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Estimation of irrigated crops areas: Generation of water demand scenarios

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Abstract. The study of the evolution of agricultural demand is one of the most significant aspects for water management, not only due to the specific weight that it represent inside the global river basin demand, but also to the difficulty to estimate it. The irrigated area map is elaborated from digital processing of available satellite images, and is based in the analysis, interpretation and classification of vegetation index maps, where numerical information is collected and is linked with the photosynthetic activity rate, vegetation cover vigour and vegetation vigour within each crop.

Keywords. Water demand – Remote sensing – Crop maps – Vegetation index.

Estimation des zones irriguées : la generation de scénarios de demande en eau

Résumé. *L'étude de l'évolution de la demande agricole est l'un des aspects les plus importants pour la gestion de l'eau, non seulement par son poids spécifique dans la demande globale dans un bassin versant, mais aussi du à la difficulté de son estimation. La cartographie de la superficie irriguée se fait à partir du traitement numérique de l'imagerie satellitale disponible et est basée sur l'analyse, l'interprétation et la classification des cartes d'indice de végétation dans lesquelles l'information numérique est recueilli liée au taux d'activité photosynthétique et à la vigueur de la végétation dans chaque parcelle et pour chaque culture.*

Mots-clés. *Demande en eau –Télédétection – Cartes des cultures – Indice de végétation.*

I – Introduction

The evaluation of the evolution of water demand over time is one of the aspects that produces major deviations and errors in the usual process of restoration of the natural regime of the contributions.

The study of the evolution of agricultural demand is one of the most significant aspects, not only because the specific weight that it represents inside the global river basin demand, but also due to the difficulty to estimate it.

Mapping of irrigated areas is made from digital image processes based on available satellite images, as well as in the analysis, interpretation and classification of vegetation index maps, where numerical information is collected and linked to the photosynthetic activity rate, vegetation cover vigour and vegetation vigour within each crop.

Vegetation indexes are calculated by reference with reflectivity values, collected by satellite, within the visible and near and medium infrared spectrums:

– Red visible, by corresponding to the absorption range of chlorophyll, to differentiate the vegetation type. This band records the reflected energy in the visible region corresponding to the red where chlorophyll pigments of the vegetation reaches its maximum absorption. Green and vigorous plants, with high rates of photosynthetic activity, absorb a very large amount of light within this range, being quite reduced the values of reflected radiation. This makes that surface with irrigated crops being identifiable in this spectrum band for representing low digital values respect to the rest of surfaces.

– Near reflected infrared, indicator of the plant biomass. This bands picks up the electromagnetic radiation reflected in the near infrared. Terrestrial surfaces with high biomass density reflect around the 45% of the received radiation. Surfaces with irrigated crops are characterised by a higher vegetation cover and a higher biomass content that non irrigated crops, and they are identified in this band for presenting very high digital values in comparison to the rest of surfaces.

– Near reflected infrared, sensible to moisture content of vegetation. Water in plants and soils absorbs the most of the radiation reaching at Earth surface, being the reflected radiation around the 30% of the received. Surfaces with irrigated crops can be discriminated in this bands for representing digital values lowest than the rest of surfaces.

II – Methodology

The methodology for each irrigated area consists of:

– Development of infrared colour compositions to each date.

– Calculation of vegetation indexes.

– Determination of thresholds for discrimination between irrigated vegetation and other types of surfaces.

1. Development of infrared colour compositions

The infrared colour composition is the combination in a single image of near infrared, visible and green visible bands, associating each band to the primary colours (RGB).

The higher photosynthetic activity rate of plants, their fraction of vegetation cover over the ground or the moisture present in the outer tissues of the plant, the more intense will be the red colour that is seen in these bands combination (Fig. 1). According to this combination:

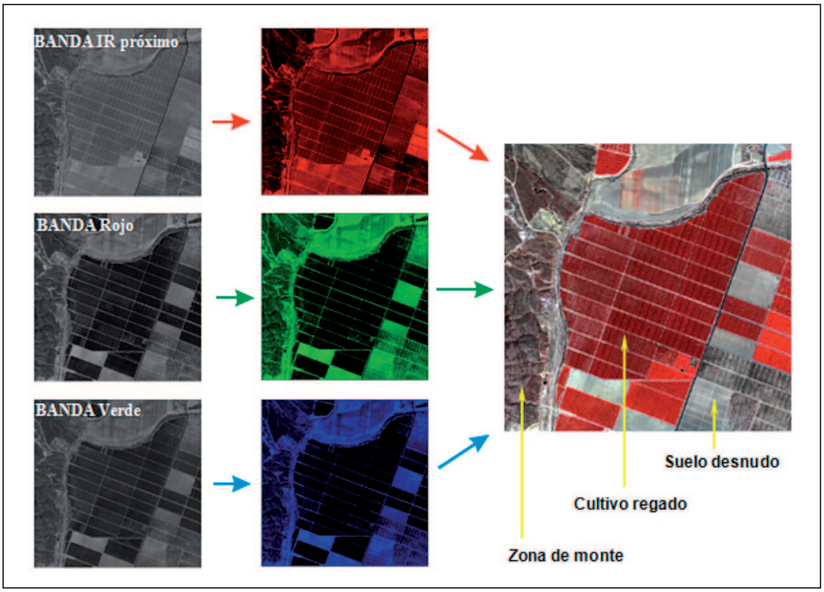

Fig. 1. Sheme of infrared false colour composition.

