European Union Network for the Implementation and Enforcement of Environmental Law

Project WODA: Water Over Abstraction & Illegal Abstraction Detection and Assessment

Pilot Feasibility Study Malta

Final Report: March 2016

Document change log

Version	*Date*	*Comments*
1.0	07/03/16	D. Bellingeri: draw up
1.1	08/03/16	M. Schembri: revision

Summary

1 Introduction

This document describes the Pilot Feasibility Study related to Malta, in the framework of WODA project (Water Over-abstraction and illegal abstraction Detection and Assessment).

1.1 Malta's context

1.1.1 Climate

The following figures summarize the main climate data and indicators referred to Malta.

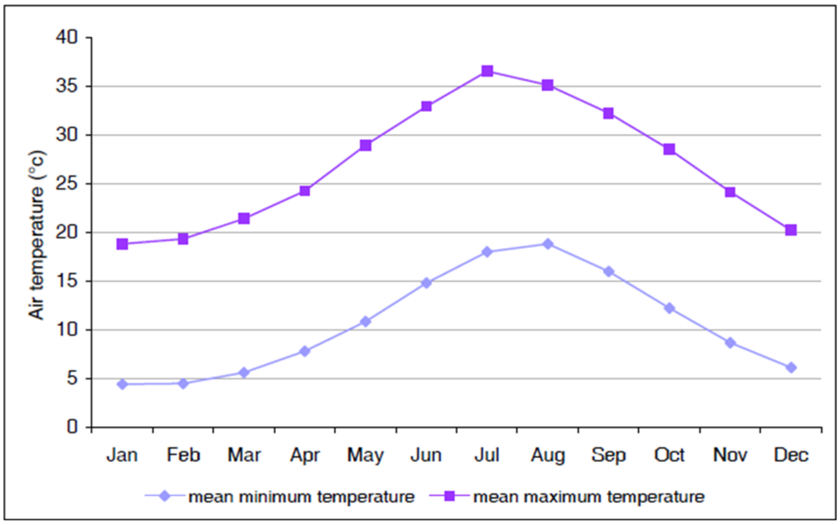

Figure 1: Mean minimum and maximum air temperature in Malta

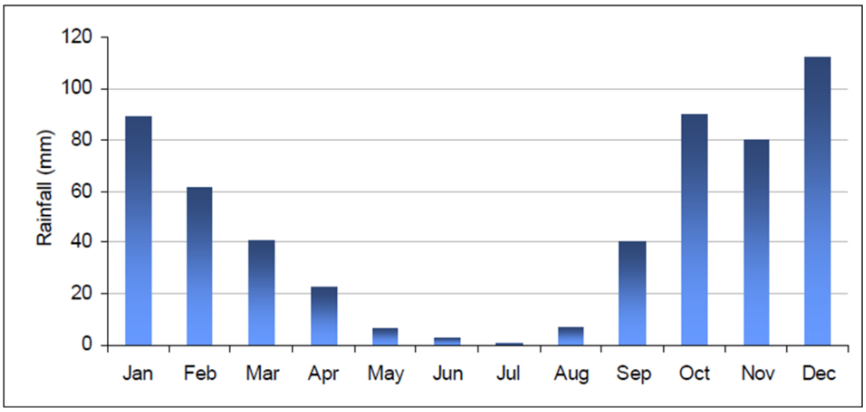

Figure 2:Monthly periodicity of the total annual precipitation in Malta

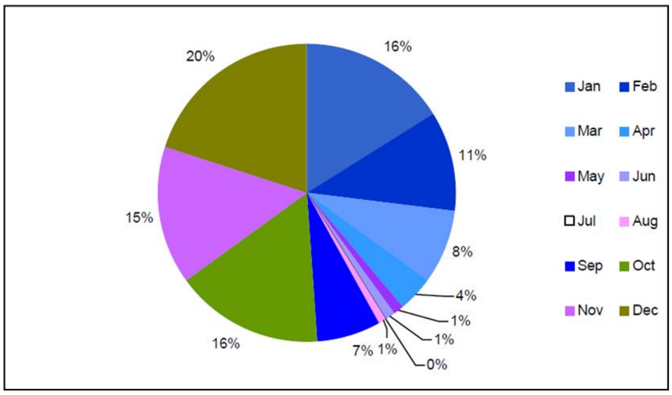

Figure 3: Percentage distribution of the total annual rainfall

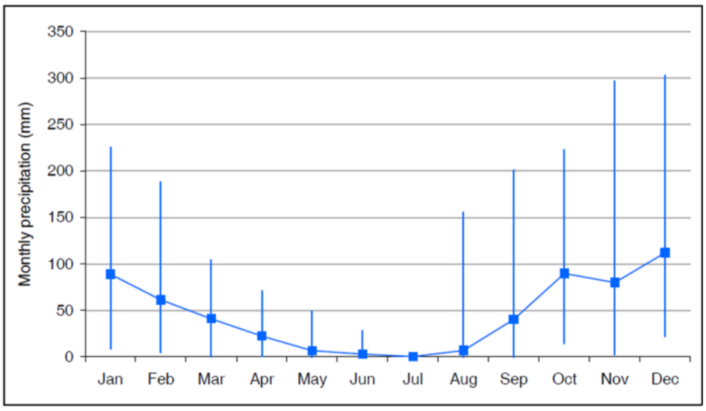

Figure 4: Monthly means and variability of the total precipitation

Consequences of the semi-arid Mediterranean climate that are of particular relevance to water management include:

- Variability in inter-annual and intra-annual rainfall
- High intensity, short duration rainfall events
- Seasonal scarcity of precipitation when the water requirements of the agriculture sector is the highest
- Low effective rainfall due to high evapotranspiration rates

1.1.2 The agricultural sector

The following tables summarize the main data and indicators referred to the agricultural sector in Malta.

Table 1: Distribution of land (ha) declared by farmers by type of land

Type of land (ha)	MALTA	%
Total declared land	**13,004**	**100.0**
of which:		
Utilised agricultural area	**11,689**	89.9
Unutilised agricultural area	**205**	1.6
Other area (including garigue land)	**1,110**	8.5

Table 2: Distribution of agricultural holdings by size class

Size class of UAA (ha)	MALTA	%
Total agricultural holdings	**12,466**	**100.0**
of which:		
0	**359**	2.9
>0 - <0.5	**6,097**	48.9
0.5 - <1	**2,971**	23.8
1 - <2	**1,607**	12.9
2 - <5	**1,129**	9.1
5 and over	**302**	2.4

Table 3: Distribution of UAA (ha) by type

Type of UAA (ha)	MALTA	%
Total utilised agricultural area (ha)	**11,689**	**100.0**
of which:		
Arable land	**8,967**	76.7
Permanent crops	**1,264**	10.8
Kitchen gardens	**1,458**	12.5

Table 4: Distribution of arable land (ha) by type

Type of arable land	MALTA	%
Total arable land	**8,967**	**100.0**
of which:		
Potatoes	**689**	7.7
Flowers and seeds	**34**	0.4
Forage plants	**5,290**	59.0
Fallow land	**959**	10.7
Vegetables	**1,996**	22.3

Table 5: Distribution of permanent crops (ha) by type

Type of permanent crop (ha)	MALTA	%
Total permanent crops	**1,264**	**100.0**
of which:		
Fruit and berry plantations	**386**	30.5
Citrus plantations	**90**	7.1
Olive plantations	**104**	8.2
Vineyards	**683**	54.0
Nurseries	**2**	0.2

Table 6: Distribution of agricultural workforce by work-time

Type of labour	MALTA	%
Total agricultural labour force	**19,066**	**100.0**
of which:		
Part-time	**17,693**	92.8
Males	**13,869**	72.7
Females	**3,824**	20.1
Full-time	**1,372**	7.2
Males	**1,245**	6.5
Females	**127**	0.7

In synthesis, concerning the agricultural sector outlook, the development of agriculture in Malta is constrained by the natural and geographical characteristics of the islands.
The major constraints facing agricultural activity are the opportunity cost of land, the scarcity of water resources, and high labour costs.
The total area of agricultural land decreased from 20 500 ha in 1955 to 13,004 ha in 2013.

When it comes to the water demand from the agricultural sector, in the past decades, we saw an increase in irrigated land (land which has a continuous supply of water all year round) from 816 ha registered in 1955 to 3498 ha in the 2010 census.
The main driver behind this increase in irrigated land area was revenue generation, declining costs of borehole construction and improvements in irrigation technology.
It is estimated that the agriculture sector is meeting about 80 percent of its demand from groundwater while non-conventional sources such as treated effluent and rainwater harvesting are only of marginal importance.
Groundwater is sourced through private abstraction wells located either in the mean seavel aquifer systems or the perched aquifer systems.
It is estimated that there are about 3300 private groundwater wells which are used for the supply of groundwater by the agricultural sector.
A groundwater source metering program has been initiated to better characterize the water demand of the agricultural sector.

2 Objectives and contents of the feasibility study

The key aspects emerging from the WODA Questionnaire and from the analysis of Malta's context analysis, taken into account in order to orientate the feasibility study, were the following:

- Surface waters in Malta are non-existent and therefore there is no surface water exploitation.
- The agricultural sector is very much dependent on groundwater for it water supply (about 80%) with groundwater contributing (about 40%) of the water demand of the domestic sector
- Owners of private groundwater sources are not given a permit but are obliged to register their groundwater source, paying a onetime registration fee. The fee is a standard fee that applies to all users.
- Monitoring of private groundwater abstraction is still in its initial phases. The process of installing flow meters on the most significant groundwater sources has been completed.
- There are good info concerning agricultural parcels (constraint: small parcel size)
- SAR interferometry approach is ineffective in Malta due to unsuitable geological conditions.
- Strong interest in optical EO approach application.

