European Union Network for the Implementation
and Enforcement of Environmental Law

Water Over-abstraction and Illegal Water Abstraction Detection and Assessment (WODA) – phase 2

Guidance Document

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Report number: 2016/14

Introduction to IMPEL

The European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL) is an international non-profit association of the environmental authorities of the EU Member States, acceding and candidate countries of the European Union and EEA countries. The association is registered in Belgium and its legal seat is in Brussels, Belgium.

IMPEL was set up in 1992 as an informal Network of European regulators and authorities concerned with the implementation and enforcement of environmental law. The Network's objective is to create the necessary impetus in the European Community to make progress on ensuring a more effective application of environmental legislation. The core of the IMPEL activities concerns awareness raising, capacity building and exchange of information and experiences on implementation, enforcement and international enforcement collaboration as well as promoting and supporting the practicability and enforceability of European environmental legislation.

During the previous years IMPEL has developed into a considerable, widely known organisation, being mentioned in a number of EU legislative and policy documents, e.g. the 7th Environment Action Programme and the Recommendation on Minimum Criteria for Environmental Inspections.

The expertise and experience of the participants within IMPEL make the network uniquely qualified to work on both technical and regulatory aspects of EU environmental legislation.

Information on the IMPEL Network is also available through its website at: www.impel.eu

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Executive Summary

WODA2 is an IMPEL project started in 2015 as WODA (Water Over-abstraction and illegal abstraction Detection and Assessment) and continued in 2016 as WODA2. The aims of WODA project were:

- To improve the capability of IMPEL members to detect illegal water abstraction and to monitor legal water over-abstraction, bringing together compliance assurance and environmental monitoring through cost-effective EO methods: optical remote sensing and SAR interferometry, taking as reference the Copernicus Guidance Document "Applying Earth Observation to support the detection of non-authorized water abstractions".

- To make IMPEL members aware of the opportunities which the Copernicus programme is going to provide in terms EO data and value added services.

The partners involved in WODA and WODA2 represent a wide range of situations in terms of geographical contexts, administrative levels (national, regional, county, basin authority), sectors (water resources management, environmental monitoring and control, …) and competences related to water resources (monitoring, inspection/control, policies development, permits/authorizations release, technical support, …). The main activities of project WODA were the following:

- The drafting of a Questionnaire whose purpose was to get a picture of the situation "as is" of each WODA partner: competences on water resources, geographical and operational context, inspection practices, criticalities, experiences in EO,…. . The Questionnaire provided a statistical glance over the complexity and diversity of EU stakeholders involved in water management, and represents a prototype for user requirement analysis for the development of new Copernicus services on water management.

- The development of Pilot Feasibility Studies whose aim was to assess the technical and operational feasibility of use of EO in the WODA partner's contexts. Three pilot studies were developed with Malta, Romania and Italy (Lombardy), in areas characterized by very different geographical contexts, water uses and management, and auxiliary data availability. As a consequence, the three studies were focused on different EO data types, developed with various approaches and methodologies, and with different output and practical applications.

In 2016 the Copernicus satellite Sentinel-2A went into full operation opening great opportunities for the development of new Earth Observation applications related to land and water management.

The purpose of WODA2 has indeed been to carry on experimenting EO methods in illegal water abstraction detection exploiting the added value offered by Sentinel-2A.

The testing activities of WODA2 have been focused on the Malta Pilot Study for the following reasons:

- To optimize the project team resources.

- The geographical and climate context of Malta, as well as the water management problems in facing the increasingly frequent drought and scarcity events, are representative of many other southern European regions.

- The full availability by the Energy & Water Agency of Malta of a large amount of auxiliary data (e.g. parcel maps, crop types, crop phenology, weather data, water licenses, meters geolocation, metering data,...) in digital format allowed the project team to put into practice to a wide extent and test the methods described in the Copernicus Guidance Document, e.g. the assessment of the Crop Water Requirement (CWR) and the matching of CWR versus the actual water abstraction. Furthermore, several statistical and geomatics analyzes over the auxiliary data have been possible giving a quantitative account of the variety of cases actually met that must be taken into account in the development of Copernicus services dedicated to water resources management.

The experience of WODA and WODA2 leads to the following considerations:

- Optical and SAR remote sensing methods for detecting illegal water abstraction and over-abstraction are mature and reliable.

- The climatic, hydrologic and geological conditions favourable to the application of the EO methods are quite common among the European countries/regions most affected by water scarcity issues.

- Copernicus data from Sentinel-1 and Sentinel-2 have an excellent quality, are free of cost and very easy to access.

- SAR interferometry products derived from Sentinel-1, as soil subsidence, are costly and are not yet available from Copernicus. It is hoped the development of a free Copernicus service on soil subsidence monitoring.

- EO data are of little use if auxiliary data (i.e. crop parcel map, water permits, water metering, meteorological data,...) are not fully available on digital format, integrated, georeferenced, validated and easily accessible through Internet.

- Competences on agriculture and water resources management are frequently shared among different organizations. As a consequence, databases have been developed separately and they are still not interoperable (Directive INSPIRE).

- Each country/region features a specific context with agricultural and water management practices frequently dating back to centuries. To make EO methods successful in supporting the controls and the monitoring of water resources is necessary to understand very deeply the local context. Thus it is necessary to develop country/region specific strategies for the implementation of EO methods.

- The development of operational EO applications for the detection of illegal water abstraction and over-abstraction is feasible but demanding. On the other side, the EO potential go far beyond the compliancy assurance providing also very effective solutions on water resources monitoring and management. Thus, to make an investment at national or regional level on EO cost-effective, the full potential of EO for water resources should be carefully taken into account.

Disclaimer

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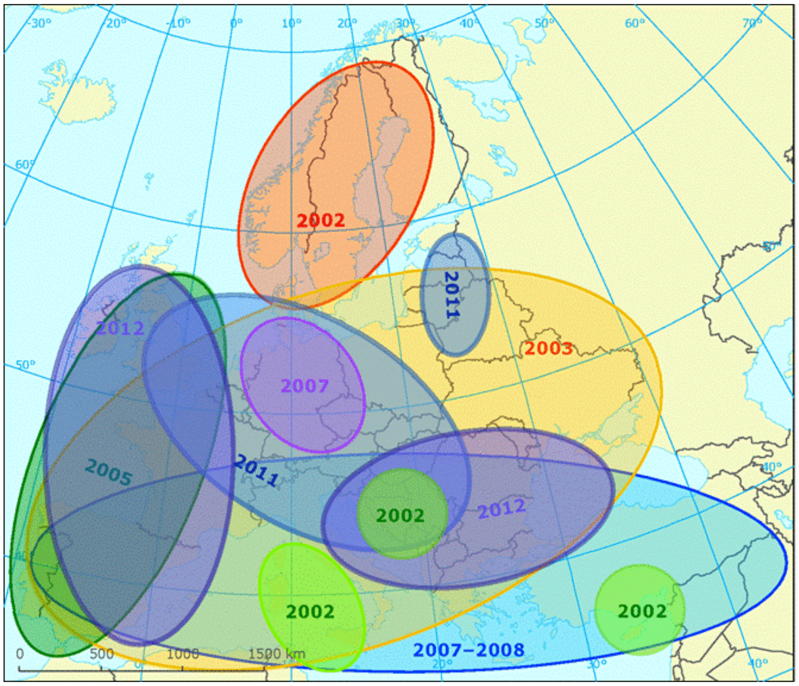
1. Introduction

1.1 Rationale

Over the past thirty years, droughts have dramatically increased in number and intensity in the EU. The number of areas and people affected by droughts went up by almost 20% between 1976 and 2006. Agriculture is a significant water user in Europe, accounting for around 33% of total water use reaching up to 80% in southern Europe where irrigation enables crop production in areas where water would otherwise be a limiting factor. Water consumption through evapotranspiration and plant growth accounts approximately 70% of water abstracted and does not return to a water body.

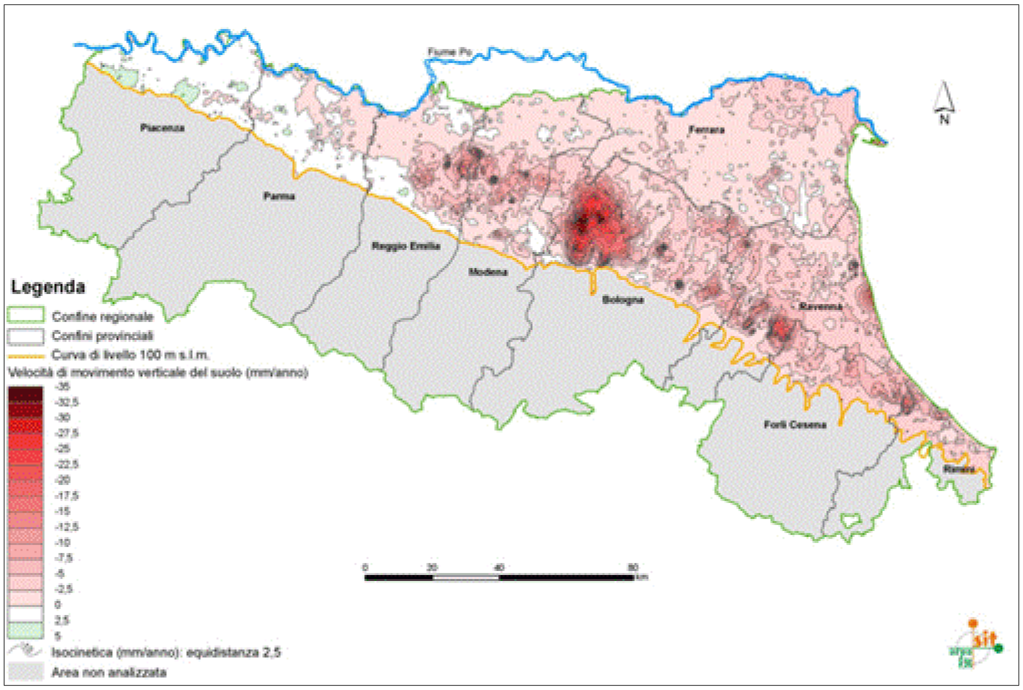
The impact of droughts (Figure 1) can be exacerbated when they occur in areas where water resources are not being properly managed resulting in imbalances between water demands and the supply capacity of the natural system. Ineffective water management have negative impacts both on quantity and on quality of the available water resources, for instance: over-abstraction of surface water may not ensure the minimum ecological flow (endangering the survival of riverine ecosystems); over-abstraction of groundwater on coastal areas can lead to the intrusion of saline water into the aquifer, furthermore, over-abstraction of ground water on lowlands can cause soil subsidence (thereby affecting the flow of water on rivers, channels and sewers and the level of lakes and reservoirs).