– Irrigated crop areas appear in intense red shade.

– Areas occupied by natural vegetation appear in green or greyish shades.

– Surfaces of stubble or bare soil appear like light grey or white shades.

For the discrimination of crops under plastic or greenhouses it necessary to use a different methodology based on the detection of the response produced by the plastic, which produces a high reflectance of light in a very specific wavelength.

It uses two bands of the visible spectrum (bands 1 and 3) and the near reflected infrared band (band 7) preparing a composition that allow to discriminate areas occupied by crops under plastic appearing in deep blue and purple shades (Fig. 2).

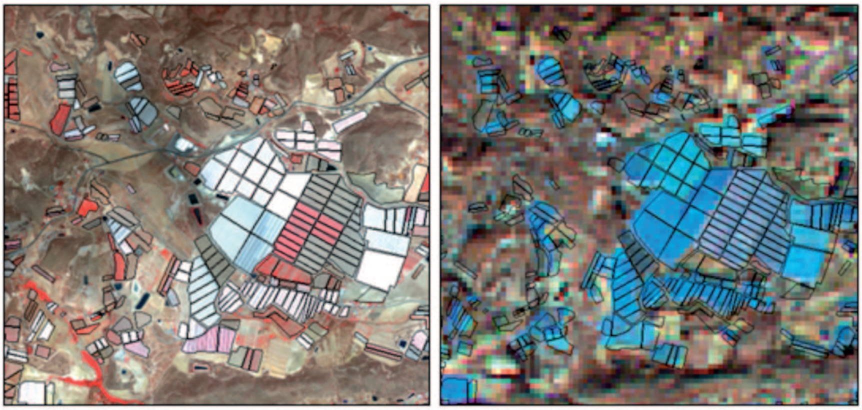

Fig. 2. Example of false infrared colour composition (right) and composition to plastic detection (right image).

2. Calculation of vegetation indexes

A *vegetation index* is a mathematical algorithm applied over stored values of two or more bands. They are used to discriminate different covers that present a very different behaviour in terms of reflectivity in these bands.

For the identification of areas occupied by crops with significant vegetation vigour and significant vegetation cover, maps have been prepared by calculating *Normalised Difference Vegetation Index, NDVI* over each one of these irrigated areas.

The NDVI is a relationship between pixel values of near infrared band and pixel values of visible red band, in the words:

$$NDVI = \frac{NearIR - Visible\,red}{NearIR + Visible\,red} \times 100$$

NDVI is a sensitive indicator of vegetation presence and its conditions. The spectral response of terrestrial surface in these two bands of electromagnetic spectrum is enlarged in the NDVI. Photosynthetically active vegetation areas with high coverage present high values of NDVI due their high electromagnetic reflectance in the range of near infrared and their low reflectance in the visible range. Bare soil and water presents very low NDVI values. Figure 3 provides and example of general map of vegetation index.

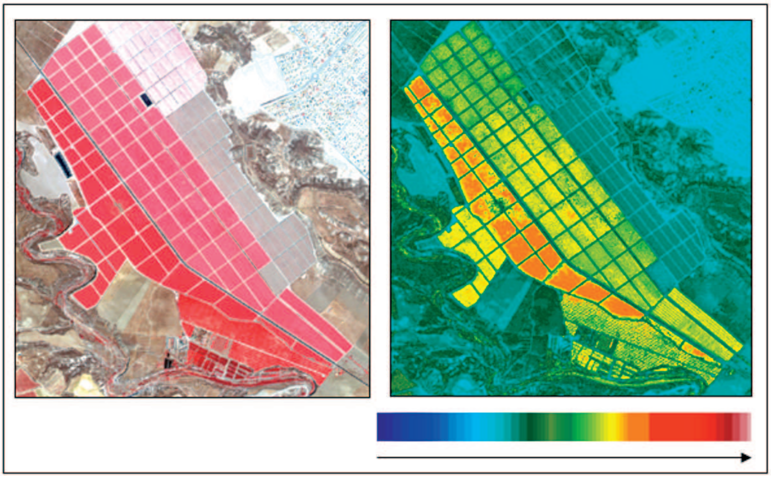

Fig. 3. Elaboration of NDVI map.

Moreover, for the delimitation of greenhouses and crops under plastic, an index called ICP *(Index of Crop Under Plastic)* is used. The mathematical formula, for Landsat bands, is presented below:

$$ICP = (Band1\text{-}Band7) * Band1 * Band4$$

Being:

Band 1: Blue band.

