development efforts carried out by a large number of sciences that benefit from the use of this tool have contributed to redefining the discipline and integrating elements that were unthinkable at the time (Chuvieco, 2007).

However, the main components that identify the main core of a GIS have been maintained throughout this evolution, and it is their appearance that defines the initial moment in which we can situate their origins.

GIS as a tool emerged in the 1960s as a result of the conjugation of some factors that converged to give rise to the development of the first information systems, these factors are mainly two: the growing need for geographic information, its management and optimal use, and the appearance of the first computers (Calvo, 2012).

These factors are those that have continued to drive the advancement of GIS as a tool since its inception, since interest in the study and conservation of the environment is also gradually increasing today, and this creates an ideal situation for techniques and tools such as GIS to remain in constant evolution.

At present, and as part of this evolution, we can find the emergence and development of some aspects of GIS such as: GIS programming languages (Chuvieco, *et al*., 2005).

These are a formal language, designed to perform processes in an automated way that can be carried out by computers. They can be used to create desktop applications that control physical and logical behaviour, to express algorithms with precision or as a mode of human communication.

The application of Geomatics is varied, ranging from sustainable land use, crop identification and monitoring, production estimation, marketing, land evaluation, to environmental impact analysis of land uses, among others (FAO, 1995; 1996; Beek, Bie & Driessen 1996).

It groups some techniques such as remote sensing and proximal sensing data relationships, which allow determining appropriate wavelengths and spectral responses to estimate variables for the quantification of vegetation indices.

Materials and methods

GIS programming language

A program is a set of instructions to carry out a task, and is composed of four essential parts:

- Code. This is the actual set of instructions. Normally, the code is written in a way that is easy for a person to understand and manipulate.

- Memory. Provides space for the program to store data for later retrieval.

- Input. This is the set of data that the program receives as it executes and that conditions the actions it performs and, consequently, the results it provides. Generally, the data comes from the user, but it can also come from other programs. In the latter case we have, for example, data sent by a web server or stored in a database.

- Output. This is the set of data generated in the form of a result during the execution of the programme. This data can be perceived as actions from the user's point of view.

The results can be various: a number, a new file, an image, etc. In computer science, programs were written in the form of holes in special cards. These holes were used to represent the data and the code, but going from the programmer's will to the holes and vice versa was not an easy task.

Fortunately, years later, so-called programming languages appeared, which used a syntax very similar to that of a conventional language to describe the actions to be performed by the computer. These programs were then interpreted by another program called a compiler, which was responsible for translating all these sentences into something lighter for the computer.

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This way of programming, with few changes, is the one that has survived to the present day.

In the GIS environment, programming has become a very useful tool for users as it helps in the automation of processes, this minimises operating costs by reducing the time to obtain results from complex processes. Among the most popular GIS programming languages are: SQL, Java, Python, JavaScript, CSS, Ruby, PHP, C++, C, C#, Visual Basic NET, R, Flex, Silverlight, Avenue, AML and VBA for ArcObjects.

Graphical user interface

The Graphical User Interface (GUI) is a computer program that operates using a set of images and graphical objects to represent the actions and information available in the interface.

Using a set of images and graphical objects to represent the actions and information available on the interface. Its main function is to provide a simple visual environment that allows communication with a computer's operating system.

Qt Designer is part of the Qt Framework suite of application development software, which designs multilingual graphical user interfaces; it generates XML files whose content is the GUI format, which can be converted with the relevant language-specific software. This is free and open source software, which uses the C++ programming language natively and can additionally be used in other programming languages through bindings.

It works on all major platforms, and is widely supported. The library's API has methods for accessing databases via SQL commands, as well as XML usage, thread management, network support, a unified cross-platform API for file manipulation and a multitude of other file handling and traditional data structures. (Ecu Red, 2010)

Copernicus programme

Copernicus is an Earth observation programme developed by the European Space Agency (ESA), one of the most ambitious programmes of its kind, designed to provide accurate, up-to-date and easily accessible information to improve environmental management, understand and mitigate the effects of climate change and ensure public safety.

