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Carlo De MICHELE,
Massimo NATALIZIO, Guido D'URSO[1]

APPLYING EARTH OBSERVATION TO DETECT NON-AUTHORISED IRRIGATION: THE CASE STUDY OF CONSORZIO SANNIO ALIFANO (ITALY)

SUMMARY

In addition to reducing global water availability unauthorized irrigation and over-consumption can have social consequences in terms of conflicting water use. In its Water Framework Directive, the European Union (EU) has outlined an agenda for future water policy, emphasizing that, to ensure a sustainable use of water resources, these practices should be strongly opposed. In order to address this problem efficiently, water managers need to map irrigated area, plan the rational use of water resources under limited availability, and prevent unauthorized irrigation. We are currently developing an innovative system to do this based on a series of multi-spectral satellite acquisitions from two sensors having different spatial and temporal resolutions (DEIMOS, Rapid Eye). In this system, the irrigated area is identified based on temporal pattern recognition, exploiting the differing developmental rates between irrigated and not irrigated crops. This method was applied in the district of Consorzio Sannio Alifano, located in Southern Italy, where irrigation is required for most crops including corn, alfalfa, fruit trees and vegetables. An accuracy assessment of the methodology has been performed and has demonstrated positive results of this approach. Future system upgrades will exploit information derived from short-wave infrared data obtained using of the newly developed Sentinel-2 sensor. The approach described herein is the technological basis of a recently-funded EU H2020 project, named ***D****etection and* ***I****ntegrated* ***A****ssessment of* ***N****on-authorised water* ***A****bstractions using Earth Observation* or DIANA.

Keywords: *Detection of non-authorised irrigation, EO & illegal irrigations, agricultural advisory services, satellite monitoring of irrigated areas, management irrigation systems.*

INTRODUCTION

European agriculture is by far the largest user of water in this region. For example, in Spain, Greece and Portugal, respectively, 64%, 88% and 80% of

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[1]Carlo De Michele, Ariespace s.r.l., Spin-off Company of the University of Naples Federico II, Centro Direz. Is.A/3, Naples, ITALY, Massimo Natalizio (corresponding author: massimonatalizio@gmail.com) Irrigation Consorzio Sannio Alifano, Viale della Libertà 61, Piedimonte Matese (CE), ITALY, Guido D'Urso Department of Agricultural Sciences, University of Naples Federico II, Via Università 100, Portici (NA), ITALY
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total water resources are destined to agriculture, with significant environmental and economic impacts (OCSE 2006). The dominance of agricultural water usage isa critical issue especially considering that, in Europe, about 75% of 16 million hectares of equipped agricultural fields is centered in Mediterranean countries (France, Greece, Italy, Portugal and Spain), a region periodically exposed to periods of crisis in water availability. In these countries, proper irrigation management and efficient utilization of water resources is a strategic goal. After an initial period of huge financial investment, based on the concept that modernization of irrigation required new irrigation infrastructure, increasing emphasis has been placed on the development of systems and technologies for better management of the modernized infrastructure.

One of the critical issues in this second phase of irrigation improvement is linked to the availability of updated data concerning the actual extension of irrigated areas and the evaluation of crops' water needs. At present, in effect, the methods applied in EU Member States to estimate irrigation water volumes are mostly cognitive, administrative or indirect. They include questionnaires, coefficients of water use, water rights, time of pumping stations and other empirical methods (Nagy, Lenz, Windhofer, Fuerst, Fribourg-Blanc,2007). Although the water directive (2000/60 CE) states that each water district must know the quality and the quantity of water allocated for various uses, to date, a comprehensive framework concerning both the localization and the amount of irrigation use is still in the future (Wriedt *et al.*,2009). In particular, the extension and the distribution of irrigated areas still remain unknown, despite the importance that these information would have on both food safety and the water/energy cycle (Vörösmarty, 2002).