Band 7: Medium infrared band.

Band 4: Near infrared band.

ICP is designed so that pixels corresponding to areas covered by pure plastic reach values of greater magnitude than most of other studied surfaces in the area (Fig. 4).

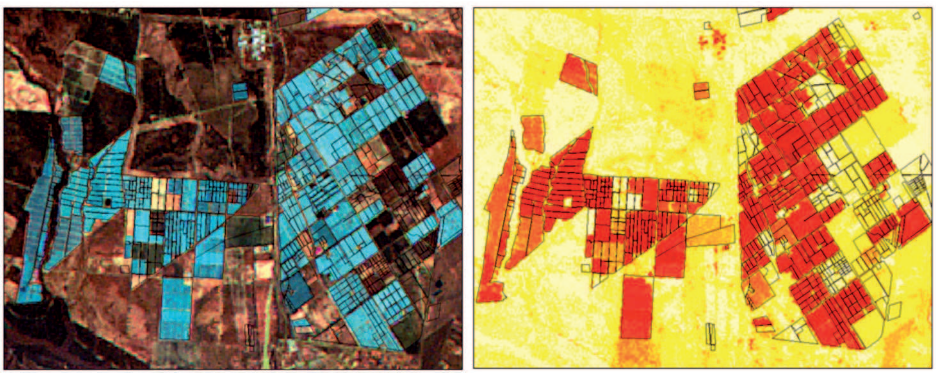

Fig. 4. Elaboration of ICP map.

Discrimination capacity of crops under plastic of this index is very high, particularly in areas occupied by greenhouses or big tunnels. However, in small plots located in borders and in exploitations with small tunnels with less density of plastic, values obtained by calculating indexes may be confused with those appeared in areas with high reflectivity like beach or dunes, industrial areas or urban areas.

3. Territorial segmentation

Prior to the definition of thresholds, a territorial segmentation must be carried out in order to define areas where agronomic traits (type of existing crops and phenological development) are as much homogeneous as possible.

The objective of this process is to minimize errors produced trying to extrapolate criteria of irrigated identification, which are adopted based on a series of concrete measures over a large territory. For this, the study area is divided in different units where climatic and environmental characteristics, as well as agricultural practices and crops typology are similar.

The process of elaboration of irrigated area maps is developped for each of the areas resulting from the territory segmentation.

4. Discrimination between irrigation and other types of surfaces

After obtaining both values of NDVI and ICP for different dates, cut-off values are defined to keep those that are interesting (those that characterize irrigated crops or crops under plastic) and discard the values of covertures not interesting.

The threshold of cut-off is a minimum value inside the index map that our unit (pixel) should have to be classified as irrigated crop or crop under plastic.

This will result in obtaining maps of irrigated areas and maps of crops under plastic for each one of the areas defined from the territorial segmentation. The union of these partial maps allows the production of irrigated area maps for each analyzed date.

III – Conclusions

The main features that support the remote sensing technique in such type of studies are:

(i) *Objectivity*. Data provided are digital images (representation of an object by a two-dimensional numerical matrix) obtained by spatial international agencies (ESA, NASA, etc.) and are commercially available by any citizen.

(ii) *Continuity of data*. Data provided by satellites are not extrapolated or interpolated from punctual observations, as with statistical techniques, but are a discretization of continuous space observed variables in units called pixels that generate a digital image.

(iii) *Frecuency of observations*. Because theie orbital models, satellites fly the same area periodically, allowing us to obtain periodical observations of an area. This means that current orbiting satellites, Landsat series per example, provides one observation over a particular area every 16 days, or 22 observations per year or 440 observations over the last 20 years. SPOT series of satellites, do it every 26 days or 14 times a year or 280 times in the last 20 years.

(iv) *Multispectrality of observation*. Sensors on board satellites capture data no only in the visible regions of spectrum (which are captured by the human eye or by aerial photography) but also in the infrared spectral region, allowing us to "see" invisible things for human eye.

(v) *Multiscale Observation*. With current orbiting satellites, it is possible to approach studies from 1:150.000 scales (from images with 30 meters of spatial resolution for a maximum tolerable error of 0.2 mm) to scales of 1:3.500 (from QuickBird images with 70 cm of spatial resolution).

(vi) *Low cost of data acquisition*. Prices of acquisition of satellite images ranging from a mission to another (Landsat, SPOT, QuickBird...), and even if it is a modern image or 10 years image, range from € 23/km^2 of QuickBird, to € 2.00 km^2 for SPOT schedule image with 2.5 m of spatial resolution, to € 0.05 km^2 current Landsat image, with 7 spectral bands and 30 m of spatial resolution.

Regardless the methodology (photointerpretation or digital analysis) used to extract information contained in the satellite images, space remote sensing is a powerful, dynamic and objective source of data for the estimation of irrigated areas and for the monitoring of their evolution through time.