SENTINEL-2 Multispectral

The Sentinel-2 mission aims to capture multispectral images of the earth at medium resolution, its main objective is to monitor the variability of the earth's surface. It consists of the MSI (Multi Spectral Instrument), which captures information of the Earth's surface in 13 spectral bands, with different spatial resolutions, four 10 m bands, six 20 m bands and three 60 m bands. Sensor 2A was launched on 23 June 2015, while its twin, sensor 2B, was launched into orbit on 7 March 2017. The revisit time between the two sensors is 5 days.

SENTINEL-2 bands	Central wavelength (µm)	Spatial resolution
Band 1 Coast	0.443	60
Band 2 Blue	0.490	10
Band 3 Green	0.560	10
Band 4 Red	0.665	10
Band 5 Edge of red	0.705	20
Band 6 Edge of red	0.740	20
Band 7 Red edge	0.783	20
Band 8 Near infrared	0.842	10
Band 8 Band 8a	0.865	20
Band 9 Water vapour	0.945	60
Band 10 SWIR - Cirrus	1.375	60
Band 11 SWIR	1.610	20
Band 12 SWIR	2.190	20

Table 1 List of spectral bands and their respective spectral and spatial resolutions
Source: Own elaboration

The products acquired by the mission are divided into 100 x 100 km tesserae.

Image processing

Sentinel-2 imagery, available for download, has two processing levels; Level 1C imagery and Level 2A imagery.

Level 1C images are ortho-rectified and have reflectance levels above atmospheric (**TOA**). That is, they correspond to atmospherically corrected images and provide reflectance data closer to reality.

On the other hand, the level 2A images are ortho-rectified with reflectance levels below the atmosphere (**BOA**).

Vegetation indices

Vegetation indices are used to highlight the characteristics of healthy, developed vegetation in relation to the soil.

The most common are Normalised Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI) and Leaf Area Index (LAI).

The application developed has a focus and application in the area of agriculture, so the indices studied and selected are focused on the estimation of chlorophyll content in crops.

Vegetation indices		Formula	Reference
Normalized difference vegetation index	NDVI	(NIR − R) / (NIR + R)	Rouse *et al.* (1974)
Soil adjusted vegetation index	SAVI	(1 + L) (NIR – R) / (L + NIR + R)	Huete (1988)
Green normalized difference vegetation index	GNDVI	(NIR − G) / (NIR + G)	Gitelson and Merzlyak (1996)
Normalized difference red edge index	NDRE	(NIR − RE) / (NIR + RE)	Fitzgerald *et al.* (2010)
Red edge chlorophyll index	CIred edge	NIR / RE − 1	Gitelson *et al.* (2005)
Green chlorophyll index	CIgreen	NIR / G-1	Gitelson *et al.* (2005)
Ratio vegetation index	RVI	NIR / R	Jordan (1969)
MERIS terrestrial chlorophyll index	MTCI	(NIR − RE) / (RE − R)	Dash and Curran (2004)
Canopy chlorophyll content index	CCCI	(NDRE − NDREMIN) / (NDREMAX − NDREMIN)	Fitzgerald *et al.* (2010)
Transformed chlorophyll absorption in reflectance index/Optimized soil-adjusted vegetation index	TCARI / OSAVI	3*[(RE − R) − 0.2*(RE − G) (RE/R)] / [(1 + 0.16) (NIR − R) / (NIR + R + 0.16)]	Haboudane *et al.* (2002)
Modified chlorophyll absorption in reflectance index/Optimized soil-adjusted vegetation index	TCARI / OSAVI	[(RE − R) − 0.2*(RE − G)](RE/R)} / [(1 + 0.16) (NIR − R) / (NIR + R + 0.16)]	Haboudane *et al.* (2002)
Red edge-based transformed chlorophyll absorption in reflectance index/Optimized soil-adjusted vegetation index	TCARI / OSAVI RE	3*[(NIR − RE) − 0.2*(NIR − G) (NIR/RE)] / [(1 + 0.16) (NIR − RE) / (NIR + RE + 0.16)]	Wu *et al.* (2008)
Red edge-based modified chlorophyll absorption in reflectance index index/Optimized soil-adjusted vegetation index	MCARI / OSAVI RE	[(NIR − RE) − 0.2*(NIR − G)](NIR/RE)} / [(1 + 0.16) (NIR − RE) / (NIR + RE + 0.16)]	Wu *et al.* (2008)

Table 2 List of the main selected indices
Source: Own elaboration

Obtaining vegetation index values

In order to obtain the normalised difference vegetation index (NDVI) values, it was necessary to use the following expression proposed by (Rouse et al., 1974):

$$NDVI = \frac{(IRC-R)}{(IRC+R)} \quad (1)$$

Where:

NIR: is the reflectivity measured in the near infrared.