Figure 1.Water scarcity and drought events in Europe during the last decade (source: EEA).



Over-abstraction occurs not only for agricultural use but even for industrial and civil uses and can cause in some cases dramatic effects on soil subsidence, for example: the current rate of soil subsidence of the metropolitan area of Bologna (Northern Italy), due to groundwater over-abstraction, is about 3.5 cm/year (Figure 2).

Figure 2. Mean annual rate of vertical soil displacement (mm/year) in 2006-2011 in Emilia Romagna by SAR interferometry (source: ARPA Emilia Romagna).



Soil subsidence can be amplified by other concurrent phenomena, for instance: non-sustainable land development policies, because soil sealing prevents the rainfall to recharge the exhausted groundwater; by oil or natural gas extraction from underground and by tectonic dynamics. The terms of reference for the sustainable water abstraction should be set in the River Basin Management Plans (RBMPs). The Blueprint to safeguard Europe's water resources (COM/2012/673) highlights the role of non-authorized abstraction and the responsibility of Member States in ensuring law enforcement. The illegal water abstraction seems to be rather widespread in Europe, particularly in arid and semi-arid regions and during drought events. The following cases of illegal water abstraction are considered: abstraction without permit and abstraction beyond the amount allowed by permit. Typical cases of illegal water abstraction occur when wells are operating without permit, or when water is pumped form rivers or channels without permit. Besides illegal abstraction, the project WODA consider also over-abstraction, which occur when water resources are exploited beyond the limits of sustainability of the ecosystems.

Illegal water abstraction is a problem of **compliance assurance** while legal water over-abstraction is a problem **environmental monitoring**. The most common cases of both phenomena are illustrated in Figure 3 and Figure 4.

Figure 3. Cases of illegal water abstraction. Case A shows the most common situation where the actual abstraction is above the permitted amount. Case B shows a more extreme situation where the water right doesn't exist or has expired. Illegal water abstraction is a problem of compliance assurance.

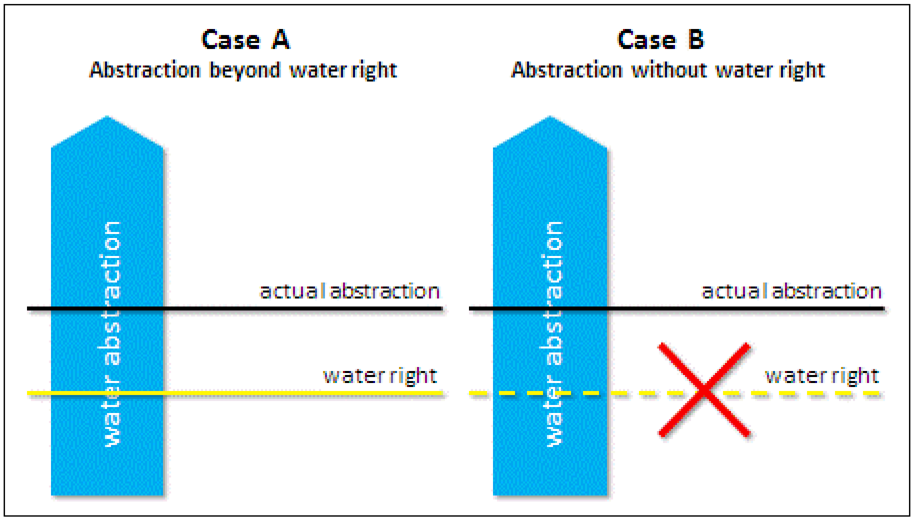
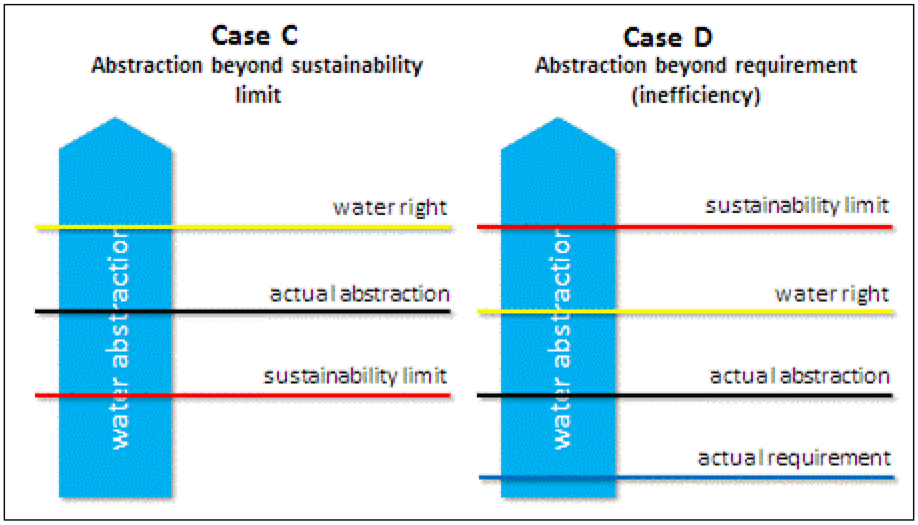
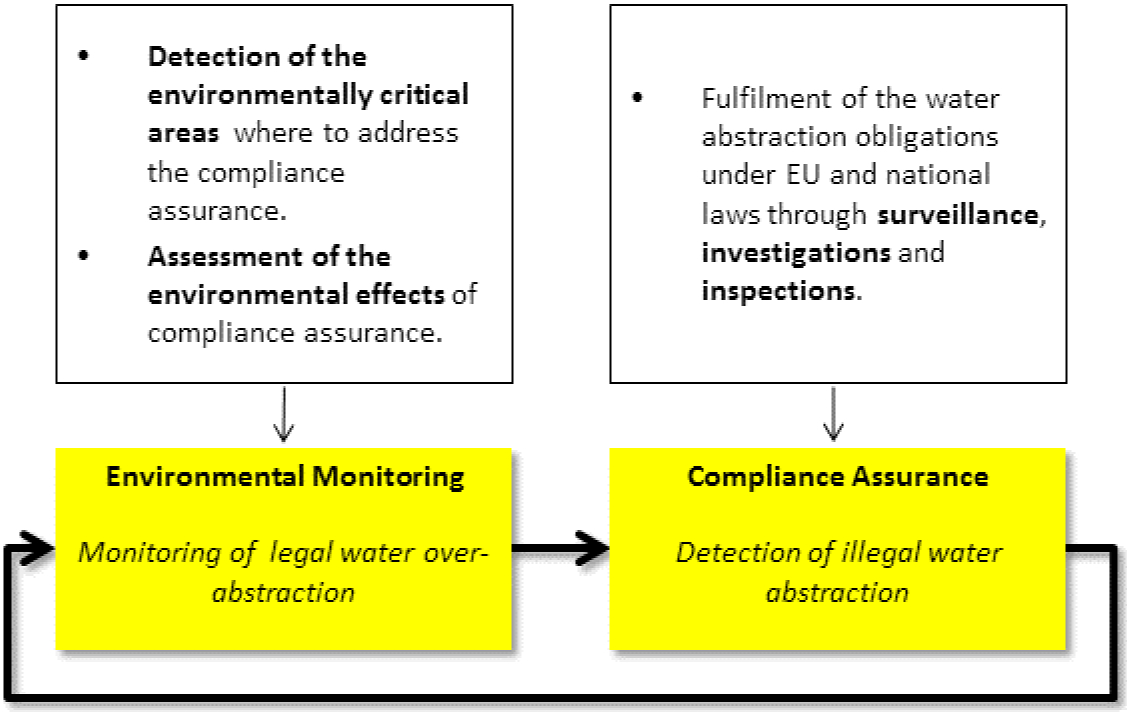


Figure 4. Cases of legal water over-abstraction. Case C shows a situation where the actual abstraction respects the water right but the amount abstracted is beyond the sustainability limit. This situation is due to a bad planning of water demand: each abstraction is legal but the sum of abstractions overcome the resilience of the system. Case D shows another example of bad planning of water demand: the water is abstracted in excess respect to the actual requirement resulting in a waste of water. The waste of water can become critical during water scarcity and drought events. Legal water over-abstraction is a problem of environmental monitoring.