The focus of the feasibility study is about the use of optical EO data, primarly for the detection and monitoring of irrigated parcels.

2.1 EO data – state of the art and data availability

The basic optical EO data used in this feasibility study are a multitemporal data set of Landsat8 data, referred to 2014 and 2015.
Malta is covered by 2 different scenes of the Landsat8 coverages, and in particular by the scene 188/035.

Figure 5: Landsat8 scene coverages over Malta

The temporal resolution of Landsat8 data (frequency of acquisition over a single scene) is of 16 days; cloud cover in the context of Malta is not a strong limiting factor and there is in general a good number of cloud free scenes over Malta, enough to characterize the temporal evolution of the main crops.
Otherwise, the spatial resolution of Landsat8 data could be in general a limiting factor, considering the average agricultural parcel size in Malta: the average parcel size in Malta is similar to the Landsat8 multispectral bands pixel size (30x30 meters); the future availability of Sentinel2 data (10x10 meters) pixel size) will be for sure a strong improvement.

Partner	Average parcel size (m^2)
Malta	1 376
Slovenia	3 000
Spain	5 000
Italy-1	10 000
Italy-2	10 400

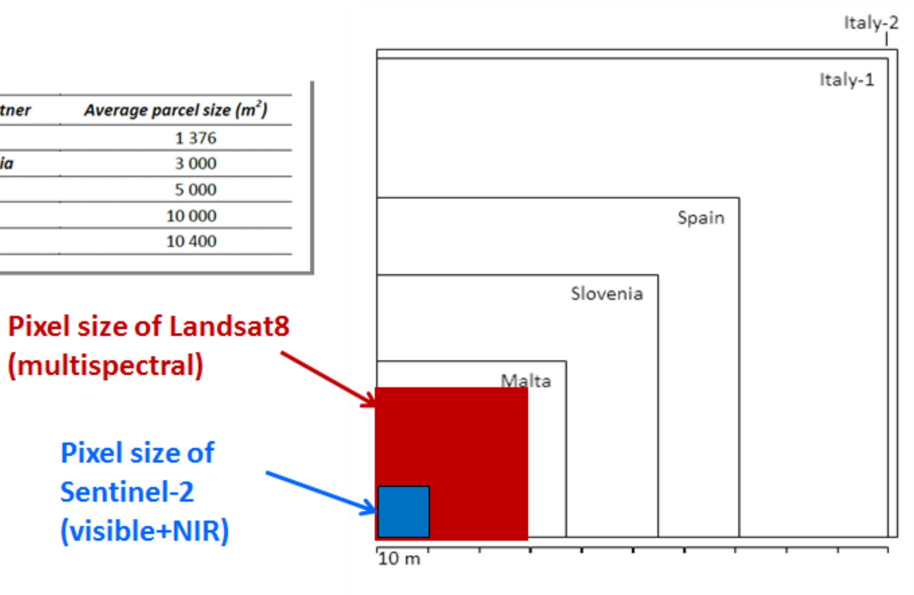

Figure 6: From the WODA Questionnaire: parcel size statistics, with a comparison of Malta's average parcels size; Landsat8 and Sentinel-2 pixel size

The general and basic concept in the feasibility study is that, due to the lack of precipitations in Malta during spring and summer, agricultural parcels must be irrigated (by groundwater) thus vegetated agricultural parcels can be considered as irrigated (see for a first example the Landsat8 Infrared False Colour images time series of four 2014 images in Figure 7), where red hues represent vegetated areas.

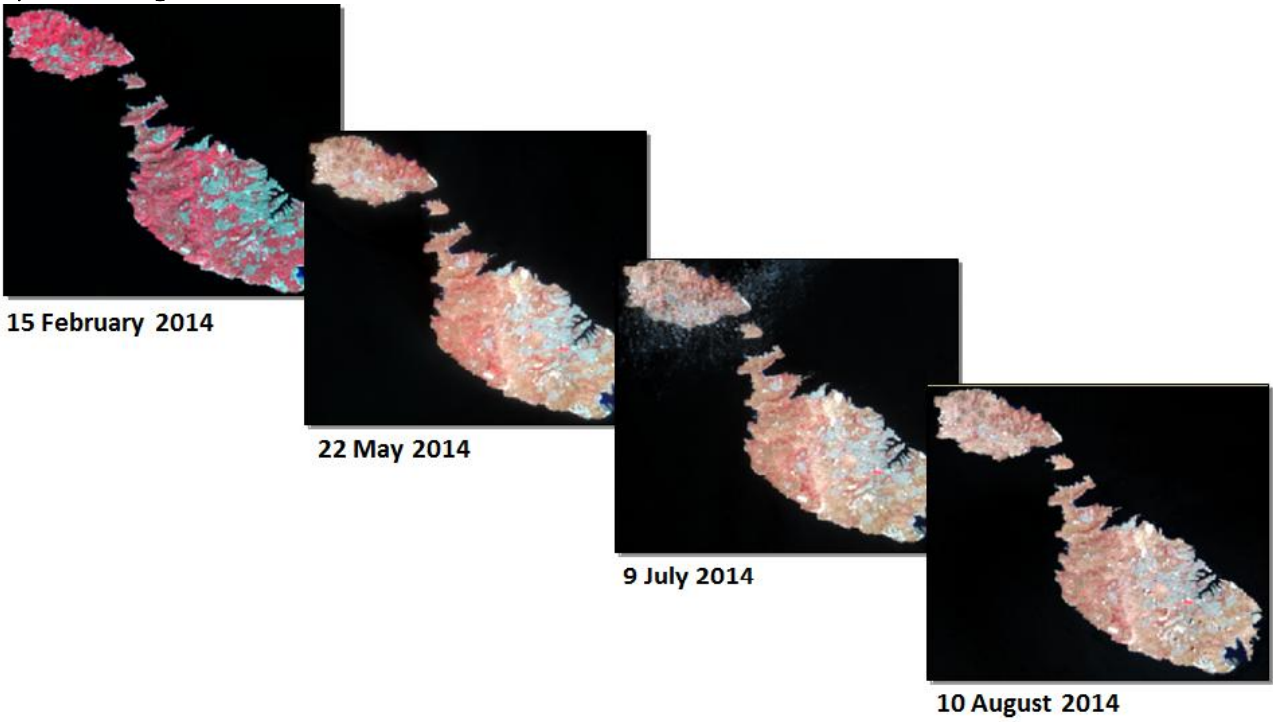

Figure 7: Examples of four Landsat8 data in 2014 over Malta (IRFC false color composite)

More in detail, and taking into account an example about non-agricultural areas (figure), it is possible to exploit the temporal variation of the spectral response of the vegetation, using for example common spectral indices like the Normalized Difference Vegetation Index (NDVI).

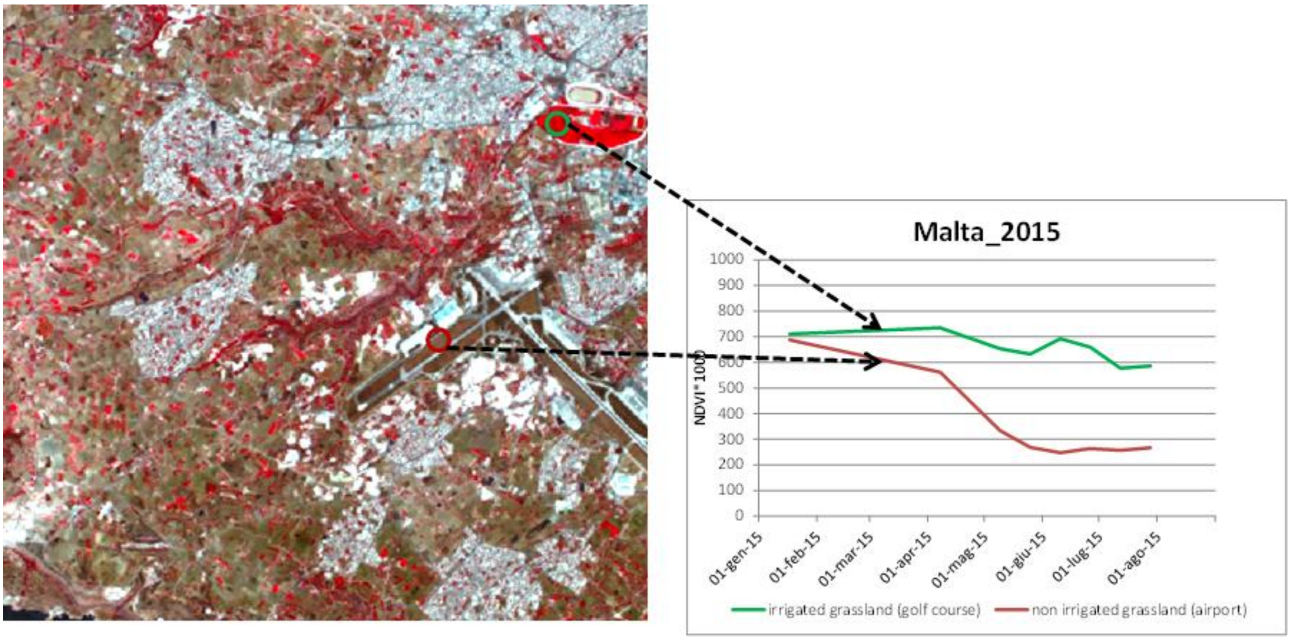

Figure 8: Trend of Vegetation Index (NDVI) in different NON agricultural vegetation types (left: Landsat8 image of 6 july 2015)

In the feasibility study this general concept has been exploited in particular over agricultural parcel, distinguishing and classifying the main crop types and the relative NDVI temporal variability in the season.