R: is the reflectivity measured in the red region.

On the other hand, the SAVI index (Huete, 1988) was used in order to reduce the alterations presented in the NDVI values in sparsely vegetated areas and is obtained by means of:

$$SAVI = \frac{(1+L)(IRC-R)}{L+IRC+R)} \quad (2)$$

Where:
IRC = corresponds to the reflectivity in the near infrared band, while.

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R = refers to the reflectivity in the red band.

L = is a constant for SAVI, if L is 0 the SAVI index becomes equal to NDVI, a value of 0.5 appears frequently in the literature for this variable (Allen *et al*., 2002).

Processing

The pre-processing phase comprises two parts: the cropping of the study area and the conversion of the digital numbers of the image to reflectance values.

For the cropping of the study area, the user must check the "shapefile" option and indicate which file will be the cropping file.

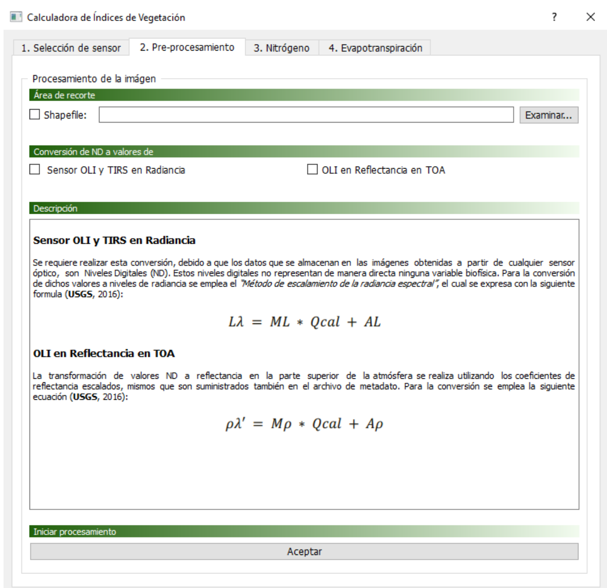

Figure 1 Graphical interface of the application, preprocessing section
Source: Own elaboration

The conversion of digital numbers is performed by selecting the corresponding option, whose results (reflectance) are stored in a folder called: "Processing", located within a specific path and where the products requested by the user are stored.

Obtaining indices

Finally, in the last stage, the user marks the option of those indices he/she wishes to obtain, the results of which are also stored in the folder mentioned in the previous step (Processing).

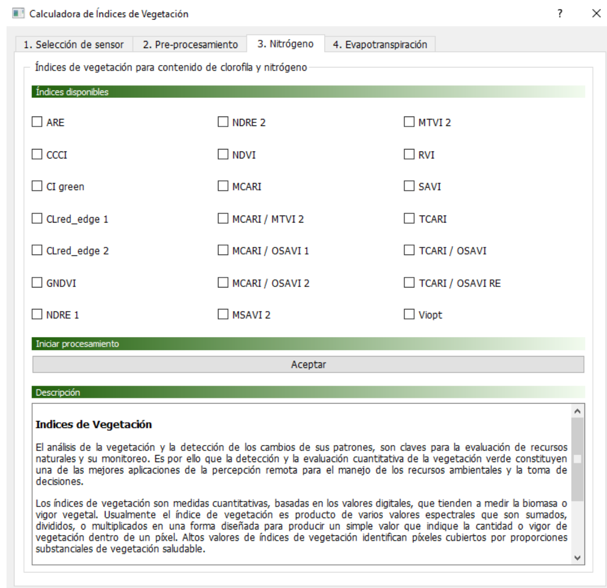

Figure 2 Indices available to the user and that the calculator performs in an automated way
Source: Own elaboration

PyQT4 – QT Designer

Using QtDesigner, a development tool, the graphical interface ("etcalculator.ui") is created and the template and functionalities available to the user are designed. The initial procedure is based on a form without buttons (Dialog without Buttons):

Once the template has been selected, the next step consists of dragging the components to be used (widgets) from the toolbar (Widget Box):

For the design of the application it has been considered to use various elements (widgets) that allow to give the desired functionality to the interface.

