v. 3, n. 26, 2023

Journal of
Engineering
Research

IDENTIFICATION AND EVOLUTION OF IRRIGATED AGRICULTURAL AREAS ON A REGIONAL SCALE THROUGH MODIS IMAGES (MODERATE RESOLUTION IMAGING SPECTRORADIOMETER). CASE STUDY IN THE COMMUNITY OF CASTILLA Y LEÓN, SPAIN

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Abstract: Remote sensing is a powerful tool for the study of natural systems. The possibility of uninterruptedly having images from various dates over long periods of time for the same area allows us to investigate the dynamics of natural and artificial processes that occur on the earth's surface.
For this work, data from the MODIS sensor (MODerate resolution Imaging Spectroradiometer) of the product MOD13Q1 has been analyzed, whose spatial and temporal resolutions (250 m and 16 days, respectively) are adapted to the study of the evolution and changes in the uses and coverage of the terrestrial surface on a regional scale. The objective of this research was to quantify and map the irrigated areas in Castilla y León throughout the period 2000-2016.
To locate irrigated areas, supervised classification methods of the annual series of Normalized Difference Vegetation Indices (NDVI) extracted from MODIS images have been used.
The results of the investigation showed a tendency to increase the irrigated area in Castilla y León, particularly in certain areas, and an increase in the duration of the irrigation period in the years analysed.
Keywords: Remote sensing, MODIS, irrigation in Castilla y León

INTRODUCTION

Freshwater is a finite and vulnerable essential resource to sustain life, human development and the environment. The control that man currently exercises over continental waters is global, and the main use of water is agriculture. The use of agrochemical substances such as fertilizers, pesticides and fertilizers are generally a cause of water pollution. Under irrigation, crop yields are notably higher than those that can be obtained under dry conditions. The decrease in available water, either in quantity or quality, causes serious negative effects on ecosystems (UNESCO, 2003; FAO, 2002) and the excessive extraction of groundwater is decimating available resources and generating unpredictable consequences (GONZÁLEZ et al., 2012). The overexploitation of aquifers and the consequent drop in piezometric levels imply changes in the chemical composition of the water, such as the increase in trace elements such as arsenic.

Castilla y León is the autonomous community with the largest area in Spain, with 94,226 km2, and most of its territory corresponds to herbaceous crops or with natural vegetation. The main use of water occurs in the agricultural field, being the second community in Spain that has grown the most in its use (INE, 2017). Hence the importance of having an objective method of monitoring irrigated areas.

Among the methods dedicated to the study and mapping of water resources, remote sensing is revealed as a powerful tool for analyzing the spatial and temporal evolution of natural and artificial systems, thanks to the orbital characteristics of satellites, which allow repeatedly obtaining images of the territory. The method is based on the inference of surface parameters from the electromagnetic energy that rises from the surface to the sensor, energy that is reflected but also emitted by it (RAWLS et al., 2003). The possibility of detecting large spaces provides a broad vision of the distribution of land uses, and also, an adequate temporal resolution of several weeks, allows studying agricultural changes in the territory (CHUVIECO, 1996).

Having images from different dates for the same area allows us to know the dynamics of the processes and land uses. The multitemporal series of images, and particularly the NDVI, allow the monitoring of the vegetation and its state (WARDLOW et al., 2007), as well as the application of very accurate classification methods, as long as they describe the different phenological cycle of the studied species (BROWN et al., 1993). For many authors, the physical magnitude derived from the images that best describes the phenological evolution and the biophysical parameters of the crops are the vegetation indices (MORAN et al., 2004). Among them, the Normalized Difference Vegetation Index (NDVI, ROUSE et al., 1974) is the most effective for determining types of vegetation cover (CIHLAR et al., 2000). The NDVI is based on the maximum radiation absorption by chlorophyll in the red band and the maximum reflection of the vegetation cover in the near infrared, and is expressed as a normalized quotient between both bands.

The multitemporal study of the changes in the surface is based on the comparison of the energy reflected by the pixels of the same roofs on different dates. The NDVI is a synoptic value of the energy reflected in the red and infrared electromagnetic energy bands that indicates the vegetative vigour, so the NDVI multitemporal series allow classifications based on the characteristics of the seasonal rhythm of each type of cover.