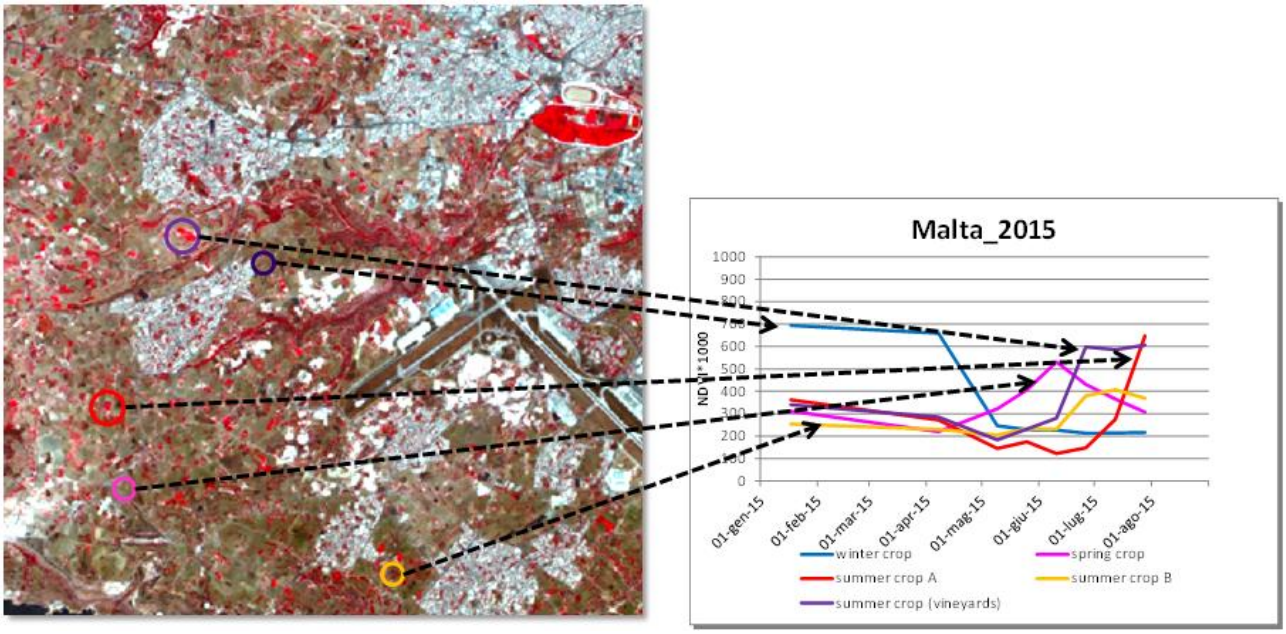

Figure 9: Trend of Vegetation Index (NDVI) in different agricultural vegetation types (left: Landsat8 image of 6 July 2015)

2.2 Test area definition

The test area defined for this feasibility study is located in the central and south-western part of the island of Malta. (3 Councils of Siggiewi, Zebbug and Qrendi).

Figure 10: Test area definition

2.3 Auxiliary data availability and pre-analysis

In the defined test area, the following were the auxiliary data available, used in the feasibility study:

Groundwater abstractions points

- Groundwater location (derived from boreholes census): location of all the registered groundwater sources present in the area of study.
- Metered groundwater data: list of all the groundwater sources present in the study area which have been metered.
- Monthly measures of water consumption: for part of the known abstraction points, data are relative to the cumulative consumption (in Liters) of the metered groundwater sources present in the area.

Agricultural parcels:

- Agricultural parcels, comprehensive of property ID: boundaries of the agricultural parcels in the study area (Siggiewi, Haz Zebbug and Qrendi councils).

- Agricultural land use in the parcels: delineates the different landcovers of the parcels or within the parcels. So for instance one parcel can have multiple landcovers (for example mixture of vineyards and fruit trees in the same parcel).

General informations:

- Reference meteorological data (referred to 2012)
- Typical crop sowing and harvesting dates for the most important and widespread crops in Malta.

2.3.1 Auxiliary data analysis

The first part of the feasibility study was related to auxiliary data analysis and pre-elaboration, in particular in order to match the available information about groundwater point source location and measured abstractions, with the agricultural parcels.

In the study area there are a total of 650 registered groundwater abstraction sources. Of these, 487 of these sources where fitted with a meter and groundwater abstraction data was available from 325 of these groundwater sources. The groundwater metering program was still being developed at the time of the implementation of the WODA project.

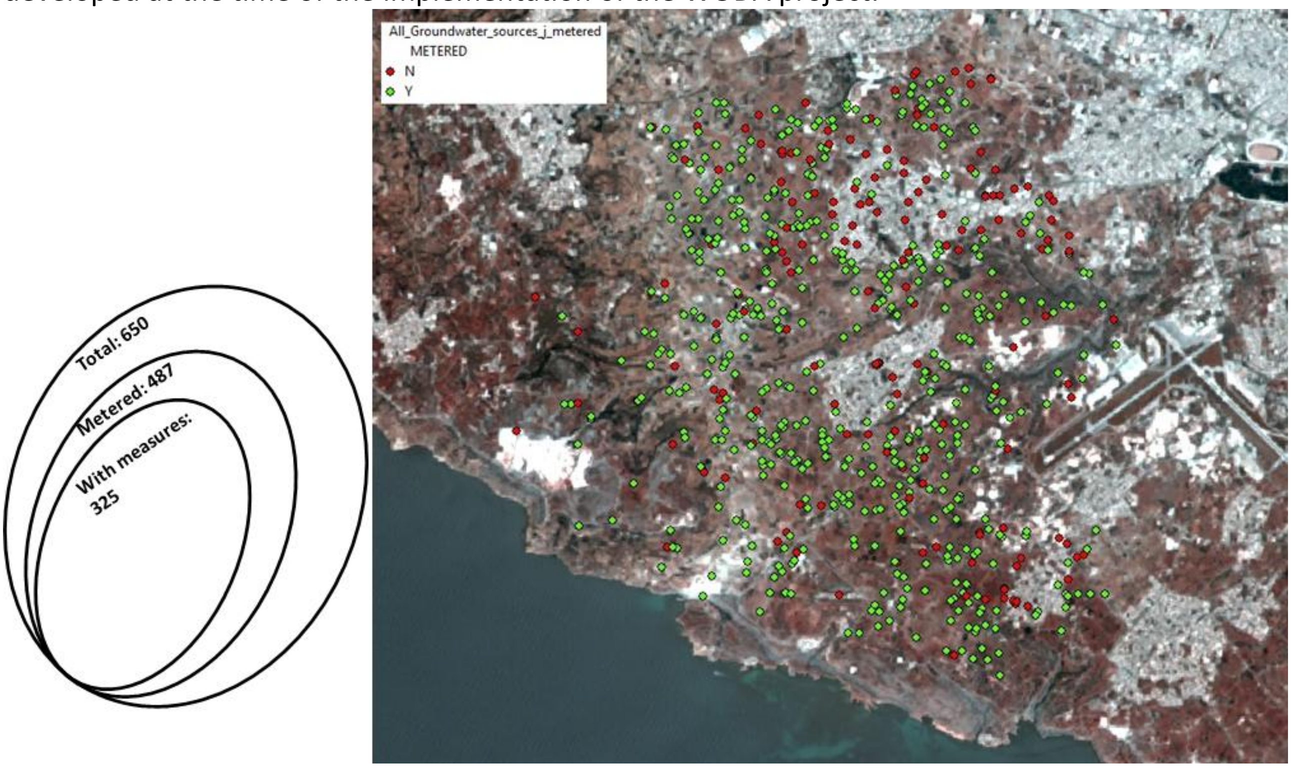

Figure 11: Georeferenced groundwater sources in the test area, with basic statistics

In the study area, the agricultural parcels are identified with the property ID (ID CUUA).
In many cases, it was possible to match the groundwater point source property (applicant ID) with the corresponding agricultural parcels property (CUUA ID), with GIS joining procedures.

In the study area there is a total of 7424 agricultural parcels, with a total of 1534 unique IDs (CUUA number). The following scheme is referred to the results of the joining process of parcels with groundwater sources.

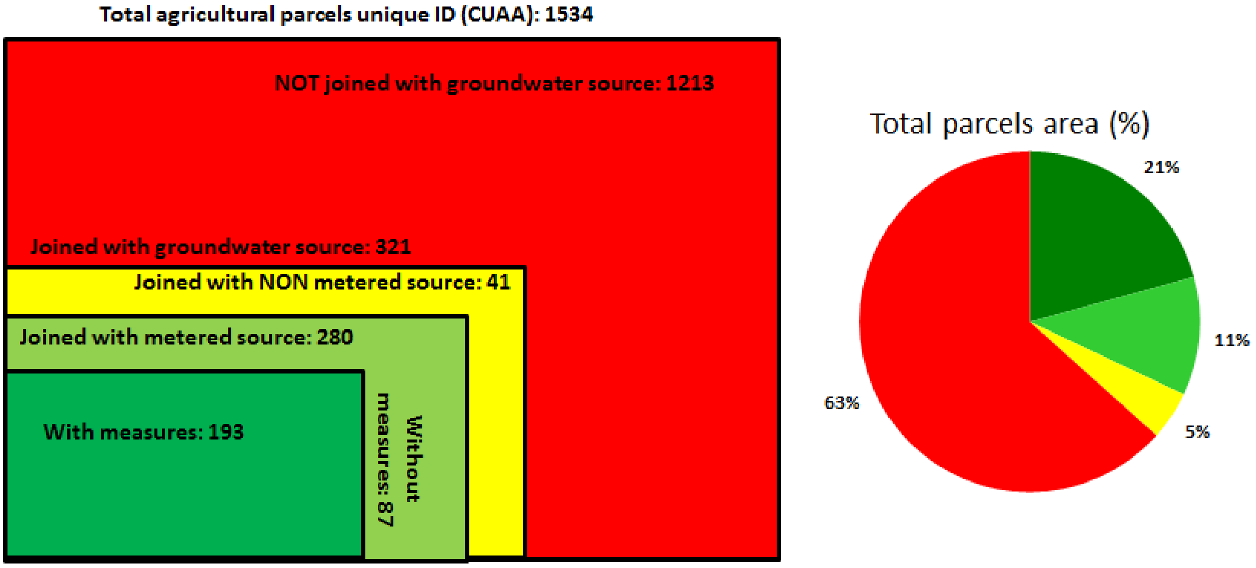

Figure 12: Basic scheme of the output of the joining process between groundwater sources and agricultural parcels.