The elements considered are:

- Tags.
- Line Edit.
- Check Box.
- Radio Buttons.
- Combo box.
- Push Buttons.
- QHBox Layout.

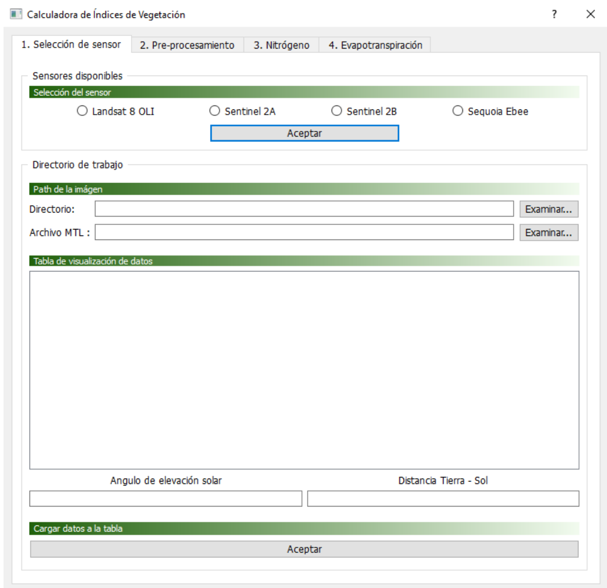

Figure 3 Graphical interface of the application, sensor selection section
Source: Own elaboration

What each of them does is described below:

Tags (QLabel)

A QLabel object acts as a placeholder to display non-editable text or image, or an animated GIF movie. It can also be used as a mnemonic key for other widgets. Plain text, hyperlinked rich text can be displayed in the label.

Line Edit (QLineEdit)

The QLineEdit object is the most commonly used input field. It provides a box in which one line of text can be entered. To enter multi-line text, the QTextEdit object is required.

CheckBox (QCheckBox)

A rectangular box before the text label appears when a QCheckBox object is added to the main window.

Like QRadioButton, it is also a selectable button. Its common use is in a scenario when the user is asked to choose one or more of the available options. Unlike radio buttons, checkboxes are not mutually exclusive by default. To restrict the choice to one of the available items, checkboxes must be added to QButtonGroup.

Radio Button (QRadioButton)

An object of class QRadioButton presents a selectable button with a text label. The user can select one of the many options presented in the form. This class is derived from the QAbstractButton class.

Radio buttons are self-exclusive by default. Therefore, only one of the radio buttons in the parent window can be selected at a time. If one is selected, the previously selected button is automatically deselected. Radio buttons can also be put in a QGroupBox or QButtonGroup to create more than one selectable field in the parent window.

Combo Box (QComboBox)

A QComboBox object presents a drop-down list of items to select. It takes minimal screen space on the required form to display only the currently selected item.

Push Button (QPushButton)

In any GUI design, the command button is the most important and most used control. Buttons with Save, Open, OK, Yes, No and Cancel etc. as captions are familiar to any computer user.

In PyQt API, the QPushButton class object presents a button that when clicked can be programmed to invoke a certain function. The QPushButton class inherits its core functionality from the QAbstractButton class. It is rectangular in shape and a text title or icon can be displayed on its face.

QHBox Layout

The QBoxLayout class aligns widgets vertically or horizontally. Its derived classes are QVBoxLayout (for arranging widgets vertically) and QHBoxLayout (for arranging widgets horizontally). (The Qt Company Ltd, 2021).

Lenguaje Python

Python is a high-level, object-oriented, scripting language. Python is also the language of choice for QGIS to automate GIS tasks, using PyQGIS. First, uic.py was used to convert the .ui file created in QTDesigner into a .py file that we will use as the project file.