The monitoring of legal water over-abstraction and the detection of illegal water abstraction are tasks of the same process of water management (Figure 5) and operate in synergy. The first task allows the detection of the environmentally critical areas where to address the compliance assurance and the assessment of the environmental effects of compliance assurance. The second task allows the fulfilment of the water abstraction obligations.

Figure 5. The monitoring of legal water over-abstraction and the detection of illegal water abstraction are tasks of the same process of water management.



- **Detection of the environmentally critical areas** where to address the compliance assurance.
- **Assessment of the environmental effects** of compliance assurance.

- Fulfilment of the water abstraction obligations under EU and national laws through **surveillance**, **investigations** and **inspections**.

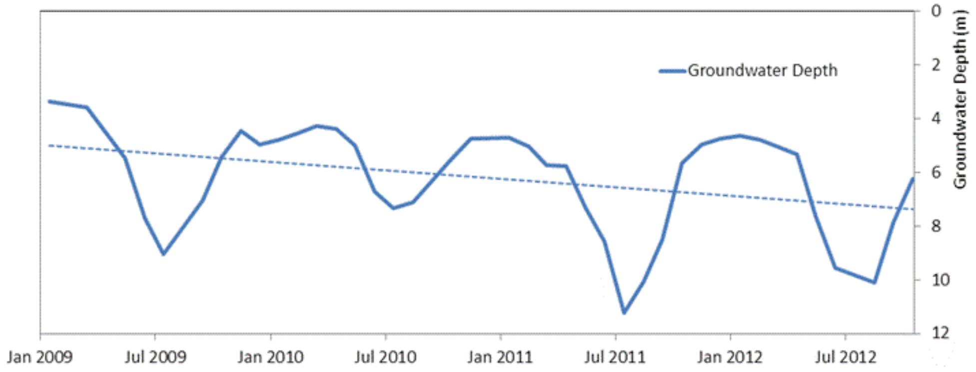
Environmental Monitoring

Monitoring of legal water over-abstraction

Compliance Assurance

Detection of illegal water abstraction

Figure 6. Example of legal water over-abstraction. Time series of groundwater depth close to Verolanuova (Lombardy). In this area groundwater is used both for irrigation and to supply pig breeding plants. The summer down peaks correspond to the peaks of demand for irrigation. The negative trend (dotted line) highlights over-abstraction: the amount of abstracted water is beyond the sustainability limit of the groundwater system.



1.2 The contribution of Earth Observation

In 2013 DG ENV charged the consortium composed of BIO-Deloitte and University of Castilla-La Mancha (UCLM) with the development of the study: "**Applying Earth observation to support the detection of non-authorised water abstractions**". The main reference points of the study are shown in Table 1.

Table 1. Reference points of the study "Applying Earth observation to support the detection of non-authorised water abstractions"

Water Framework Directive 2000/60/EC	• Member States must control water abstraction through the maintenance of registers and a requirement of prior authorisation for abstraction from users.
Roadmap for a resource efficient Europe (2011)	• Water abstraction should stay below 20% of available renewable water resources.
Copernicus	• The European Earth Observation programme, provides satellite imagery and user tailored services.
Blueprint to safeguard Europe's water resources (COM/2012/673)	• Stresses the importance of the issue of non-authorised abstractions. • Identifies Copernicus as an approach to complement field data and address water quantitative issues.

The study provided two deliverables (Table 2).

Table 2. Deliverables of the study "Applying Earth observation to support the detection of non-authorised water abstractions"

1. Proposed Guidance document	• The Guidance document is addressed to water resources managers. • Informs on the EO potential for supporting the detection and monitoring of water abstraction for irrigation, including the detection of non-authorised abstractions. • Reviews the currently available EO tools and services and share the lessons learnt from their practical implementation in different countries. • Provides guidance on whether and how these tools and services can be used to complement conventional approaches in different local contexts.
2. Discussion paper for the European Commission	• Assesses the opportunities to develop a Copernicus service dedicated to the management of abstractions for irrigation. • Provides a basis for the discussion on its key technical specifications.

The Guidance document proposes a series of well-established EO products and services effective in supporting the detection of the illegal water abstraction and, more in general, useful to the management of water resources (Table 3).

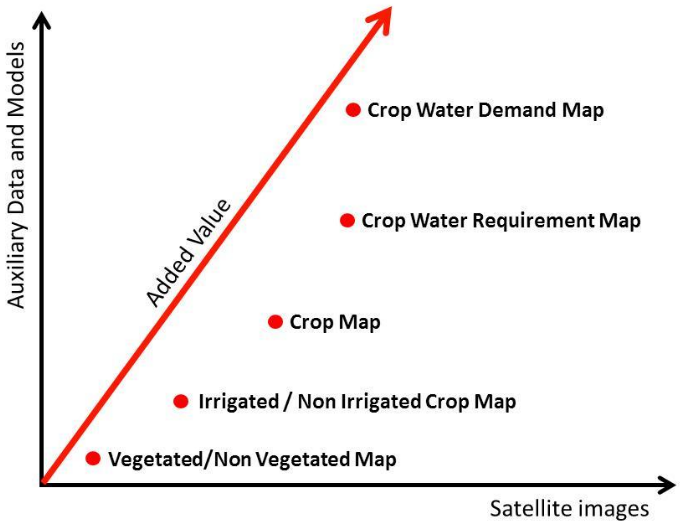
Table 3. EO products and services proposed by the Guidance document. The added value increases from 1 to 5.

EO Product/Service	Comments
1. Vegetated / Non vegetated map	Requires few images, very simple processing. Auxiliary data not necessary.
2. Irrigated / Non irrigated crop map	Requires few images, simple processing. Auxiliary data not necessary.
3. Crop map	Crop map can be implemented at different levels of detail depending on the user requirements and on the available EO and auxiliary data. A basic crop map could include, for instance, the following classes: summer crop, winter crop, pasture and meadow, permanent crop. A more advanced crop map could provide a second level of classes, e.g. summer crop could split into: maize, durum wheat, soybeans, sunflower,…. Auxiliary data: crop

EO Product/Service	Comments
	calendars, crop statistics, a set of ground truth points where the actual crop is known.
4. Crop Water Requirements map	The crop water requirement is estimated through the potential evapo-transpiration, i.e. the amount of water transferred as vapour from the soil-vegetation system to the atmosphere. Auxiliary data: meteorological data from ground stations (wind, air temperature, air humidity, solar radiation); ground truth: crop phenological state.
5. Crop Water Demand map	The crop water demand provides a more realistic estimate of the actual need of water. Besides evapo-transpiration, it takes into account the water exchanges between soil and crop and the efficiency of the irrigation system. Auxiliary data: soil map, aquifer, irrigation system.

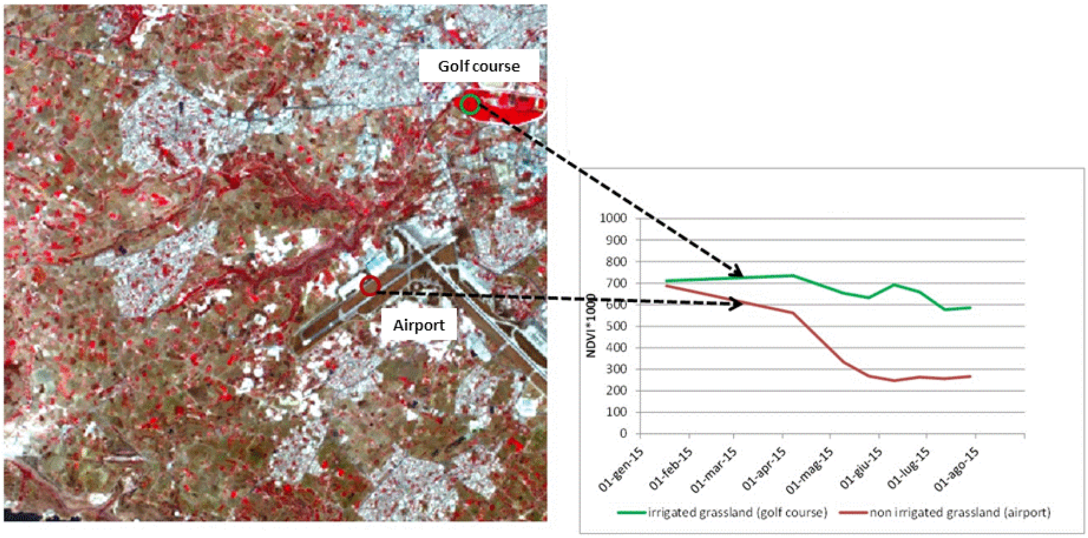
Auxiliary data and mathematical models add value to the EO data. The more advanced the EO product/service, the more auxiliary data, models and satellite images are required. The concept is shown in Figure 7.

Figure 7. Relationship among the value of EO product/services and the amount of auxiliary data and models and satellite images.



The discrimination between irrigated and not irrigated vegetation using satellite remote sensing is an easy task (Figure 8).

Figure 8. Example of discrimination between irrigated and non-irrigated grassland by satellite remote sensing. At left: a false-colour infrared image acquired by the satellite Landsat8 over Malta the 6 July 2015. The intensively irrigated grassland of the golf course appears in light red while the non-irrigated grassland of the airport appears in pale brown. At right: the time series of the NDVI (Normalized Difference Vegetation Index) of the two grassland sites. The gap between the NDVI of the irrigated and non-irrigated grassland increases with the proximity of the dry season.