The result of the joining process is also shown in the map in the next figure: the agricultural parcels correctly joined with the relative groundwater sources are shown in green (in particular, dark green if monthly measures of actual groundwater abstractions are available; in the figure, the size of the points is proportional to the total groundwater abstraction in 2015 january-july period).

Figure 13: classification of agricultural parcel based upon the joining with groundwater sources (points, with dimension proportional to total abstractions in jan-jul 2015)

3 Case studies analysis

The focus of this part of the feasibility study was on the matching and analysis of the available information regarding groundwater abstractions (in terms of location, property and, when available, quantities), agricultural parcels (type, size, land use, properties), and the main information derived from EO data (in particular from the temporal evolution of NDVI index derived from Landsat8 2015 images).

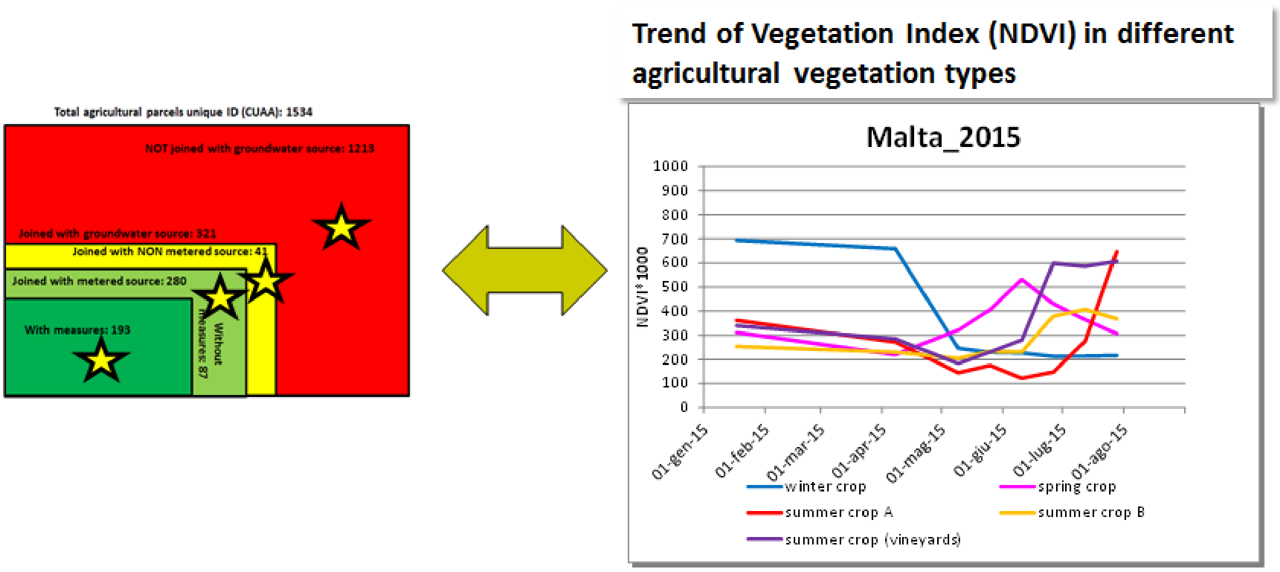

Figure 14: Scheme of the focus of the feasibility study: matching of the available information about groundwater sources location and abstractions, parcels and EO multitemporal data.

This kind of activities has been performed generally at parcel scale, and in the next paragraphs some examples are shown, describing the main situations explored and the main findings.

3.1 Case A: agricultural parcels joined with metered and measured groundwater sources

This case is related to the 193 agricultural parcels joined with a metered and measured groundwater source.

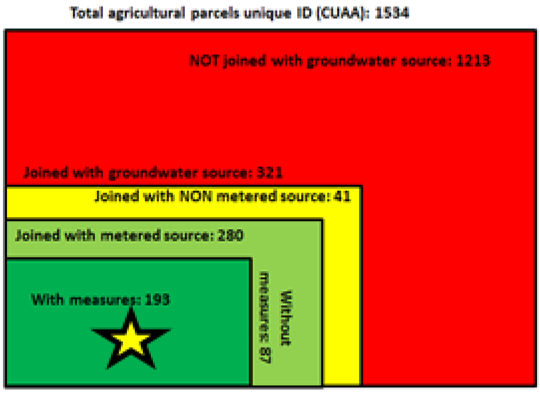

Figure 15: Scheme of the focus of this paragraph: parcels joined with metered and measured groundwater sources

A first example of this type of situation is the following; in this case, a metered groundwater source can be correctly joined with a single parcel (using the property ID and the CUAA parcel number).
The joining process in this case highlighted a 1:1 relationship between a single groundwater abstraction and a single group of parcel (parcels unique ID), as shown in fig (a).
This particular well is metered, and the monthly readings of cumulative groundwater abstraction (b), derived to monthly water total abstractions (c) shown a strong water demand in spring and summer months of 2014 and 2015 of the relative agricultural parcels (mainly vineyards, as shown in (d)). The NDVI temporal variation (derived from Landsat8 2015 data) in this parcel is fully compatible with the available data.

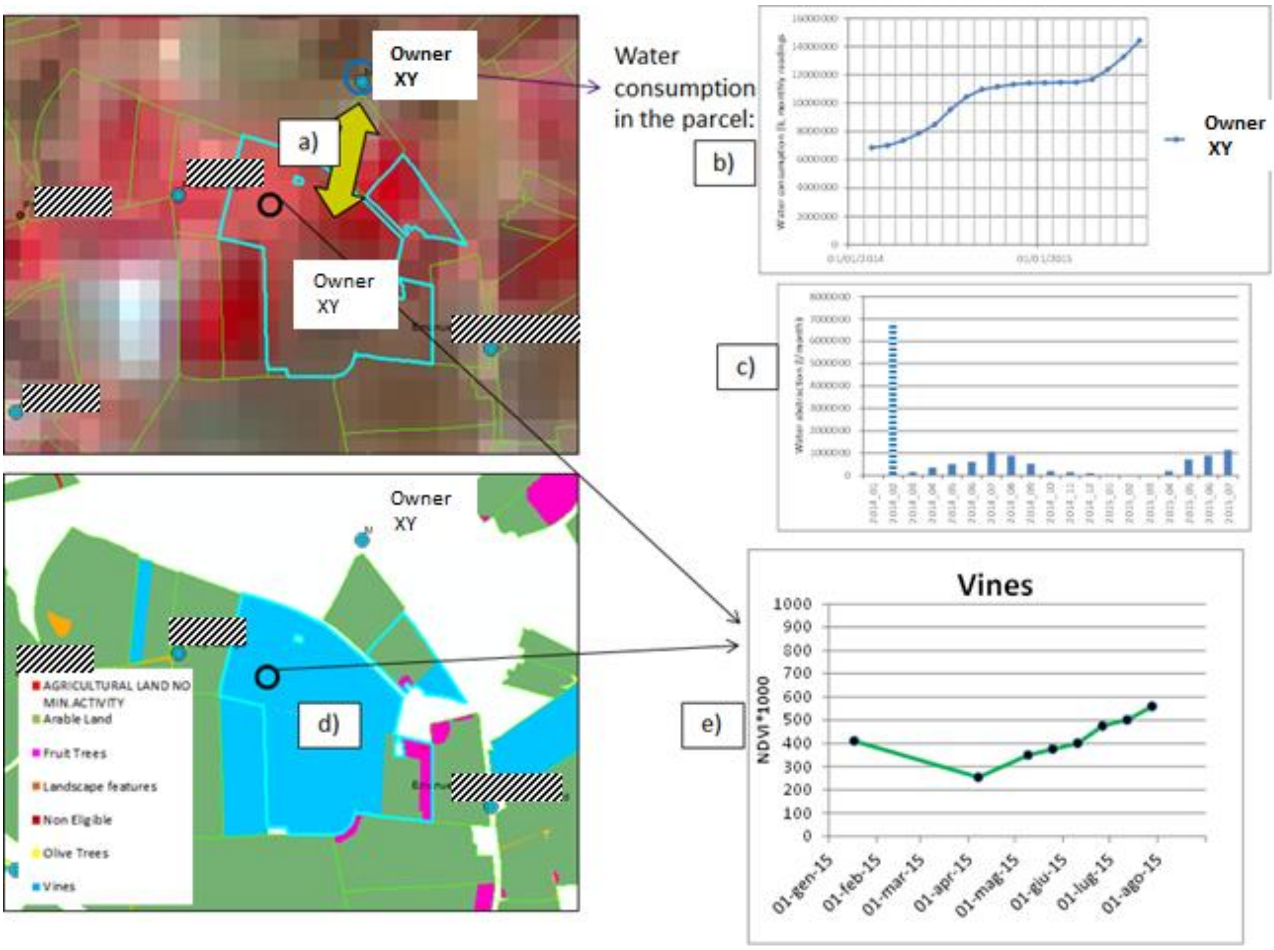

Figure 16: Example of comparison between groundwater consumption, agricultural landuse, multitemporal NDVI (see text for details)

The key-findings and the short-message to the water authority in this case are:

⇨ Water consumption compatible with land use and multitemporal NDVI

Another example is shown in the next figure; also in this case the joining process highlighted a 1:1 relationship between a single groundwater abstraction point and a single group of parcel (parcels unique ID), as shown in fig (a), where the main agricultural use is the generic class "arable land" (c). The well is metered, and the monthly readings of cumulative groundwater abstraction (b), shown a little water demand only in 2014 summer and very little water abstraction in 2015. The 2015 NDVI temporal variation (d) in this parcel is typical of a winter crop.