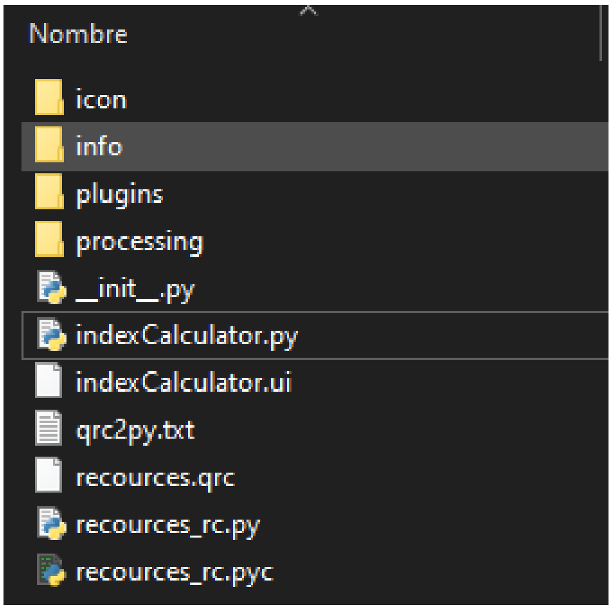

Figure 4 Resources of the application
Source: Own elaboration

Inside the plugins folder (work folder) there is a Python module called processing which contains a script called process, in which the functions for calculating radiation, reflectance and the different vegetation indices available for the user to execute are defined.

There is also a folder called icon, which contains the graphics used in the design and presentation of the graphic interface.

On the other hand, the file indexCalculator.py is the script that gives functionality to the graphical interface.

```
        QtGui.QFileDialog.ShowDirsOnly
    )
    self.lineEdit1.setText(str(imgDir)) ## Introducimos la ruta como
    global imagen ## Creamos una variable global
    imagen = self.lineEdit1.text() ## A la variable le indicamos que
    return self.lineEdit1.setText ## Esta función devuelve el acceso

def mtlPath(self):
    """Selecciona la ruta donde se encuentra el archivo MTL"""
    ## Se abre una ventana de diálogo para indicar la ruta del archiv
    mtlDir = QtGui.QFileDialog.getOpenFileName(
        None, 'Test Dialog', os.getcwd(), '*.txt')
    self.lineEdit2.setText(str(mtlDir)) ## Introducimos la ruta como
    global MTL ## Creamos una variable global
    MTL = self.lineEdit2.text() ## A la variable le indicamos que es

def shpPath(self):
    """Selecciona el archivo shapefile que servirá de área de recorte
    if self.chBoxShapefile.isChecked(): ## En el caso de que SI se in
        shpDir = QtGui.QFileDialog.getOpenFileName(
            None, 'Test Dialog', os.getcwd(), '*.shp') ## Se abre una
        self.lineEdit5.setText(str(shpDir)) ## Se introduce la ruta e
    else: ## En el caso de que NO se introduzca shp de área de recort
        QtGui.QMessageBox.information(self, "Alerta", '''Para cargar
                                      QtGui.QMessageBox.Ok) ## Si se det

def openMTL_LANDSAT(self):
    """Agregamos los encabezados de la tabla de visualización"""
    self.tableWidget.insertRow(1)
    headers =['Banda', 'Rad_MULT', 'Rad_ADD', 'Ref_MULT', 'Ref_ADD']
    self.tableWidget.setColumnCount(len(headers))
    print 'listo'
    for c in range(len(headers)):
        item = QtGui.QTableWidgetItem(headers[c])
        #print item
        self.tableWidget.setHorizontalHeaderItem(c, item)
```

Figure 5 Example of the Python code of the calculator
Source: Own elaboration

Results

In the field of remote sensing there are studies that have currently been developed for the automation of the calculation of vegetation indices, one of them was carried out by Castellanos, Moreno and Maldonado, whose objective was to obtain vegetation indices by applying the techniques for the calculation of the SAVI and NDVI, from multispectral images with reflectance values.

The images used in the application are LANDSAT 8 from the OLI sensor and the software used is QGIS 2.8.3. The technique starts with the radiometric calibration of the images and the calculation of the metadata file parameters using the QGIS GeoSudTOA add-on.