Malta, Landsat8 image of 6 July 2015

The crop water requirement map is based on the estimation of the evapotranspiration. Evapotranspiration is the amount of water dispersed into the atmosphere by the vegetation-soil system. Satellite remote sensing allows for the estimation of two different evapotranspiration parameters:

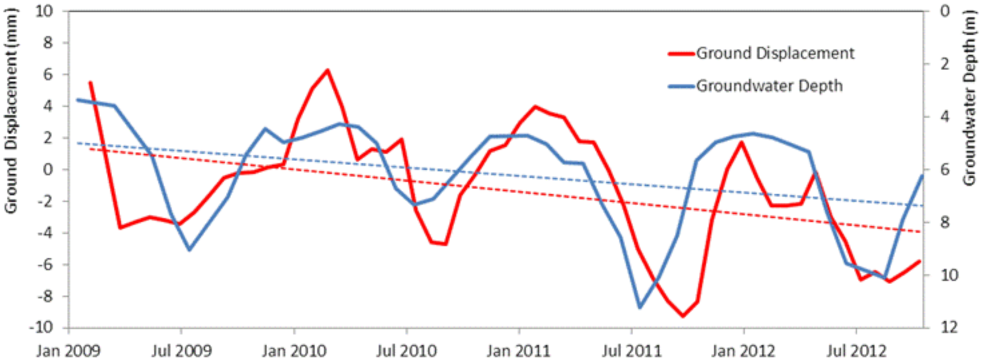
1) Evapotranspiration under standard conditions (ET_c): is a theoretical value generally computed through the Penman-Monteith equation (FAO Guidelines No. 56); it approximates the evapotranspiration of a crop under standard irrigation conditions and represents therefore the optimum crop water requirement.

2) Actual evapotranspiration (ET): is the actual amount of water evapotranspired by crop. In arid non irrigated areas ET is close to zero. Under standard irrigation conditions ET approximates ET_c while under over-irrigation or abundant precipitations, ET tends to an upper limit called potential evapotranspiration (PET). The monitoring of ET is a powerful tool to assess irrigation efficiency and detect water stress situations.

The above methods require meteorological information from ground weather stations (generally: net solar radiation, air temperature, air humidity, wind speed). Besides evapotranspiration, remote sensing provides information about crop type and growth state (phenology and biomass). In some semi-arid regions the contribution from rainfall and surface water is negligible and most of the required water comes from groundwater, thus ET_c directly represents the crop water requirement from groundwater. If well permits are up-to-date and archived in a geo-referenced database, the detection of areas where water is abstracted from illegal wells (or in excess of the levels prescribed in the operational permits of the wells) is quite straightforward. On the other side, in temperate regions where irrigation comes mainly from surface water and only partly from groundwater, the detection of illegal water abstraction through EO and GIS methods may be very difficult.

Earth Observation provides a very powerful tool to monitor soil subsidence based on satellite SAR (Synthetic Aperture Radar) differential interferometry. This method, not considered in the study "Applying Earth observation to support the detection of non-authorized water abstractions" is taken into account in WODA and is the subject of the Pilot Feasibility Study of Lombardy. SAR differential interferometry allows to measure vertical displacements of soil with millimeter accuracy. Under specific geological conditions, quite common in sedimentary basins (e.g. Po River Basin), groundwater over-abstraction causes soil subsidence (Figure 9). Because different concurrent factors may affect soil subsidence, e.g. tectonics, extraction of natural gas or oil, … the measures of soil displacement must be carefully analyzed.

Figure 9. Example of monitoring the subsidence induced by groundwater over-abstraction through SAR differential interferometry. The case refers to Figure 6. The red line shows the vertical displacement of ground measured by SAR interferometry. The agreement between the movement of the groundwater level and the soil surface level is high. The scales are different: the variation is in the order of metres for groundwater and in the order of millimetres for soil surface. Subsidence, in proper conditions, can be taken as a proxy of groundwater over-abstraction.



The EO methods used for the detection of illegal water abstraction and for the monitoring of legal water over-abstraction differs not only from the technical approach (optical remote sensing versus SAR interferometry) but also from the conceptual point of view. We can catch the difference using as frame of reference the DPSIR (Drivers, Pressures, State, Impacts, Responses) scheme. The EO method for the detection of the illegal water abstraction provides the estimation of an environmental pressure (Figure 10) while the EO method for the monitoring of legal water over-abstraction provides an estimation of an environmental impact (Figure 11).

Figure 10. Taking as reference the DPSIR (Drivers, Pressures, State, Impacts, Response) scheme, the EO method for the detection of the illegal water abstraction provides the estimation of an environmental pressure.

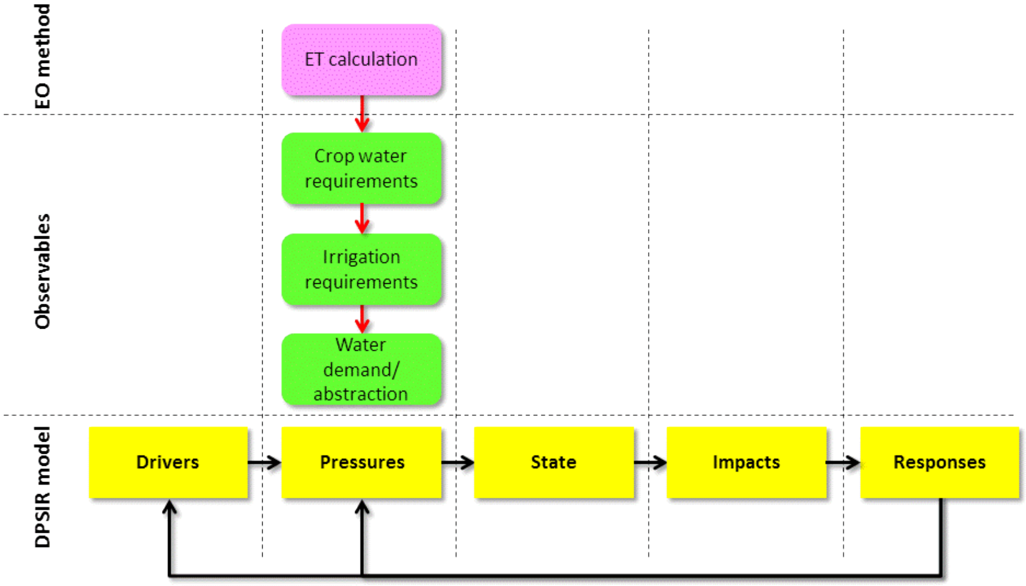
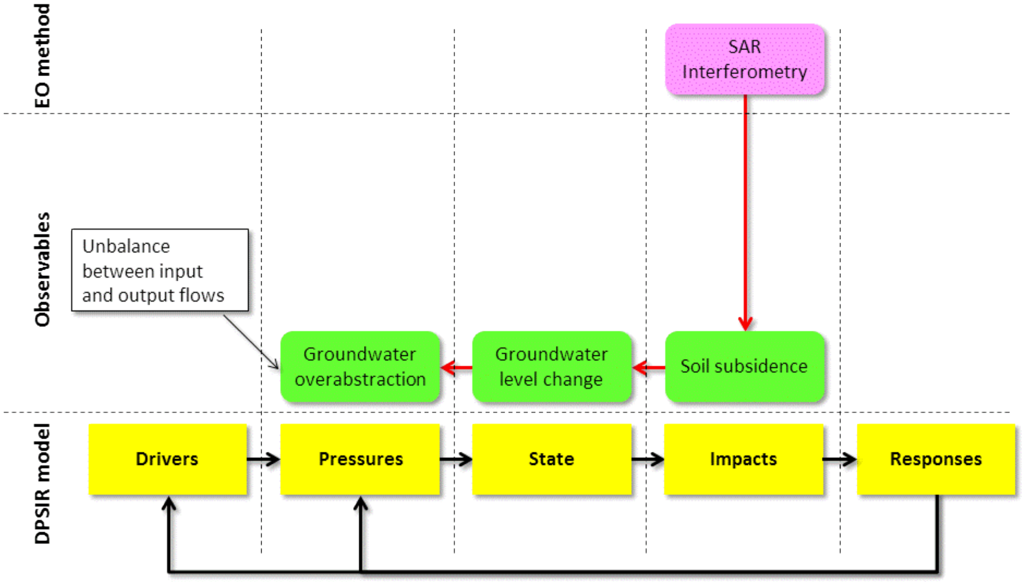