For this work, the MODIS (MODderate resolution Imaging Spectroradiometer) sensor has been selected. The characteristics of the sensor, with 36 spectral bands, make it suitable for studies on a global and regional scale (SALOMONSON et al., 1989; JUSTICE et al., 1998). MODIS orbits on board the Terra and Aqua satellites of the EOS (Earth Observation System) program, owned by NASA, which were put into operation in 1999 and 2002 with the aim of providing data from the atmosphere, land and oceans. The spatial resolution varies between 250 m, 500 m and 1 km, and the temporal resolution is daily, although the operational products may have a longer interval, as is the case of NDVI, which is 16 days.

Different automatic techniques have been developed to discriminate objects and covers from the series of satellite images (HAY et al., 2003). Under the classification term, in remote sensing, a set of techniques are grouped whose purpose is the assignment of pixels to a reduced number of classes and, consequently, the transformation to a map of classes. The assignment to the classes (KEY et al., 2001) can be done automatically, under an assignment algorithm that looks for similarities and performs the grouping (unsupervised classification) or with a previous training work in a number of classes specified and characterized by the user, after which the assignment and grouping of pixels is carried out similarly (supervised classification).

In this work we have tried to map and quantify the irrigated areas in Castilla y León in order to know the variation of the irrigated surfaces throughout the period 2000-2016 and their annual distribution in the form of maps. It has been the first step in a larger study whose objective is to detect areas in which there is overexploitation of aquifers due to the increase in irrigated areas and subsequently study the implications on water quality and public health.

MATERIALS AND METHODS

SATELLITE IMAGES AND PRE-TREATMENT

The MODIS sensor travels aboard the Terra and Aqua satellites, which follow a sun-synchronous polar orbit. For the work, only the Terra product has been considered, since including both satellites for the classification would be redundant. MODIS provides multispectral observations and derived products such as vegetation indices, cloud cover, aerosol concentration, surface temperature, etc. Its sweep width spans up to 2,330 km in 36 bands, and it makes observations every other day at most.

Of the existing MODIS-Terra products, the MODIS-Terra product has been chosen for the MOD13Q1 vegetation indices (HUETE et al., 2002), with a pixel size of 250 m, a temporal resolution of 16 days and with 12 information bands, including two of vegetation indices, four of reflectivities of the red, near-infrared, blue and mid-infrared bands, and other data such as angles and quality indices (DIDAN et al., 2 015). The images corresponding to scene h17 v04, which covers the northwest of the Iberian Peninsula, between the months of April and October, have been used. This calendar is adjusted to the vegetative cycle of most irrigated crops in the area, resulting in a total of 14 images for each year from 2000 to 2016.

The NDVI information band has been extracted from each of the images. Next, an image has been created with the time series in which the NDVIs of the 14 scenes of each year have been incorporated as bands. The next step has been the reprojection to work in the official coordinate system. Finally, a cut has been made selecting the surface of Castilla y León with altitudes lower than 1100 m, following the methodology of PABLOS et al. (2017). This process excludes mountainous areas where there are no irrigated areas and whose tree covers may have a spectral behavior similar to that of irrigated land (Figure 1).

METHODOS OF CLASSIFICATION

The supervised classification begins with a training phase consisting of delimiting representative pixels of each of the previously established classes in the image. After training, each image pixel is assigned to a class using a classification algorithm.

The selection of the legend is a crucial point that determines the quality of the final result. In the present case, the classification has been tested by varying the number of cover classes, starting with six (irrigated, dry, bodies of water, artificial soil, bare soil and forest-pasture) and finally reducing the number to three (irrigated, dry and others) after visual analysis of the results. Similarly, the selection of training areas influences the result. It has been tried to carry out the sampling initially in 6 areas for the irrigated and rainfed classes distributed regularly throughout the study area, and reducing the number to three in the definitive classifications, since the result was similar. At all times, the map of crop uses and other areas of Castilla y León has been used as a reference (DEL BLANCO MEDINA et al., 2015).

Finally, the sampling for all years has been rigorously systematized, using the same areas and approximately the same number of pixels (Figure 1). It has been decided to select dispersed pixels within the sampling zones, obtaining a large number of small samples that provide more information than that extracted from contiguous pixels (CONGALTON, 1988).