In this context, a replicable and updated methodology allowing the identification of irrigated areas would be a valuable tool to monitor the use of water resources for irrigation purposes. Several authors point out that satellite-based technology, particularly those related to Earth observation, may be an effective tool for mapping irrigated areas all over the world and at different spatial scales (global, regional, local) (Ozdogan *et al.*, 2010) (D'Urso *et al.*, 2010).

The aim of this study is the definition of an innovative methodology based on Earth observation data for mapping irrigated areas on a local scale in semi-arid environment. The following example shows how the method was applied to map the irrigated area of a part of the general district served by the Consorzio Sannio Alifano, in Southern Italy, illustrating aspects of the study which can be generalized in favor of Authorities and management bodies committed to ensuring a sustainable and legal use of water resources in agriculture.

MATERIALS AND METHODS

The basic assumption of the proposed methodology is that, under conditions of hydrologic deficit typical of semi-arid environments, high crop growth trends are compatible only with external irrigation supplies. Based on this assumption, the detection of the irrigated areas can be conducted independently of the actual cultivated crops. Practically, this means that a detailed knowledge of the spatial distribution of the different crops is not required. Rather, it is enough to take into account the timing of some indexes able to represent the vegetative vigor, such as NDVI.

The proposed approach is based on the use of two time series of satellite multispectral images (Double Series Irrigation Mapping - DSIM) acquired from the beginning to the end of the irrigation season. The first series, consists of data with low spatial resolution and high temporal frequency, in order to follow the phenological development of crops. The second, consists of 1 or 2 images with high spatial resolution, acquired in coincidence of the peak crop growth, in order to obtain a better segmentation of individual fields.

From an operational point of view, the procedure consists of the following stages:

a) Choice of data and preliminary processing

In this phase the types of sensors most suitable for the study are chosen based on the requirements in terms of spatial resolution, temporal and spectral.

b) Production of multi-time series of vegetation index NDVI maps

At this stage, a spectral index map NDVI is produced for each of the acquisitions of the low spatial resolution series. Subsequently, a temporal stack (layer stack) is created (a secondary activity conducted is the manual masking of areas not of interest, typically urban, mountain and wetlands such as rivers, lakes and water basins in these maps).

c) ISODATA unsupervised classification applied to time series of NDVI index maps.

d) Automatic extraction both of temporal NDVI index and vegetation peak pattern.

e) Labeling of vegetative areas

Identification of classes of vegetation categories that, given the water deficit conditions, show NDVI pattern compatible only with irrigation;

f) Supervised classification of the high-resolution image

This is done using such training pixels the irrigated areas identified via the multi-time classification of NDVI index made on the long series of low-resolution images. This phase is aimed at improving the spatial resolution of the data.

g) Mapping of irrigated areas along with possible integration with GIS data.

This process is illustrated schematically in Figure 1.

In summary, the time series maps of NDVI index collects all the information needed, pixel-by -pixel, parcel-to-parcel, to establish whether or not a given area is irrigated. However, the final solution to the problem of identification requires a single map for the whole irrigation season. Ideally, this would include a binary information (irrigated/non-irrigated) in which regions are divided into classes (irrigated with high, medium or low probability).