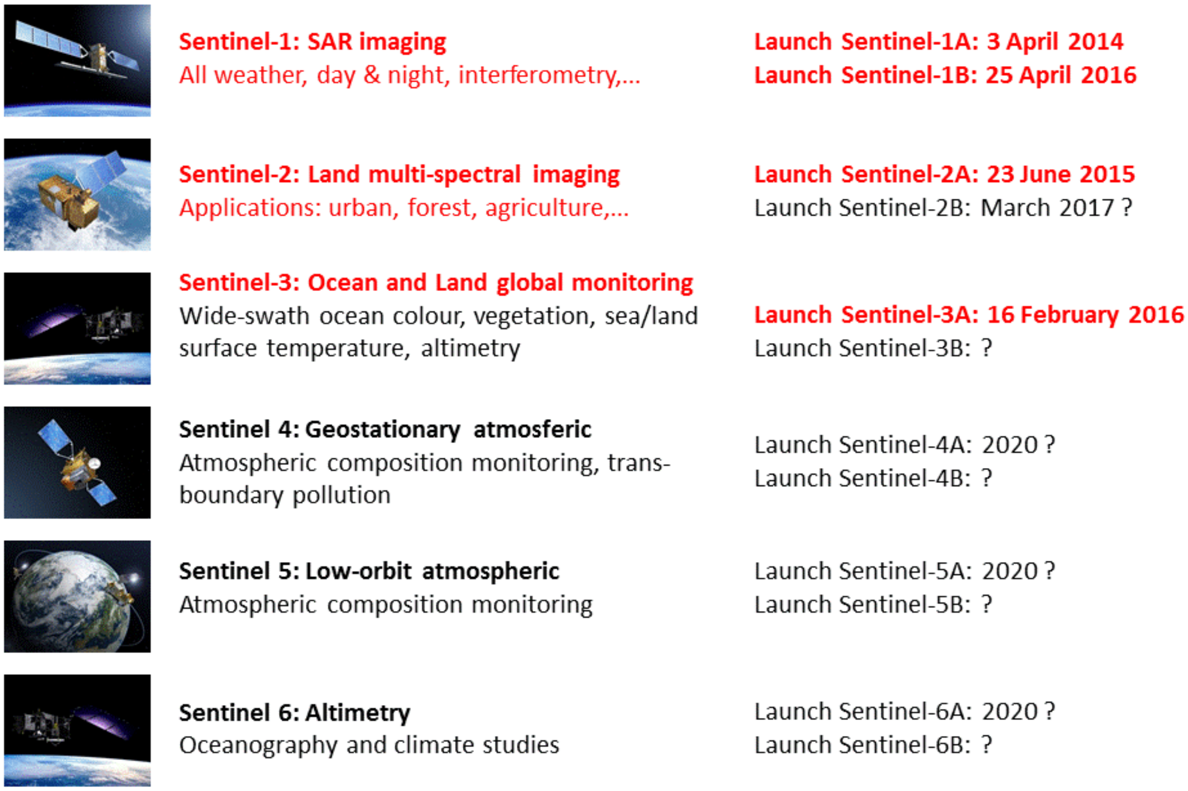
Figure 11. Taking as reference the DPSIR (Drivers, Pressures, State, Impacts, Responses) scheme, the EO method for the monitoring of the legal water over-abstraction provides the estimation of an environmental impact, i.e. the soil subsidence, caused by a change in the state of the groundwater level, caused in turn by an environmental pressure, i.e. the groundwater over-abstraction. Soil subsidence is a proxy of groundwater over-abstraction.



1.3 The Copernicus programme

Copernicus is a European Programme for the establishment of a European capacity for Earth Observation, launched in 1998 as GMES Programme (Global Monitoring of Environment and Security). Regulation (EU) No 377/2014 stated a new development stage of the Copernicus programme, which will feature new operational services by 2020. The aims of Copernicus are: promoting the use and sharing of Earth Observation data and information; strengthening European Earth Observation markets, with a view to enabling growth and job creation; supporting the European research, technology and innovation communities. Copernicus collects data from multiple sources: Earth Observation satellites and in situ sensors (e.g. ground meteorological stations). It processes data and provides a set of services related to environmental and security issues. The services address six thematic areas: land, marine, atmosphere, climate change, emergency management and security. Copernicus is made up of two components: the service component and the space component. The space component includes the launch of six constellations of satellites, called Sentinels (Figure 12).

Figure 12. The Copernicus Sentinels constellations of satellites for Earth Observation. The Sentinels highlighted in red have already been launched.



Sentinel-1: SAR imaging All weather, day & night, interferometry,...	**Launch Sentinel-1A: 3 April 2014** **Launch Sentinel-1B: 25 April 2016**
Sentinel-2: Land multi-spectral imaging Applications: urban, forest, agriculture,...	**Launch Sentinel-2A: 23 June 2015** Launch Sentinel-2B: March 2017 ?
Sentinel-3: Ocean and Land global monitoring Wide-swath ocean colour, vegetation, sea/land surface temperature, altimetry	**Launch Sentinel-3A: 16 February 2016** Launch Sentinel-3B: ?
Sentinel 4: Geostationary atmosferic Atmospheric composition monitoring, trans-boundary pollution	Launch Sentinel-4A: 2020 ? Launch Sentinel-4B: ?
Sentinel 5: Low-orbit atmospheric Atmospheric composition monitoring	Launch Sentinel-5A: 2020 ? Launch Sentinel-5B: ?
Sentinel 6: Altimetry Oceanography and climate studies	Launch Sentinel-6A: 2020 ? Launch Sentinel-6B: ?

Sentinel-1, based on a SAR sensor, is useful for soil subsidence monitoring.

Sentinel-2, based on high-resolution multi-spectral optical sensors (resolution: 10m in visible and near infrared bands and 20 m in short wave infrared), is useful for all the application described in Table 3.

Sentinel-3, based on medium-resolution multispectral optical sensors (even on thermal infrared), (resolution: 500m - 1000m), useful for estimating potential evapotranspiration and actual evapotranspiration at regional scale.

1.4 Objectives

The aim of the work has been to improve the capability of IMPEL members to monitor water over-abstraction, both legal and illegal, through cost-effective EO and GIS methods. This can increase the IMPEL Members' efficiency in the use of inspective resource on field for tackling illegal abstraction of water; the increase of capabilities in interpreting water use for agriculture, civil and industrial use can be useful to foster Member States in implementation of WFD and achievement of the targets set in Roadmap for a resource efficient Europe.

Through this project, IMPEL members have acquired a better knowledge about EO methods and the opportunities provided by the Copernicus programme. The outcome of this project could be useful in the context of the evolution of the Copernicus land monitoring service.

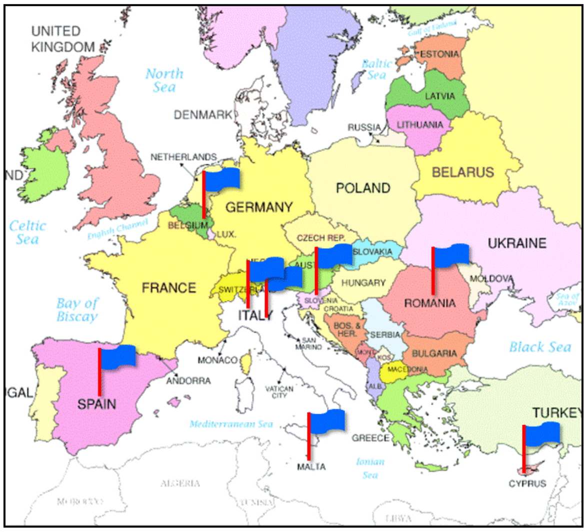
1.5 Project partners

The following partners have actively participated to project WODA (**Error! Reference source not found.** and **Error! Reference source not found.**).

Table 4. Partners of the project WODA

WODA partner	Country
Environment, Nature and Energy Department. Flemish Government. Region of Flanders.	Belgium
Water Development Department. Ministry of Agriculture, Natural Resources and Environment.	Cyprus
ARPA (Regional Environmental Protection Agency) Emilia Romagna. Region of Emilia Romagna.	Italy
ARPA (Regional Environmental Protection Agency) Lombardia. Region of Lombardy.	Italy
Sustainable Energy and Water Conservation Unit. Ministry for Energy and Health.	Malta
National Environmental Guard - Bihor County Commissariat. Bihor County.	Romania
Inspectorate of the RS for Environment and Spatial Planning, Ministry for the Environment and Spatial Planning.	Slovenia
Consejero técnico. Confederación Hidrográfica del Miño-Sil. Ourese.	Spain

Figure 13. Location of partners of the project WODA



2. Use Case 1: Pilot Study Malta

The following table summarizes the contents and the characteristics of the Malta case study.

Table 5. Main contents and characteristic of the Pilot Study Malta

Use case	**Malta Pilot study**
Pilot area	3 Local Councils (Siggiewi, Haz Zebbug and Qrendi) in the south-west region of the island of Malta
Analysis in WODA and/or WODA2	Pilot feasibility study in WODA (2015) and further tests in WODA2 (2016)
Water uses target	Water uses in agriculture
Water sources type target	Abstractions from groundwater
EO-data type and approach	Optical data; multitemporal analysis of vegetation indices; Kc/NDVI approach for ETc calculation
Copernicus EO-data suitable for implementing future operational activities	Sentinel-2
Availability and quality of in-situ data for testing operational services	Agricultural parcels with property ID, water abstraction points (location, property, ..), monthly measures of actual abstractions, meteorological data, reference agronomic data for the main crop types in the area
Type of product / EO-services tested (accordingly to Copernicus Guidance Document)	Vegetated/not vegetated areas maps, crop type maps, multitemporal evolution of crops, irrigated and non irrigated areas maps, Crop Water Requirements estimations, preliminary Crop Water Demand estimations
Usefulness and potential inputs for inspections	Yes
Main stakeholders (type)	Water Monitoring Authorities, Water Services, Agricultural Department, Policy makers, …
Extensibility of the tested approaches to other areas	High; Mediterranean countries, semi-arid regions
Level of EO technical requirements	Medium