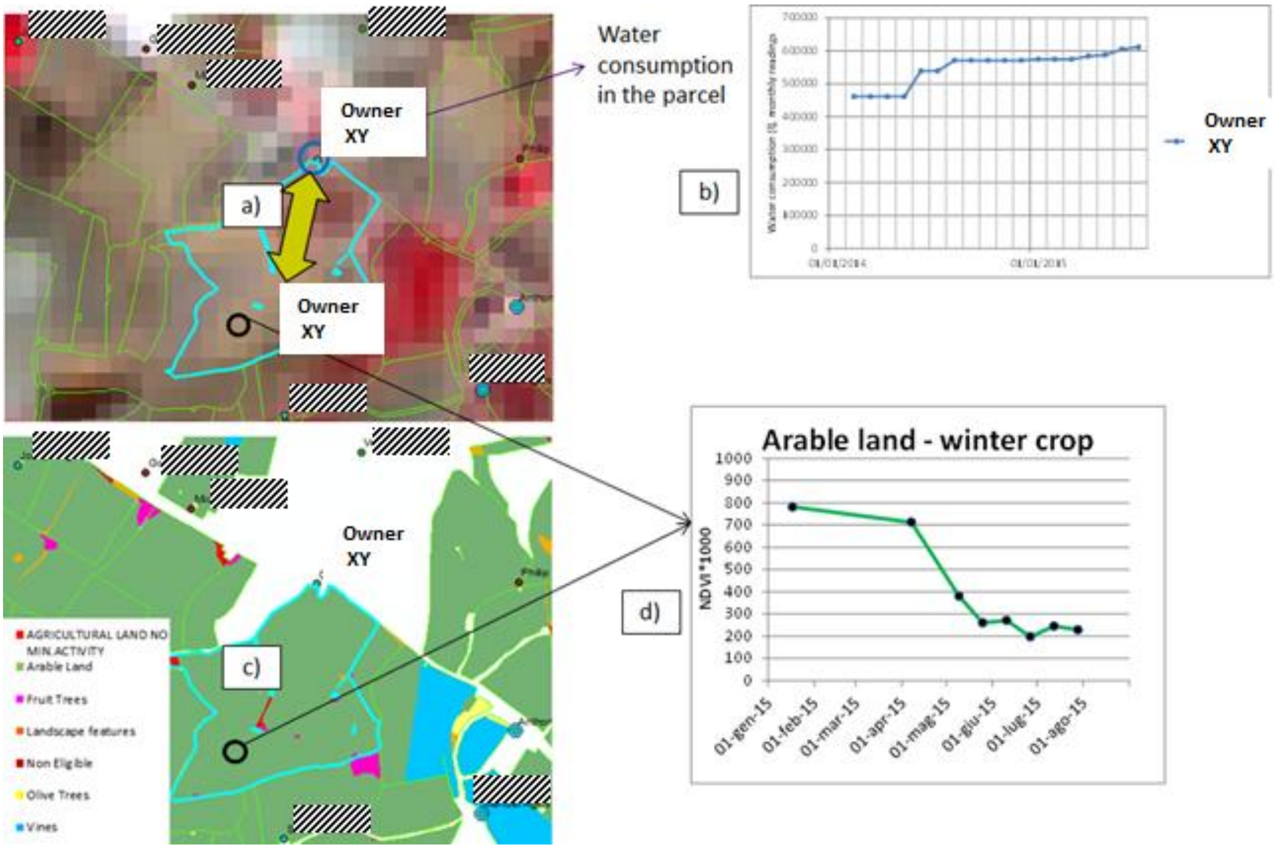

Figure 17: Example of comparison between groundwater consumption, and multitemporal NDVI (see text for details)

The key-findings and the short-message to the water authority in this case are:

⇨ Water consumption compatible with land use and multitemporal NDVI

A similar situation, but with higher complexity is shown in the next example: in this case the joining process highlighted a 1:N relationship between a single groundwater abstraction point and a different group of parcel (parcels unique ID), but with very different agricultural landuse (arable land, vineyard, fruit trees, ..). The well is metered, and the monthly readings of cumulative groundwater abstraction shown a strong water demand in 2014 and 2015.

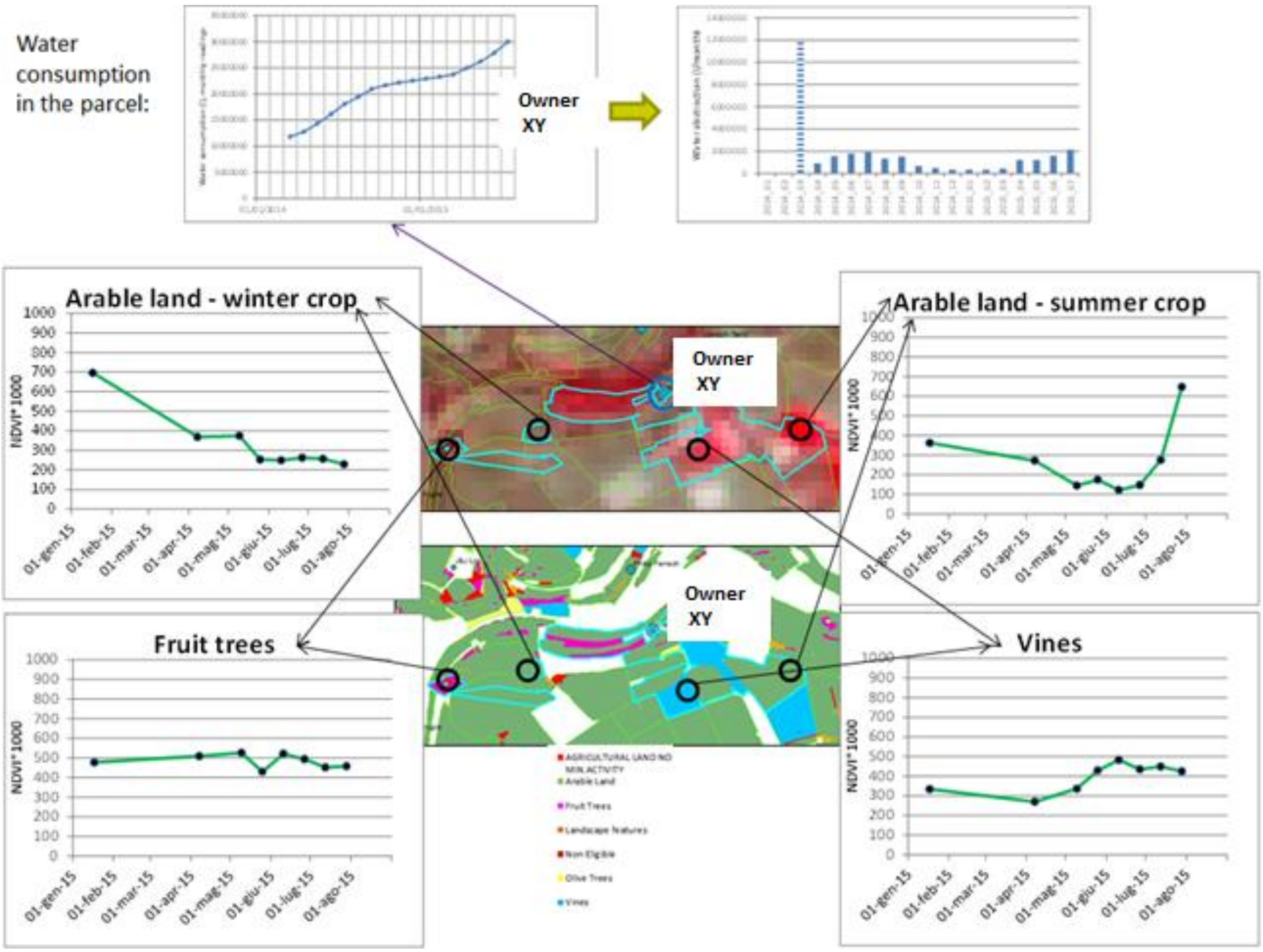

Figure 18: Example of comparison between groundwater consumption, agricultural landuse, multitemporal NDVI (see text for details)

In these cases, the NDVI temporal variation in the different parcels are helpful to distinguish which parcels are water demanding, and to provide a first indicator of the total water irrigation requirement during the season.

An higher complexity case is shown in the next example: in this case the joining process highlighted a N:M relationship between two groundwater abstraction points (with the same property) and a different group of parcel (parcels unique ID), but with very different agricultural landuse (arable land, vineyard, fruit trees, ..). Both wells are metered, and the monthly readings of cumulative groundwater abstraction shown different water demand in 2014 and 2015.