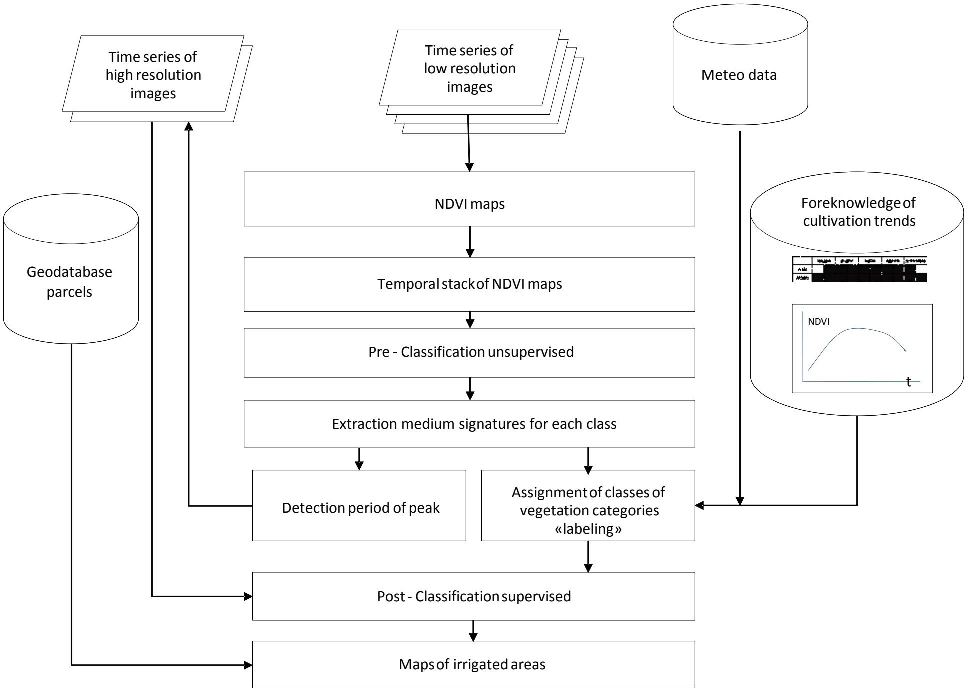


Figure 1. - Work flow of the detection process of irrigated areas

Given the complexity of the 3-dimensional problem (two defined by the plane of the investigated surface and the third, time, i.e., growth trends) that develops, an automatic classification of the temporal series of NDVI maps was performed. This is equivalent to eliminating the time dimension from the derived solution: the index NDVI trend is analyzed, pixel by pixel, and the result of this analysis assigns the pixel to a class (irrigated/non-irrigated).This operation is carried out automatically by a statistic algorithm that divides the pixels into clusters with similar characteristics, i.e. temporal trends NDVI index which can be gathered together. Finally, with the help of metrics and model diagrams, the different classes irrigated and non-irrigated can be recognized by following the procedure illustrated in Figure 2.

The application of this method leads to the classification of irrigated areas into three types:

1. **Class A irrigated areas**: characterized by a strong trend of crop growth, that is irrigated with high probability (mainly crops such as corn);
2. **Class B irrigated areas**: characterized by a time trend of NDVI index with "saw tooth shape", definable as irrigated with medium probability (mainly crops like alfalfa); in case of satellite acquisitions very spaced in time their recognition is very difficult;
3. **Class C irrigated areas**: characterized by a fairly steady and high-value NDVI index, definable as irrigated with low probability; they are mainly permanent crops i.e. some tree crops (including vineyards; in such cases)

where it is difficult to recognize the practice of irrigation because of the stress condition in which they are normally subjected during the growth or for limited vegetation dynamics.

4. **Non-irrigated areas**.