The identification of irrigated and rainfed pixels is made from the spectral curve of these classes (Figure 2), which indicates the NDVI values throughout an annual cycle. It is observed that the irrigated NDVI increases from May, the maximum occurs in July-August (coinciding with the period of maximum vigor of these crops), and from that moment the decline begins. On the contrary, in dry land, the maximum value of NDVI occurs in May. Both types of uses present an inverse behavior for the NDVI, already known in the study of the evolution of multitemporal series of these roofs (SÁNCHEZ et al., 2012). Figure 2 shows the mean NDVI values of the years studied throughout the April-October period.

For the evaluation of the supervised classification method, the confusion matrix between the training areas has been used (CONGALTON & GREEN, 2008), a common validation method based on the Kappa index

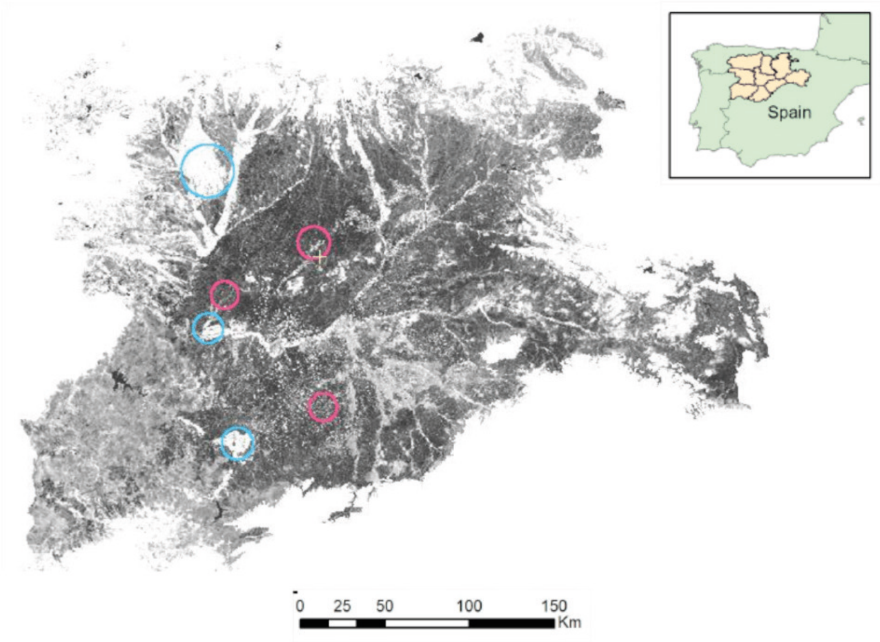

Figure 1. NDVI MODIS representing the study area over Castilla y León and sampling areas of the irrigated land classes, in blue, and dry land, in red.

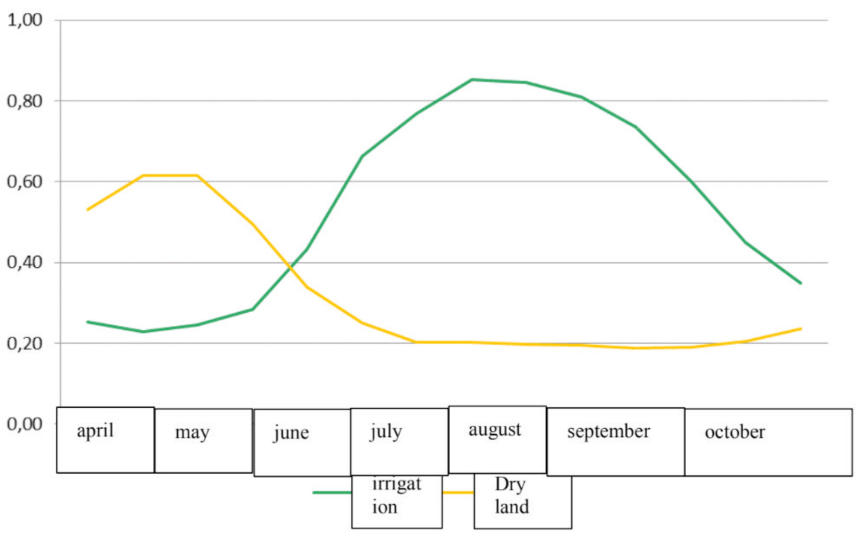

Figure 2. Average temporal evolution (2000 to 2016) of the NDVI for the irrigated and rainfed classes.

DOI 10.22533/at.ed.3173262301087

(variable between 0 and 1, with 1 being the optimal choice of training areas) and the average and global precision of the process (%).