Feasibility of future downstream services	High

2.1. Context

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

Figure 14: Mean minimum and maximum air temperature in Malta

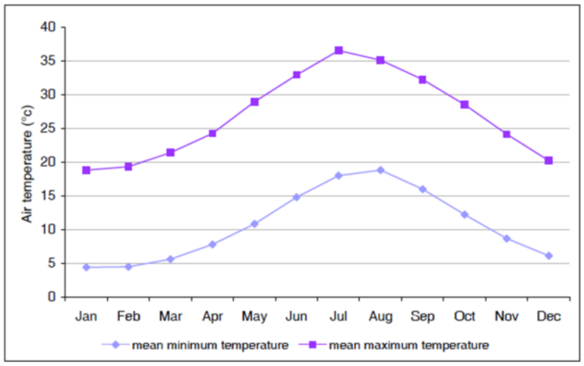
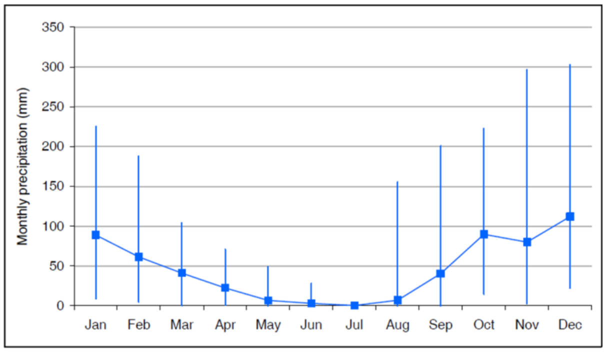


Figure 15: Monthly means and variability of the total precipitation



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

- Variability in inter-annual and intra-annual rainfall.
- High intensity, short duration of rainfall events.
- Seasonal scarcity of precipitation which coincides with the water requirements of the agriculture sector being highest at the time when rainfall is least available.
- Low effective rainfall due to high evapotranspiration rates.

The semi-arid climate of Malta is ideal to use optical remote sensing techniques due to the limited days of cloud cover and is well representative of the climate of other Mediterranean countries.

The focus of the use case was on agricultural water uses; 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, the fragmentation of land and small parcel size which leads to high labour costs.

As regard to the water demand from the agricultural sector, in the past decades, there was 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 to date of marginal importance. Groundwater is sourced through private abstraction wells located either in the mean sea level 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 carried out to better characterize the water demand of the agricultural sector.

2.2. Requirements

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 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%).
- Owners of private groundwater sources are required to register their private groundwater sources and pay a onetime registration fee. The fee is a standard fee that applies to all users.
- Monitoring of private groundwater abstraction is in its initial phases. The process of installing flow meters on the most significant groundwater sources has been completed and currently the information is being analysed.
- There is a good database concerning the location and delineation of 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 first part of the Malta feasibility study (in WODA, during 2015) was about the use of optical EO data primarily for the detection and monitoring of irrigated parcels. The second part of the study (in WODA2, during 2016) was focused on the use of the exploitation of the EO data from the

Copernicus program (Sentinel-2 multitemporal data) in order to improve the evaluations carried out in the previous year, and evaluating other potential operative EO-based services, taking as reference the EO products and services proposed by the Copernicus Guidance Document.

2.3. Materials

2.3.1. In-situ data

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

Groundwater abstractions points:

- Location of groundwater abstraction points (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 abstraction (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 land covers of the parcels or within the parcels. So for instance one parcel can have multiple land covers (for example mixture of vineyards and fruit trees in the same parcel).

General information:

- Reference meteorological data (daily measures of temperature min-max, humidity, wind velocity, solar radiation, precipitation), and reference evapotranspiration estimation (ETo).
- Typical crop sowing and harvesting dates for the most important and widespread crops in Malta, and reference crop coefficients (Kc).

2.3.2. Earth Observation and Copernicus data

The basic optical EO data used in the first year of WODA project (2015) was a multi-temporal data set of Landsat8 data, referred to 2014 and 2015 (for details, please see the WODA Final report).

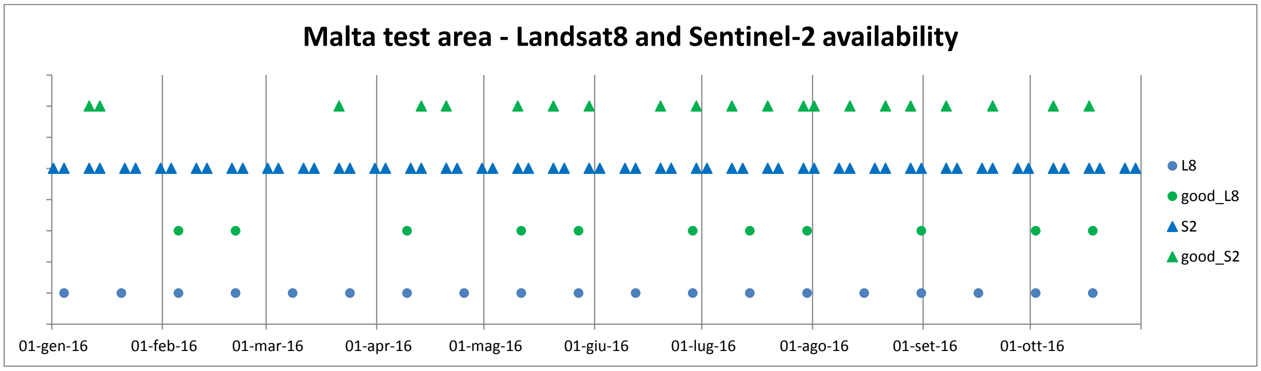
During 2016, Sentinel-2 satellite from the Copernicus Program became fully operational, and Sentinel-2 multispectral data were the basic EO-data source in the second part of the feasibility study.

The island of Malta is covered by the Granule ID 33SVV of the Sentinel-2 standard product; the study area is covered by two different orbits (ID 79 and ID 36), so the time revisit of acquisition of the satellite is less than the nominal 10 day spatial resolution.

During 2016, 21 single acquisitions with null or low cloud cover percentage of Sentinel-2 satellite were selected, covering all the seasons from January to October.

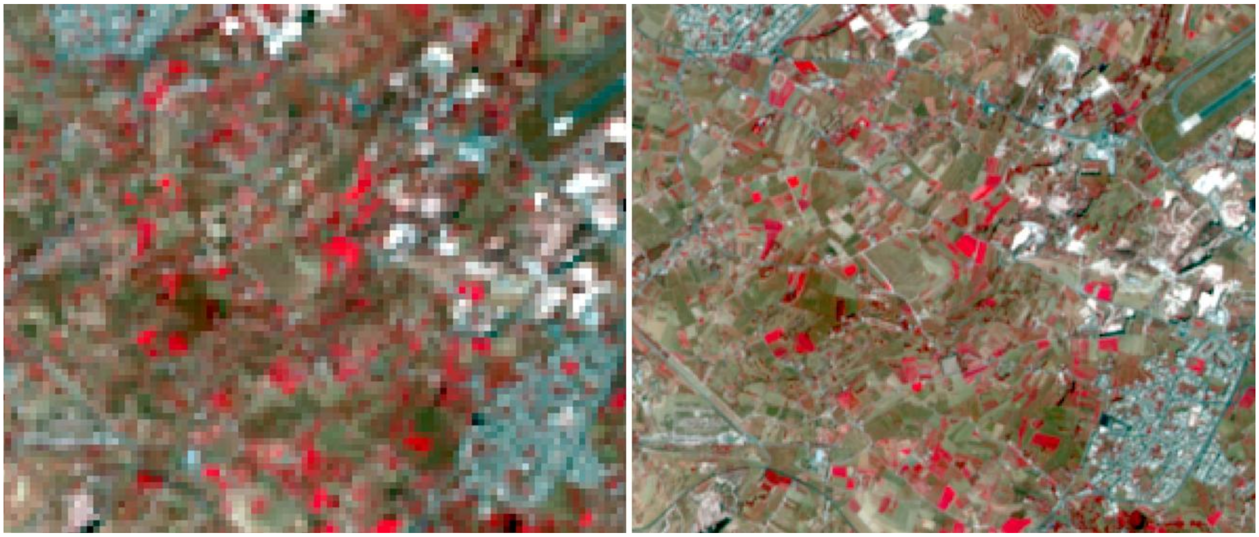
The next figure shows the comparison of the nominal and actual (cloud free) time revisit of the previously freely available optical medium resolution satellite (Landsat8, from USGS – blue and green dots) with the nominal and actual availability of Sentinel-2 data (blue and green triangles) over the test area in Malta.

Figure 16: Comparison of Landsat8 (L8) and Sentinel-2 (S2) data availability comparison (nominal temporal revisit and useful cloud-free data) over the test area in Malta during 2016



The following figure shows a comparison, over part of the pilot area in Malta, of Landsat8 (pixel at 30 meter of spatial resolution) data and Sentinel-2 data (pixel at 10 meter of spatial resolution); images are in infrared false color composite (IRFC), extracted at 1:15000 map scale.

Figure 17: Comparison of Landsat8 (left) and Sentinel-2 (right) data over part of the test area in Malta (acquisition of the same day, IRFC composite)



While the spatial resolution of Landsat8 data could be in general a limiting factor due to its lower resolution capabilities, the availability of Sentinel2 data (with a 10x10 meter pixel size) clearly provides a strong improvement in context like those of the Malta case study of small parcels size.

Key findings: Confirmation of the strong improvement provided by Copernicus data, in terms of both spatial and temporal resolution. Moreover, Copernicus data is freely available from the ESA portal, and generally is made available the day after the acquisition.