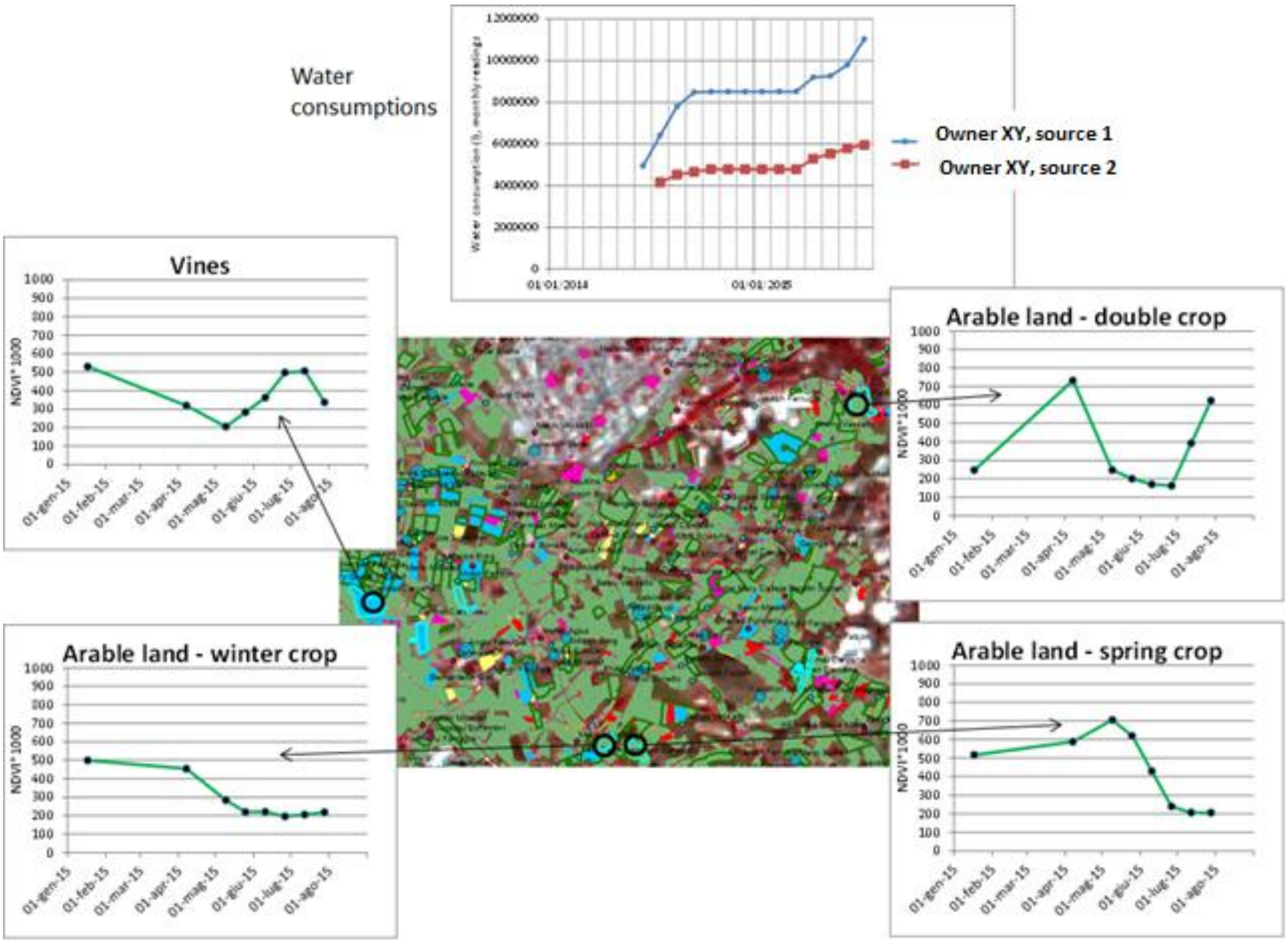

Figure 19: Example of comparison between groundwater consumptions, agricultural landuse, multitemporal NDVI (see text for details)

In these cases, the NDVI temporal variation in the different parcels are helpful to distinguish which parcels are water demanding, and to provide a first indicator of the total water irrigation requirement during the season.

This type of approach and analysis is also useful to investigate particular situations, as in the following example, where one groundwater abstraction (metered) is irrigating different parcels, with different crops and landuse, and there are readings only in 2014 and no more in 2015.

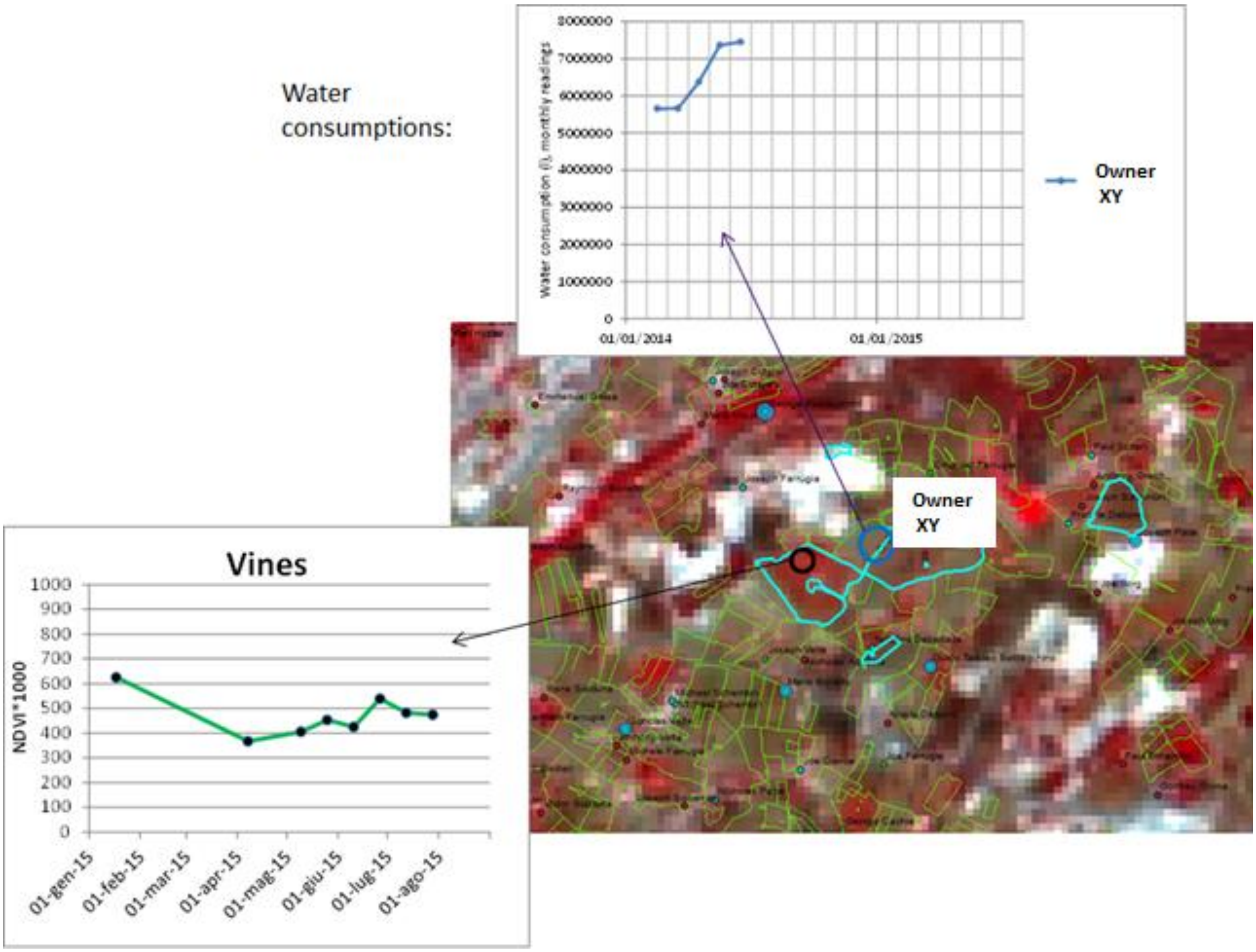

Figure 20: Example of comparison between groundwater consumption and multitemporal NDVI (see text for details)

The key-findings and the short-message to the water authority in this case are:

⇨ Matching land use information, summer Lndsat8 data and derived multitemporal NDVI, some water consumption also in summer 2015 appears very probable.

Other possible and future activities in these situations (i.e. the cases of agricultural parcels correctly joined with metered groundwater sources) are related to a more quantitative analysis, with the following general objectives:

- Identification and comparisons between parcels with similar area and same crop type but very different amount of water consumption
- Water irrigation requirement estimations
- Balances between crop water requirements and actual abstractions over wide areas

3.2 Case B: agricultural parcels joined with potentially metered groundwater sources

This case is related to the 87 agricultural parcels joined with a potentially metered groundwater source but actually with no groundwater abstraction measures.

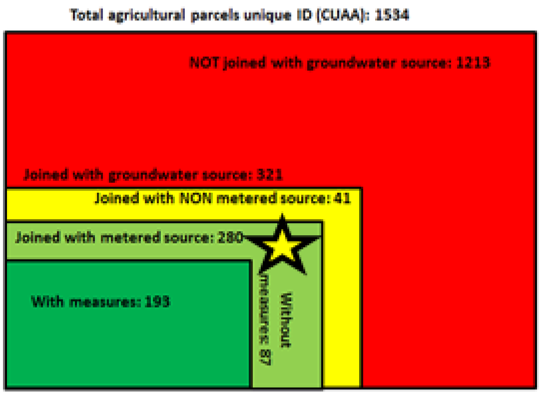

Figure 21: Scheme of the focus of this paragraph: parcels joined with metered and not-measured groundwater sources

An example of this type of situation is the following; in this case, a metered groundwater source can be correctly joined with a single parcel (using the property ID and the CUAA parcel number) (1:1 relationship).
This particular well is metered, but there are not yet monthly readings of actual water consumption.
The NDVI temporal variation (derived from Landsat8 2015 data) in this parcel is typical of a summer crop, and a certain amount of water irrigation demand is expected in this field.