RESULTS

The evaluation of the training areas used in the supervised process yielded a high level of reliability of the results. The Kappa index ranged between 0.998 and 1 for all the series, the average precision between 99.81% and 100%, and the overall precision between 99.92% and 100%.

The results of the total annual irrigated areas for Castilla y León for the years 2000 to 2016 (Table 1 and Figure 3) showed an increasing trend, with minimums in the years 2004, 2005 and 2014; and a maximum in 2015, which coincides with the statistical information about irrigated areas in the region (INE, 2017). In general, it could be affirmed that the overall value of irrigated areas has increased in the region in the period studied. However, there are notable interannual oscillations in the absolute values of the irrigated area, which could be attributed to the classification procedure itself, but which in reality are not so relevant if considered as a percentage of the total agricultural area (Table 1). The percentages obtained, variable between 2% and 4%, coincide with previous studies based on remote sensing in the region (DEL BLANCO MEDINA et al., 2015, SÁNCHEZ et al., 2012).

Year	Surface (km^2)	% Irrigated area
2000	2200	2,34
2001	2221	2,36
2002	1855	1,97
2003	2501	2,66
2004	1666	1,77
2005	1784	1,90
2006	3296	3,51
2007	2624	2,79
2008	2280	2,43
2009	3189	3,39
2010	3243	3,45
2011	3268	3,48
2012	2258	2,40
2013	2724	2,90
2014	1829	1,95
2015	3835	4,08
2016	2411	2,56

Table 1. Areas and percentages of irrigation in Castilla y León in the period 2000 to 2016 obtained with the classification procedure.

In addition to the total surfaces, the resulting maps have revealed the different zoning of the irrigated areas in Castilla y León throughout the study period. Thus, based on the annual maps derived (Figures 4 and 5), the appearance of new large irrigated areas has been observed, such as in the Moraña de Ávila region, in 2010, and to the Northwest of Salamanca, in the Las Villas region, in 2012. This zoning opens up research on the exploitation of aquifers and shallow waters in specific areas and allows a detailed study of particularly problematic areas, which constitutes the final objective of the work.

Finally, the interannual study has allowed the comparison of the duration of the vegetative cycle of these surfaces throughout the study period. In the total temporal evolution, it was observed that the period of vigor of irrigated crops has been extended over time, beginning in June in the first years and moving forward until the end of May in recent years. This effect coincides with the increasing use of long-

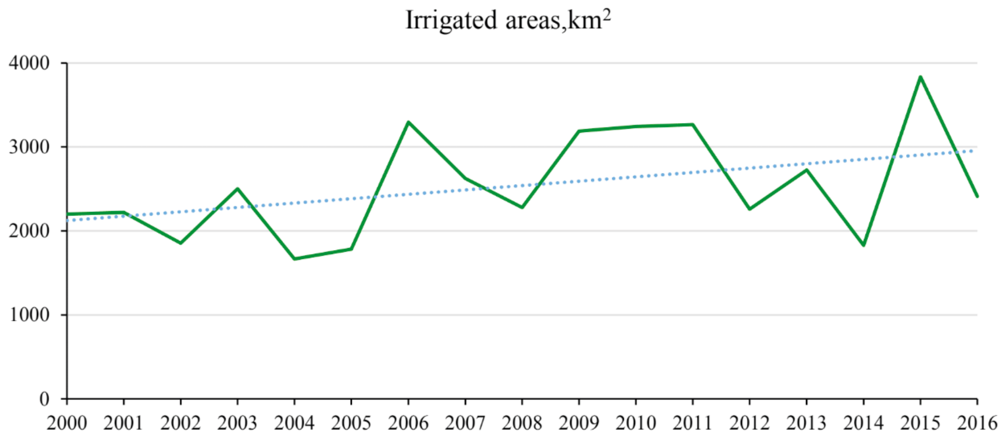

Figure 3. Evolution of irrigated areas in Castilla y León.