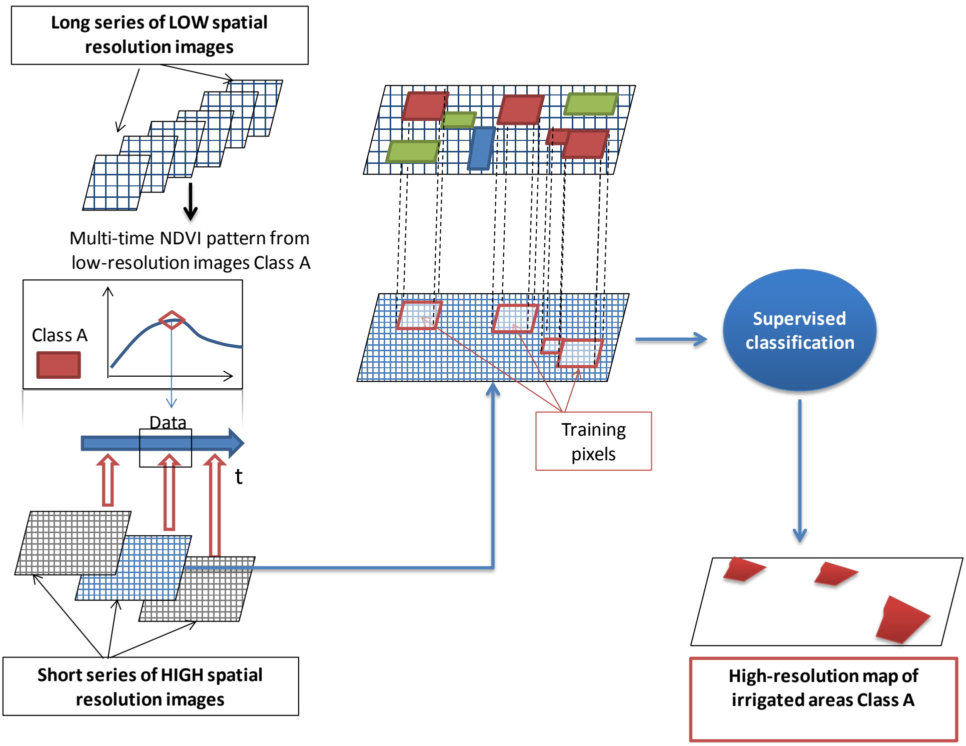
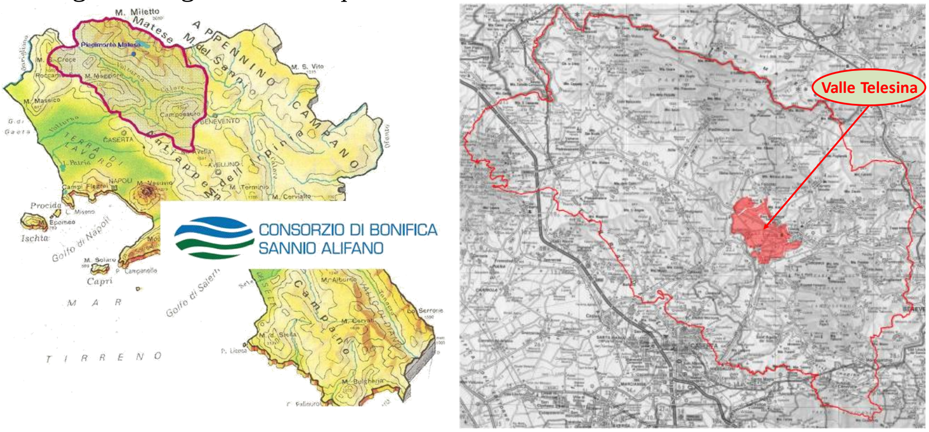


Figure 2. Procedure for the classification of high-resolution images (short series) by choosing the training pixels on the basis of multi-time classification NDVI index made on the long series of low-resolution images**.**

RESULTS AND DISCUSSION

The methodology described above was applied to map the irrigated area of a part of the overall district served by Cosorzio Sannio Alifano, located in Southern Italy, encompassing a surface of about 5,000 hectares and named Valle Telesina. This region is shown in Figure 3.The study area is characterized by agriculture irrigation in the period from May to September, with main crops grown corn, alfalfa, fruit trees and vegetables. The average size of each plot is about 2 hectares.

An important source of knowledge for this study has been the irrigation information system used by the Cosorzio Sannio Alifano. In 2013, the Consorzio set up a geographic information system (GIS) to streamline irrigation management. The system, designed by the academic spin off company Ariespacesrl., which is consulted and updated via web, allows the Consorzio to generate single irrigation plot mapping referred to land parcels, irrigation districts, distribution networks, etc. and also integrates information supplied by the farmers about the type of cultivated crops, the time of planting and harvesting, the irrigation techniques etc.



a) b)

Figure 3. a) The overall district of Cosorzio Sannio Alifano (area of about 195,000 ha) outlined in red within the larger Campania region; b) The study area (in red) named "Valle Telesina" (about 5,000 ha).