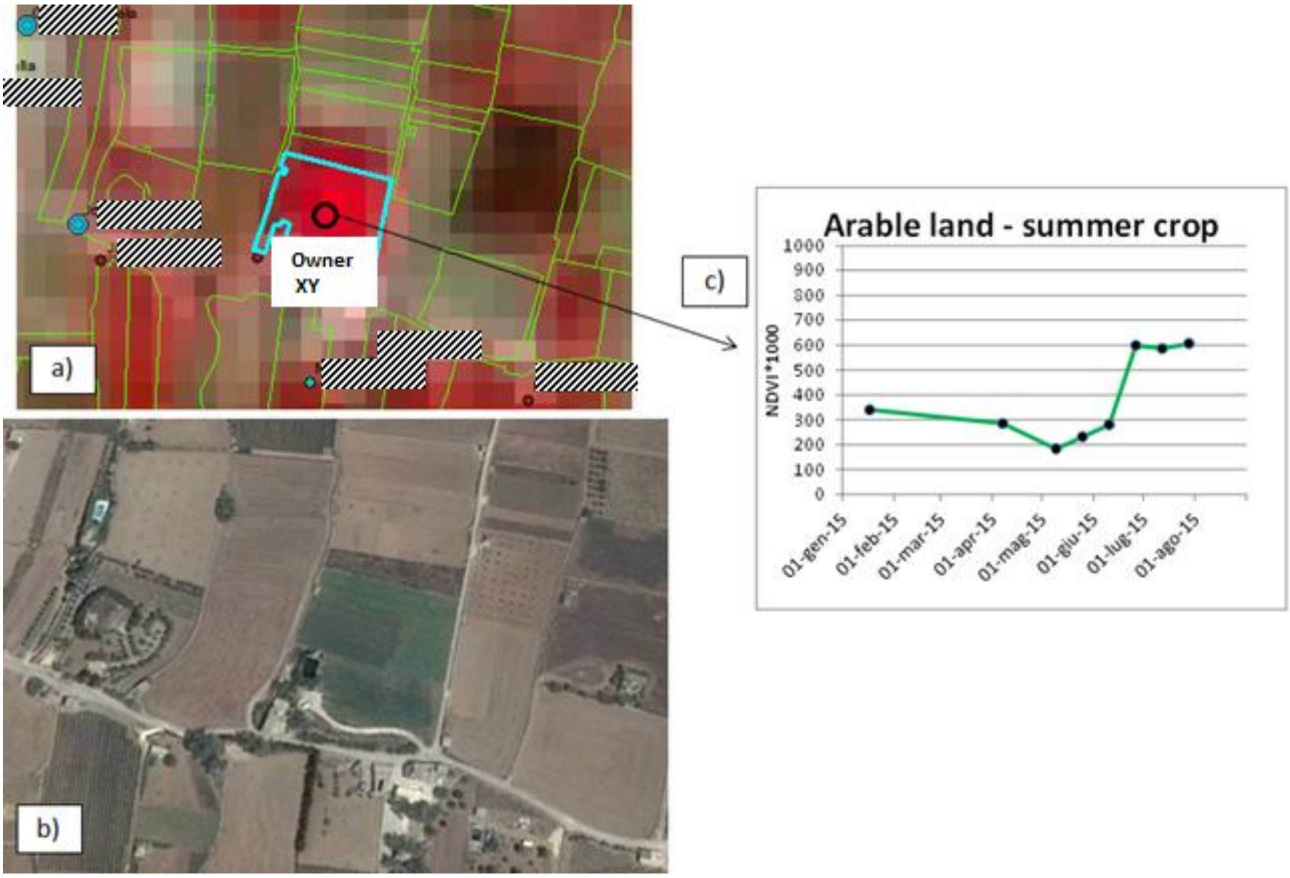

Figure 22: Example of analysis of multitemporal NDVI over a parcel with no measures of groundwater abstraction (see text for details)

The NDVI temporal variation (derived from Landsat8 2015 data) in this parcel is typical of a summer crop, and a certain amount of water irrigation demand is expected in this field.

The key-findings and the short-message to the water authority in this case are:

- ⇒ Very probable water consumption in this parcel in summer 2015
- ⇒ *"Memo": Check the groundwater meter*

3.3 Case C: agricultural parcels joined with non-metered groundwater sources

This case is related to the 41 agricultural parcels joined with non-metered groundwater source.

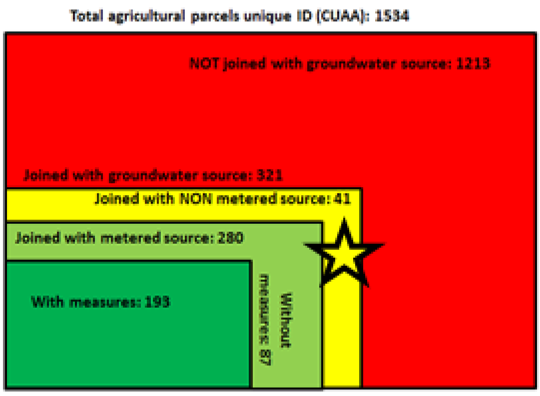

Figure 23: Scheme of the focus of this paragraph: parcels joined with not-metered groundwater sources

An example of this type of situation is the following; in this case, a non-metered groundwater source can be correctly joined with a single parcel (using the property ID and the CUAA parcel number) (1:1 relationship).

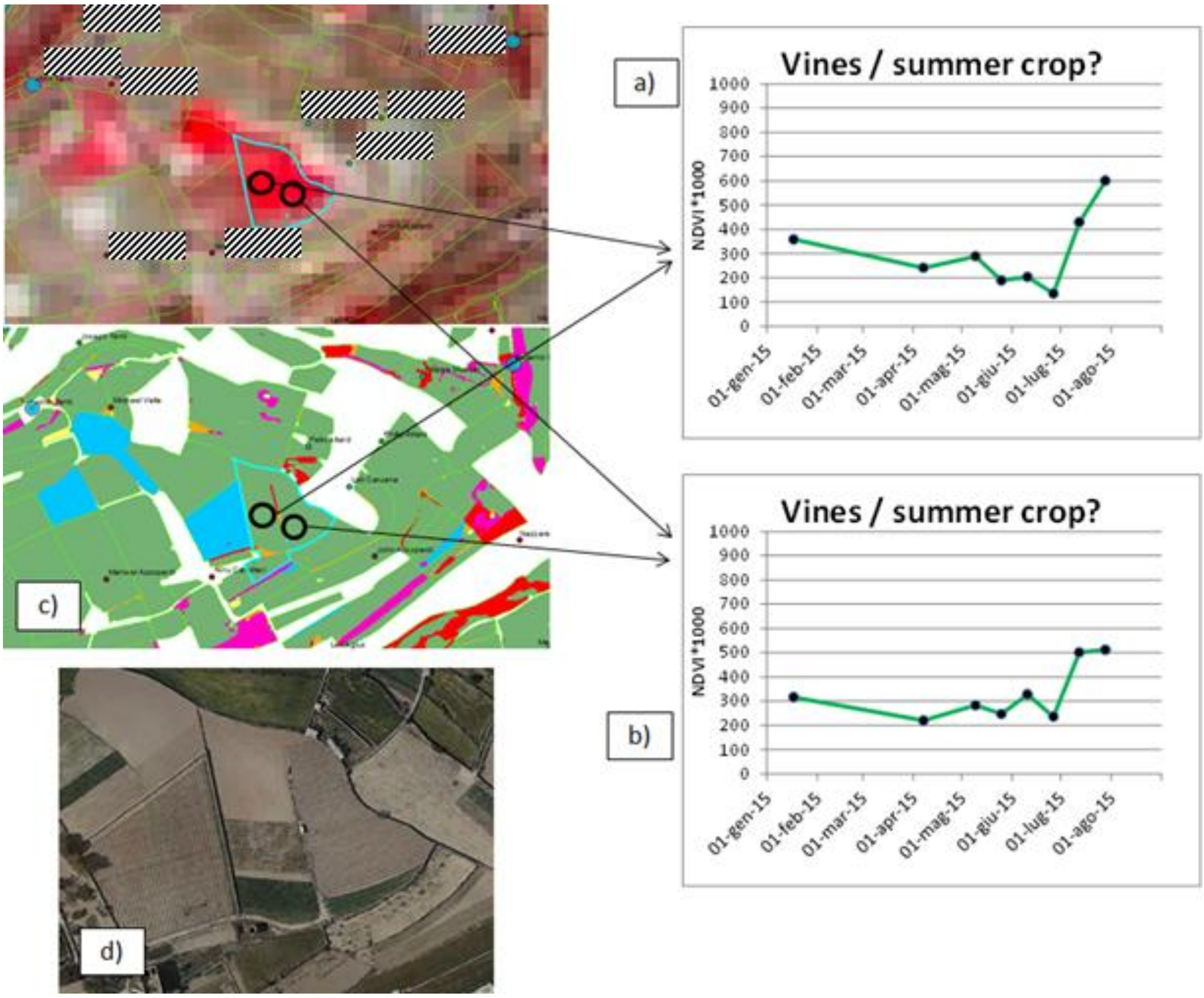

Figure 24: Example of analysis of multitemporal NDVI over a parcel with no measures of groundwater abstraction (see text for details)

This particular well is not yet metered (the metering process is still ongoing).
The NDVI temporal variation (derived from Landsat8 2015 data) in this parcel is typical of a summer crop, although it’s not possible distinguish the specific crop, and a certain amount of water irrigation demand is expected in this field.