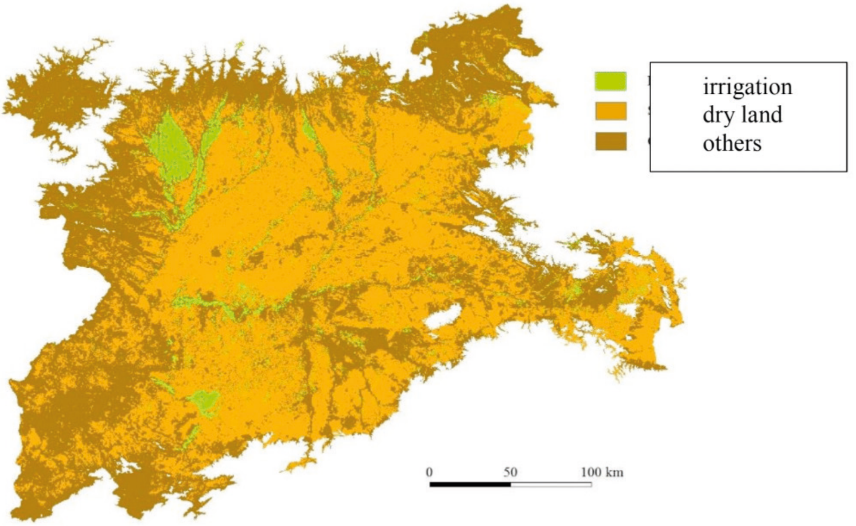

Figure 4. Map obtained for the year 2010

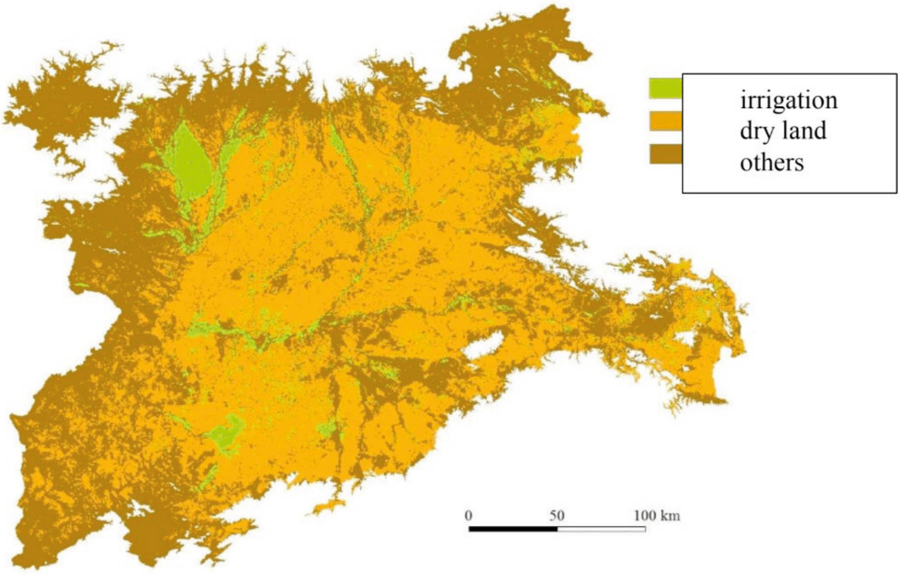

Figure 4. Map obtained for the year 2015

cycle seeds, which advance the development of the plant and prolong its vegetative phase with the aim of increasing production. This is precisely what has been observed in the NDVI cycle. This fact also has an immediate consequence in the use of water for irrigation, and that is that a greater provision is necessary to maintain these new varieties.

CONCLUSIONS

The objective of the study has been to use the capacity of the NDVI multitemporal series for the characterization of land uses and, particularly, the monitoring of irrigated areas in the Castilla y León region. MODIS MOD13Q1 annual series allowed classification on a regional scale. Its temporal resolution of 16 days offers the possibility of elaborating multitemporal series throughout the vegetative period of the plants and identifying the irrigated land class.

The satellite series allow to know the real vegetative cycles of the crops. The cycles detected between irrigated land and other crops and natural surfaces are very different, which gives rise to their classification. The resulting maps gave an idea of the total areas dedicated to irrigated crops, but also their spatial distribution and their phenological calendar.

It has been detected that the annual vegetative cycle has been expanding, which implies a greater consumption of water. This trend during the study period reflects the actual evolution of irrigation practices in the region. In recent years, the use of long-cycle seeds has spread, which advance the development of the plant and prolong its vegetative phase with the aim of increasing production. Regarding the total surfaces, despite the logical interannual differences, an increasing trend was detected throughout the study period. All of this, added to a significant increase in irrigated plots in specific areas, makes the remote sensing study a valuable tool for subsequent studies of water consumption in agriculture and the repercussions that this may have on variations in the groundwater table of aquifers and on the composition of groundwater due to possible overexploitation.

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