The results obtained are very similar to those obtained with the application proposed here, the difference lies basically in the input, considering the specific characteristics of both sensors.

The main factor to consider is the temporal resolution and spatial resolution; that is, while the LANDSAT sensor has 15 days and 30 m per pixel respectively, the SENTINEL 2A and 2B sensors have 5 days of temporality and 10 m per pixel.

It is important to mention that, although the results have been very satisfactory, due to its recent development, it is recommended to continue validating the data obtained through the script developed in order to control if any possible error arises in the process, detect it and therefore correct it. It is hoped that this will not be the case.

The processing time of the images was reduced considerably, obtaining a total of 21 vegetation indices in a time of less than 5 minutes, ready to be analysed and interpreted by the user.

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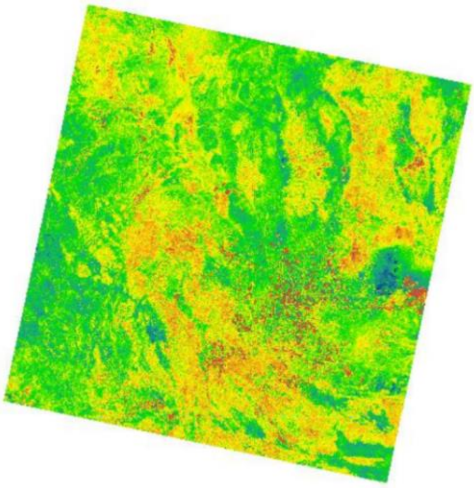

Figure 6 NDVI obtained with the use of the calculator
Source: Own elaboration

ARE.TIF	14/10/2020 10:55 a. m.	Archivo TIF	473,461 KB
CCCI.TIF	14/10/2020 10:55 a. m.	Archivo TIF	473,461 KB
CIgreen.TIF	14/10/2020 10:55 a. m.	Archivo TIF	473,461 KB
CLredE1.TIF	14/10/2020 10:55 a. m.	Archivo TIF	473,461 KB
CLredE2.TIF	14/10/2020 10:56 a. m.	Archivo TIF	473,461 KB
MCARI.TIF	14/10/2020 10:57 a. m.	Archivo TIF	473,461 KB
MCARI_OSAVI1.TIF	14/10/2020 10:58 a. m.	Archivo TIF	473,461 KB
MCARI_OSAVI2.TIF	14/10/2020 10:59 a. m.	Archivo TIF	473,461 KB
MSAVI2.TIF	14/10/2020 11:00 a. m.	Archivo TIF	473,461 KB
MTVI2.TIF	14/10/2020 11:00 a. m.	Archivo TIF	473,461 KB
NDRE1.TIF	14/10/2020 10:56 a. m.	Archivo TIF	473,461 KB
NDVI.TIF	14/10/2020 10:57 a. m.	Archivo TIF	473,461 KB
RVI.TIF	14/10/2020 11:01 a. m.	Archivo TIF	473,461 KB
SAVI.TIF	14/10/2020 11:02 a. m.	Archivo TIF	473,461 KB
TCARI_OSAVI.TIF	14/10/2020 11:02 a. m.	Archivo TIF	473,461 KB
TCARI_OSAVI_RE.TIF	14/10/2020 11:03 a. m.	Archivo TIF	473,461 KB
Viopt.TIF	14/10/2020 11:04 a. m.	Archivo TIF	473,461 KB

Figure 7 Results obtained with the application
Source: Own elaboration

It should be mentioned that it is expected to continue working with the application, so that the application not only generates the products but also provides the user with an interpretation of the values obtained, which would make the development more complete and would have an immediate application.

Would be more complete and would have an immediate application.

Currently the application already has three modules, it is capable of processing images from LANDSAT and SENTINEL sensors and images obtained by Unmanned Aerial Vehicles (UAVs), as well as including a module for obtaining useful variables in the estimation of crop evapotranspiration.

Conclusions

GIS programming languages allow the estimation of vegetation indices with a fairly acceptable accuracy. The application is very user-friendly, which allows the user to obtain the different indices without major inconvenience.

The development of the graphic interface reduces the processing time of satellite images and also automates the processes and also automate complex calculation processes for the generation of vegetation indices, which implies great benefits within the working reality.

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