The key-findings and the short-message to the water authority in this case are:

⇒ Very probable water consumption in this parcel in summer 2015

⇒ *“Memo”: install groundwater meter*

3.4 Case D: agricultural parcels not joined with groundwater sources

This case is related to the 1213 agricultural parcels not joined with groundwater sources.

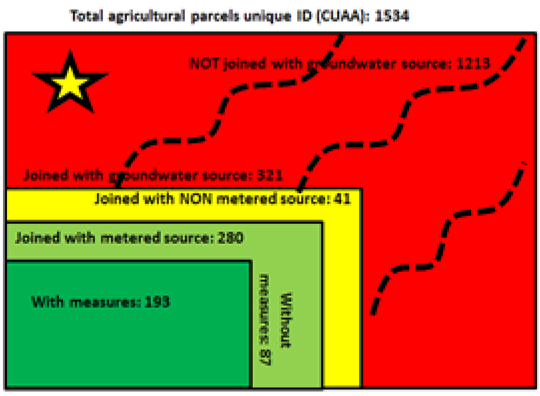

Figure 25: Scheme of the focus of this paragraph: parcels not joined with groundwater sources

There are different possible causes for the non-joining process between groundwater sources and parcels.

Case D1.

In many case, these particular agricultural parcels are actually not water demanding, due to the particular crops harvested. A significant percentage of the agricultural landuse in the study area is related to low (or null) water demanding crops (olive trees, pastures, landscape features, other non-irrigated arable land like winter crops).

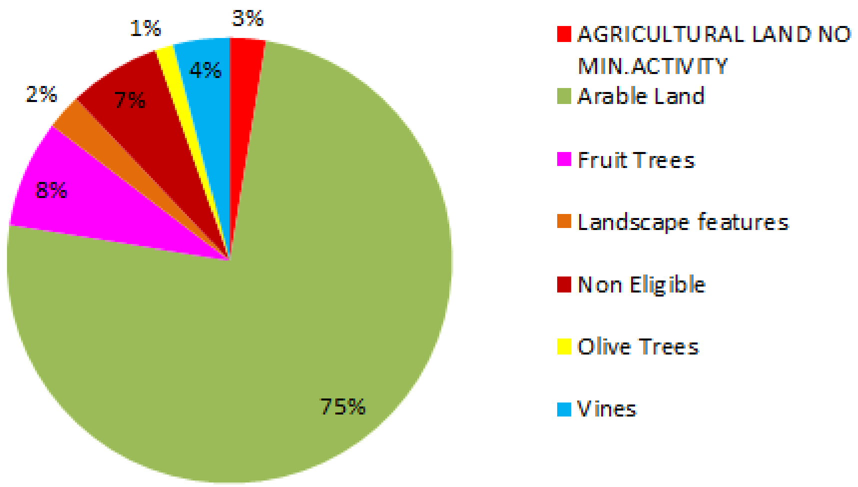

Figure 26: Land use in agricultural parcels not joined with groundwater sources (%)

Case D2.

In most cases, the non-joining process between groundwater sources and parcels appears due to problems in the two different registries, or in general, differences in the unique-ID of the two databases. In some case, the applicant-ID of the groundwater source is personal, while the CUUA ID of the agricultural parcels could be related to the private society.

These cases could be resolved only with a "case by case" analysis, by local knowledge, or by GIS analysis in order to argue the matching of groundwater source and specific irrigated parcels.

In some case the same property (same ID) is related to multiple groundwater abstraction points. In many of these cases it was possible to find the related agricultural parcels and to check the NDVI temporal variation.

Anyway, also in these case we could have some important benefit from EO data, identifying the fields where water consumption is highly probable.

The key-findings and the short-message to the water authority in this case are:

⇒ *"Memo": Align the registries, check the groundwater meter readings, install new meters where necessary...*

Case D3.
The last situation explored is related to totally unknown or unregistered groundwater sources.

The methodology is able to highlight the specific parcel with no groundwater sources matched and with a potential water irrigation requirement. In the following figures there are two of these cases; the two parcels are both classified as "arable land", and the NDVI temporal variation derived from 2015 Landsat8 data is typical, for the first parcel of a double crop harvesting, and for the second, of a spring crop.

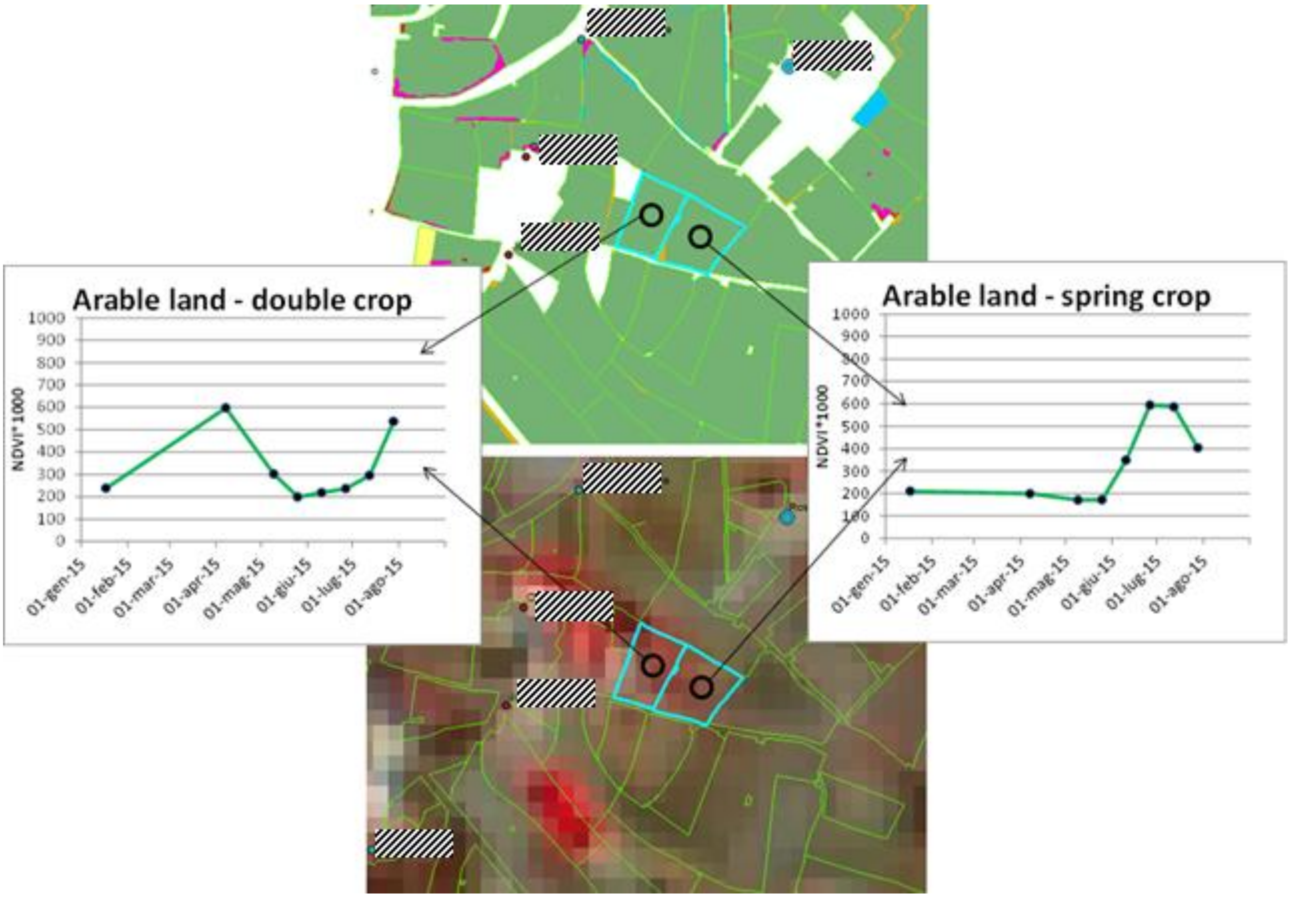

Figure 27: Example of analysis of multitemporal NDVI over parcels not joined with groundwater sources (see text for details).

In many of these situations, the irrigation water requirement could be fulfilled not by local groundwater sources abstraction, but by water transfer with “water carriers”.

The key-findings and the short-message to the water authority in this case are:

- ⇒ Very probable water consumption in these parcels in spring and summer 2015
- ⇒ *“Memo”: install new meters where necessary...*

4 Conclusions and outlooks

The Malta's feasibility study highlighted a very wide panel of situations.
Strong knowledge improvements were achieved matching the available local registries (from different sources) related to groundwater abstractions and agricultural landuse, joining GIS analysis and EO data analysis.
EO-data local applications are possible in relation to the support to groundwater abstractions monitoring and control at field scale, and more general potential applications are expected in support to sustainability analysis of groundwater uses (with a "wide-area surveillance" approach).

In particular for the cases of agricultural parcels correctly joined with metered groundwater sources, more quantitative analysis are expected for the future, with the following general objectives:

- Identification and comparisons between parcels with similar area and same crop type but very different amount of water consumption
- Water irrigation requirement estimations
- Balances between crop water requirements and actual abstractions over wide areas

From the EO data point of view, with Sentinel-2 data there will be in the future a strong improvement in monitoring capabilities, thanks to temporal and spatial resolution improvements.

The main outlooks and the major efforts for possible evolution in the future are related to:

- Sentinel-2 exploitation
- improvements in quantitative analysis, towards water uses sustainability analysis
- auxiliary data availability improvements
- non-technical feasibility issues improvements (auxiliary data availability, data exchange protocol, technical capacity building, etc..)