A portion of this map is shown in Figure 4. For the purposes of this study, the access to the geographical database, allowed the improvement of the segmentation and resolution of the maps produced, by using the information vector cadastral layer to compare the data declared by farmers with the real land use and detect non-authorized irrigation.

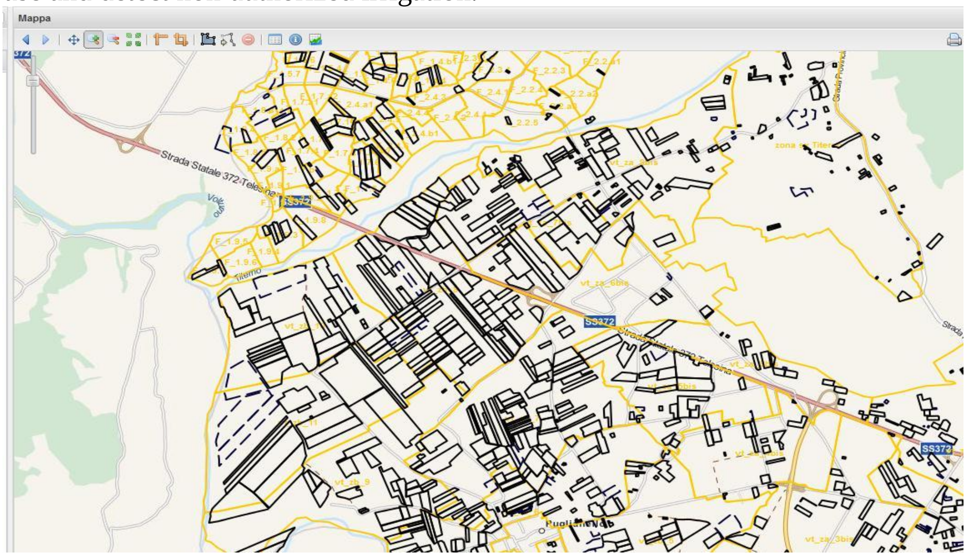


Figure 4. - View of a portion of the Consorzio Web-GIS map

The study was based on 8 DEIMOS images (long multi-time series at a lower spatial resolution, 22m) and 4 Rapid Eye images (short multi-time series with higher spatial resolution, 6.5 m), acquired in the period May 1 - September 30.The results showed a high accuracy of the maps could be achieved (see Figure 5). In particular, the reliability of the classification was assessed by comparison with the ground truth obtained from irrigated land database and, sometimes, through field inspection of plots evenly distributed in the study area.