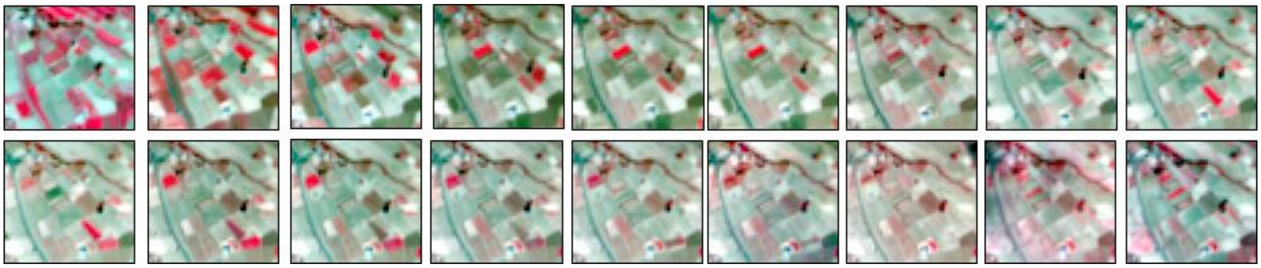
2.4. Methods and Results

2.4.1. EO data analysis

The nominal temporal resolution of Sentinel-2 data (frequency of acquisition over a single orbit) is of 10 days; considering that the test area is covered by two different orbits, and that cloud cover in the context of Malta is not a strong limiting factor, there is in general a good number of cloud free scenes over Malta, enough to characterize the temporal evolution of the main crops.

For example, the 18 pictures in the next figures are IRFC composites of a small agricultural area in Malta (in Siggiewi Council), from January to October 2016, qualitatively show the evolution of the different crops in the single parcels; in the IRFC composite, red hues represent vegetated areas.

Figure 18: Temporal evolution of 18 Sentinel-2 images (IRFC) from January to October 2016 in a small agricultural area in Siggiewi Council

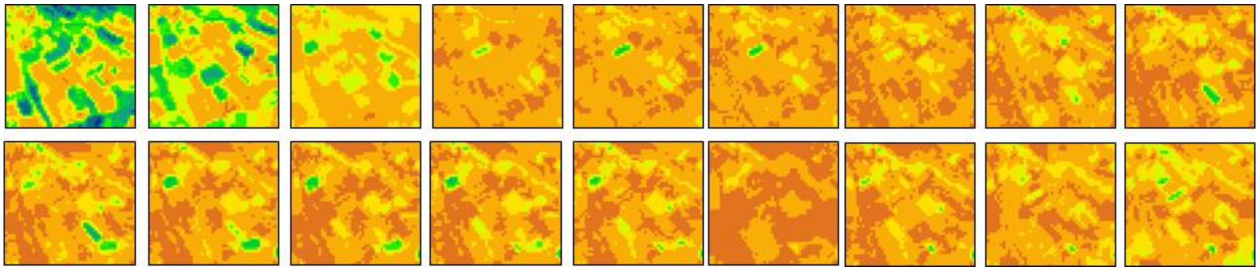


The general and basic concept in the feasibility study is that, due to the lack of precipitation in Malta during spring and summer, agricultural parcels must be irrigated (in this case by groundwater) thus vegetated agricultural parcels can be considered as irrigated.

Moreover it is possible to exploit in a more quantitative way the temporal variation of the spectral response of the vegetation, using for example common spectral indices like the Normalized Difference Vegetation Index (NDVI). In the 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.

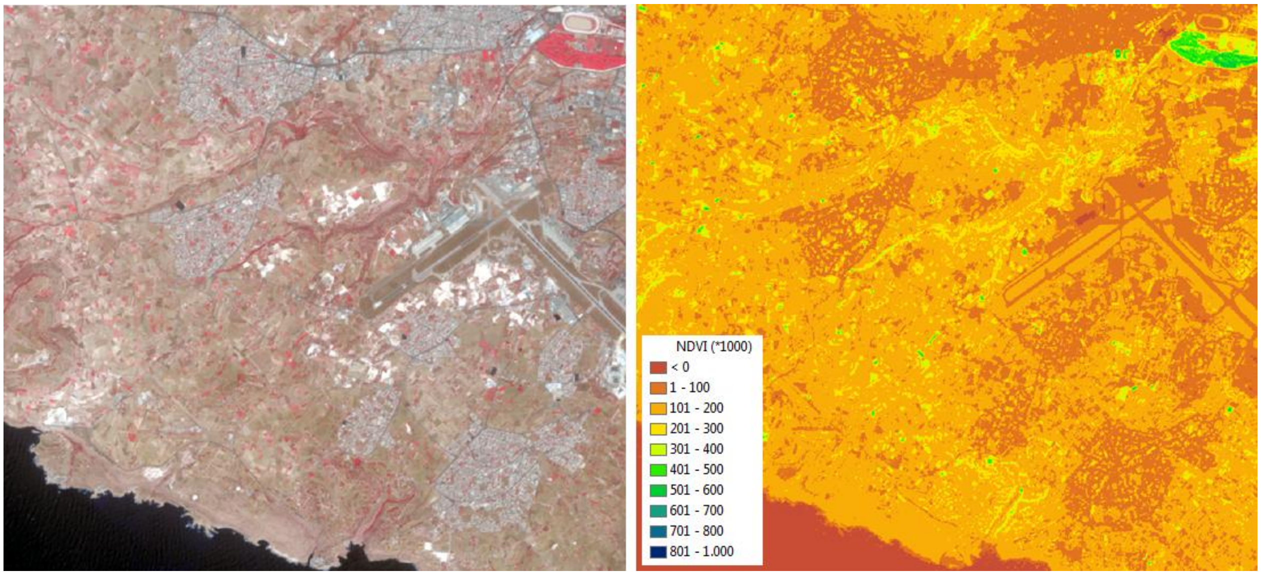
Over the same area shown in Figure 19, Figure 20 shows is the temporal variation of NDVI index (in standard color composite) from January to October 2016.

Figure 19: Temporal evolution of 18 NDVI maps from Sentinel-2 from January to October 2016 in a small agricultural area in Siggiewi Council



The approach of interpreting, distinguishing and classifying the vegetated and non vegetated areas through NDVI could be applied on each of the single satellite image once it is available from the ESA portal (in general until the day after the acquisition) (see next figure for example, relative to 19th July 2016).

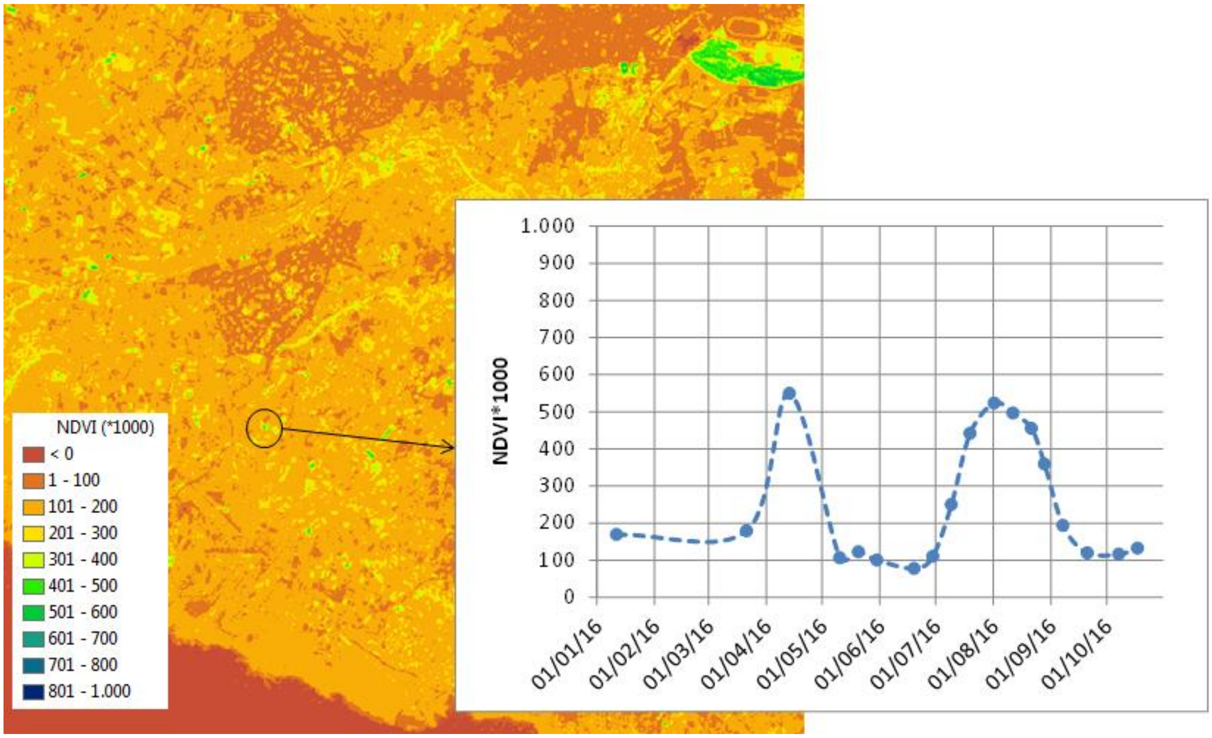
Figure 20: Sentinel-2 acquisition of the 19th July 2016 over the pilot area in Malta, and calculation of the corresponding NDVI map



The analysis’s approach becomes more and more effective when exploiting the multitemporal capabilities of Sentinel-2 data; for example, every parcel could be monitored based upon the temporal variation of NDVI during the season.