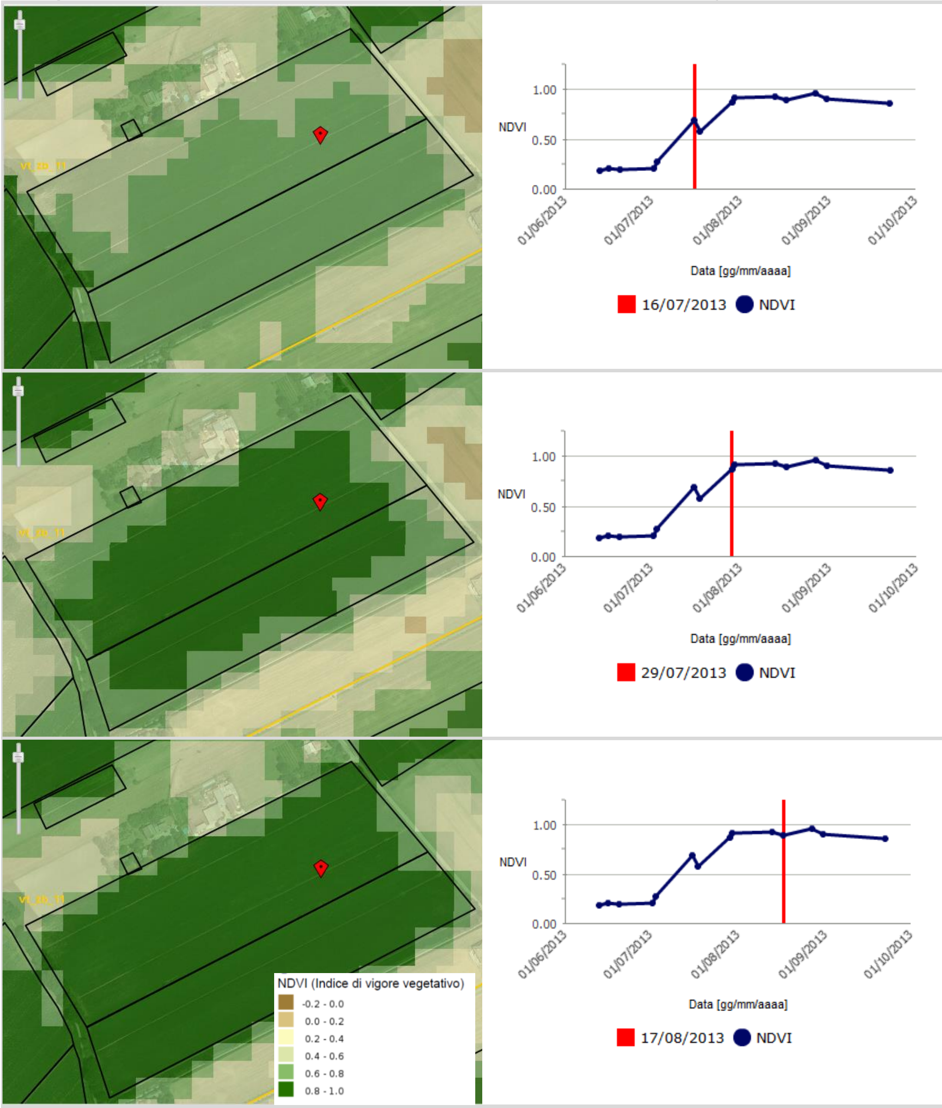


Figure 5. Time trends of NDVI index of an irrigated parcel (corn, Class A): notice the growth trend of NDVI index during the period June-September 2013 (dates: July 16; July 29; August 17).

Table 1. - Error matrix and values of accuracy measures of the procedure

		Data reference / ground truth				**Total per class in the map**	**UA**
		Class A	Class B	Class C	No irrigation		
Classification data	Class A	25	1	0	0	27	93%
	Class B	1	2	0	0	8	63%
	Class C	0	3	1	1	6	50%
	No irrigation	0	0	0	8	9	89%
Total per truth class		26	6	6	9	50	
PA		96%	56%	50%	89%		82% GA

The accuracy of the method was assessed by the following error matrix, in which the quality indexes have been calculated in terms of global (overall) accuracy (GA), user accuracy (UA) and producer accuracy (PA), as shown in Table 1.GA was defined by the ratio of the total of the agreements to the total test samples, and represents the probability that a point taken at random is correctly classified in the thematic map. It can be seen from Table 1that the estimated GA was 82%.

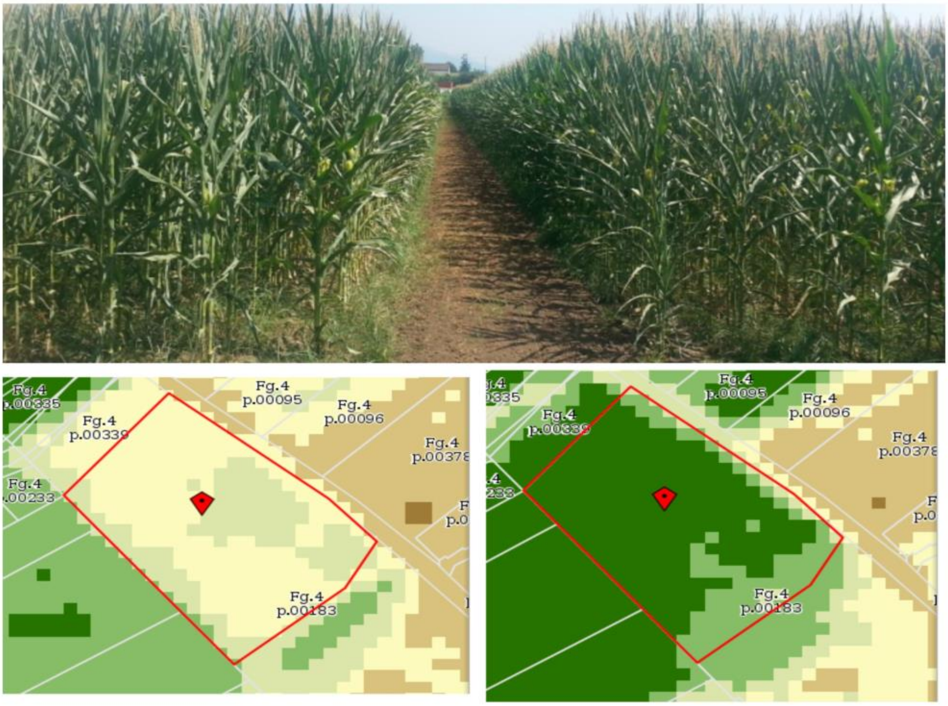


Figure 6. Inspection of a corn field for the detection of the ground truth, originated from the observation of the time trends of NDVI index. a) picture of the inspected field; b) NDVI map at beginning of the season; c) NDVI map at the period of field inspection.

As a result of the analysis, computer experts of Ariespacesrl Company identified and promptly indicated to the staff of Consorzio the lists and the maps of land parcels to be checked. The information was provided in terms of cadastral coordinates - Municipality, Sheet and Parcel - and identity of land owners. These parcels (266 in total) correspond to approximately 114 hectares (compared to a total surface of 920 hectares registered as “irrigated”) to be checked because they were identified as potentially irrigated but lacking of irrigation demand. The field inspection carried out by the staff of Consorzio have verified the accuracy of the predictions (see Figure 6), given that in 89% of the cases the presence of irrigated crops in the reported lands was observed.

CONCLUSION

This study has demonstrated that the mapping of irrigated areas obtained by EO data is a reliable support tool for irrigation management capable of identifying unauthorized irrigation in agriculture rapidly and remotely. The system used has the following strengths:

- qualitative/quantitative information data is provided on the real performance and the status of crops growth;
- programming many acquisitions during the entire irrigation season is easy;
- large areas can be covered with a single image;
- processing of the data is rapid (images are usually supplied already pre-processed);
- support can be readily provided to water managers, i.e. it’s possible to carry out targeted controls on the ground based on satellite information, thus maximizing the utilization of dedicated personnel;
- procedures can be simply automated;
- information provided at an affordable cost.

This same methodology can also be applied to give farmers and water managers an additional service, i.e. the “irrigation advice” (timely information about crop water requirements), without appreciable increased costs, amplifying the advantages of EO systems.

Future developments of the proposed methodology are related both to the possibility of improving the analysis of the temporal vegetation indexes and the improvement of the segmentation using classifiers, i.e. “object oriented” instead "pixel based". In particular, the study on vegetation indexes can benefit greatly from the opportunity to use the new generation of Sentinel-2 constellation sensors that allows to frequently updating the mapping of land cover. Moreover, using short-wavelength infrared data (SWIR), can improve the evaluation of biophysical parameters of vegetation, taking into account the water content of the vegetation.

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