For example, Figure 21 highlights the temporal variation of NDVI in a single agricultural parcel (vegetated on a single date - 19th July 2016): analyzing the NDVI pattern through the year, we could argue that this is a case of double cropping in this specific agricultural parcel.

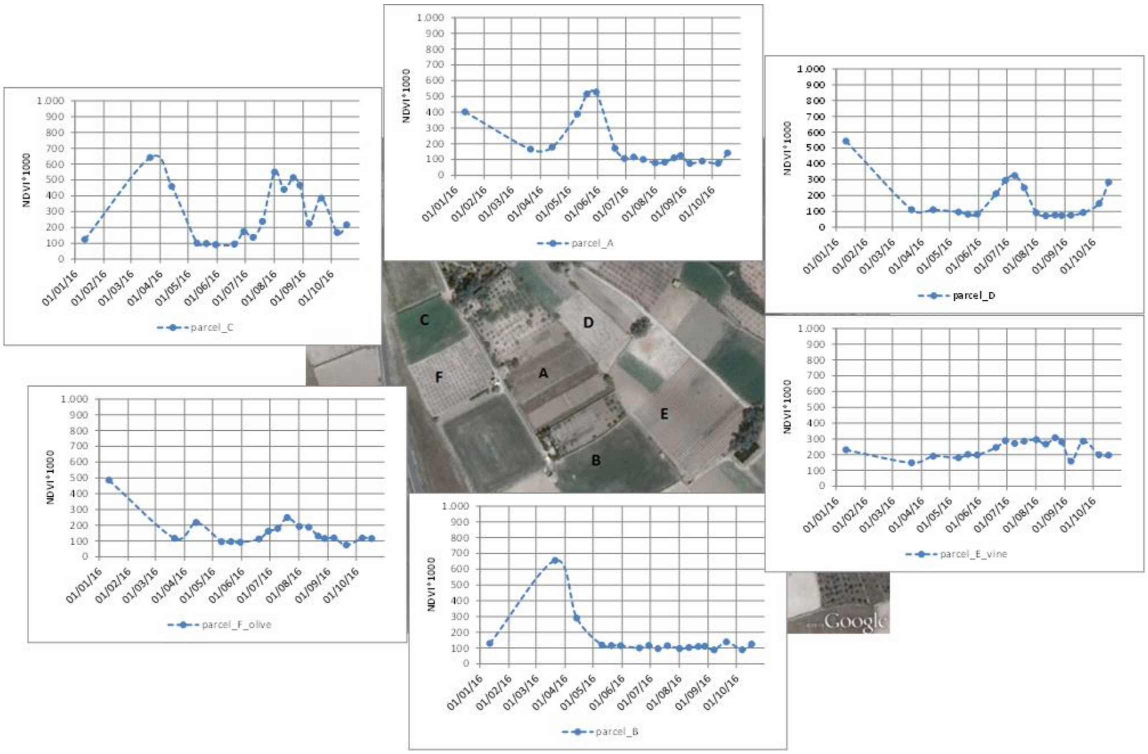
Figure 21: Example of the focus of the 2016 temporal evolution of NDVI in a specific agricultural parcel in the test area



Key findings: the analysis of Sentinel-2 data through NDVI multitemporal approach is very effective in order to characterize the spatial-temporal variation of agricultural vegetation in context like those of Malta.

This kind of approach of analysis is feasible on every single parcel, and is effective also in cases, like those of Malta, where parcel sizes are very small and agricultural land is very fragmented. For example, in the next figure there is a comparison of NDVI temporal profiles of different small and neighboring agricultural parcels; the different NDVI plots denotes the different crop macro-types (i.e., spring crop, summer crop, double crop, permanent bare soil, etc..).

Figure 22: Example of the focus of the 2016 temporal evolution of NDVI in different, small and neighbouring agricultural parcels.



Key findings: The multitemporal NDVI approach is quite simple but requires some pre-elaboration on Sentinel-2 data, once downloaded from ESA portal (spectral bands selection and combination, band math calculations, multitemporal data composites, etc..). This approach could be object of part of a future "downstream service" from Copernicus; otherwise, every user should manage a process of "EO capacity-building" for develop this or other more complex analysis starting from EO data.

2.4.2. In-situ data analysis

This part of the 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 equipped with a flowmeter, and groundwater abstraction monthly data are available from more than 300 of these groundwater sources. The groundwater metering program was still being developed at the time of the implementation of the WODA project.

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).

For a more complete description of the process of In-situ data analysis, data integration, etc., see the WODA Final Report.

Key findings: The different In-situ data exploited in the Malta pilot are managed by different Authorities; generally data are in different formats and therefore might need some reworking prior to be integrated with EO-data; the process of involving the different Authorities, like the process of signing proper and effective data-exchange protocols, is essential. This kind of activity of in-situ data analysis is essential for the success of the further analysis and the full exploitation of EO-data. The availability of auxiliary data can greatly enhance the application of EO-data for environmental management, better regulation and policy development. Therefore public entities should try as much as possible to combine/streamline existing auxiliary data with earth EO-data.

2.4.3. In-situ data and EO-data matching

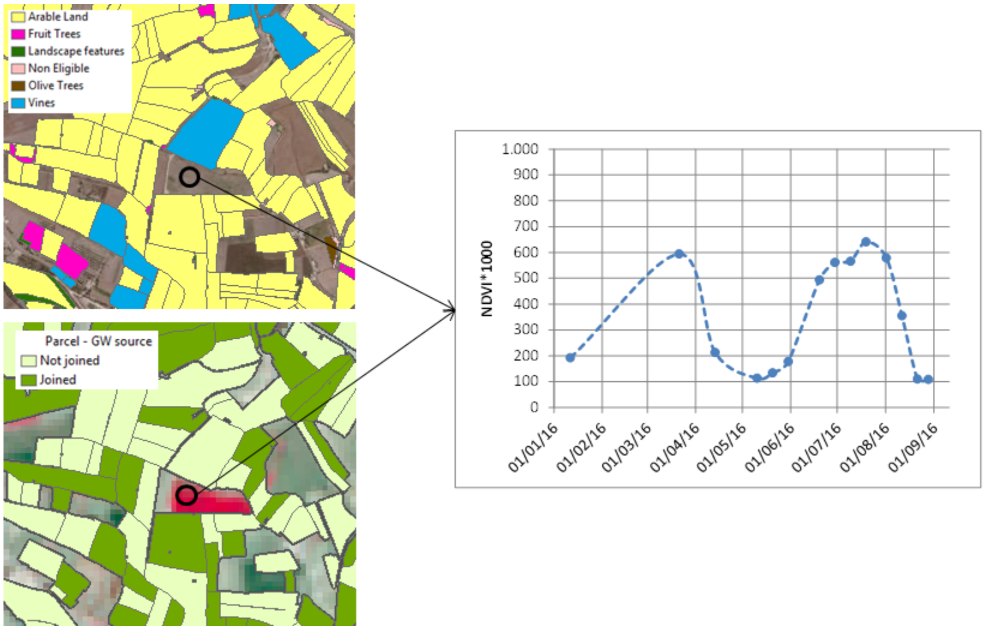
The focus of this part of the feasibility study was on the matching and analysis of the available information regarding groundwater abstractions (in terms of location, property and, when available, quantities), agricultural parcels (type, size, land use, properties), and the main information derived from EO-data (in particular from the temporal evolution of NDVI index derived from Sentinel-2 2016 images).

The output of these activities, in terms of specific case studies analysis, could be seen as prototypes of “EO services” at different level of complexity. This kind of activity has been performed generally at the parcel scale, and in the next paragraphs some examples are shown, describing the main situations explored and the main findings.

Input for improving agricultural land use mapping

This kind of application is independent, and preliminary, to the other quali-quantitative analysis related with the water abstractions and water uses. In fact, matching the available agricultural parcels (LPIS) in the test area, and the analysis of the temporal variation during 2016 of NDVI index derived from Sentinel-2, can potentially highlight areas which are used for agricultural purposes but are outside the area of parcels registered as agricultural land. Moreover, in the climatic conditions like those of Malta, these situations are very probably referred to some amount of water exploitations for irrigation purposes.

Figure 23: Example of detecting through Sentinel-2 multitemporal data potential agricultural use outside the currently mapped agricultural parcels (LPIS)



Key findings: the analysis of Sentinel-2 data through NDVI multitemporal approach is very effective in order to improve the knowledge on agricultural land-use, and to improve the mapping of agricultural land uses.

Input for water management and groundwater abstractions monitoring improvements

This part of applications and of EO-service development and testing is related to the matching of the In-situ data (particularly agricultural parcels and groundwater abstractions location and measurements) with multitemporal analysis from EO data. As highlighted before and in the Copernicus Guidance Document, the approaches and the results strongly depend on many factors, in particular on how well the agricultural and the irrigation system is well known, and particularly depends on the complexity of the irrigation system, etc.

In the case of the pilot area in Malta, the system is pretty well known; a key factor was the preliminary in-situ data analysis process described before, particularly in order to match the agricultural parcels with the groundwater abstraction points (on the base of applicant-property unique-IDs matching). Of course, the complexity could be very high; in the case of the pilot study in Malta, for example, complexity refers to the way water is abstracted and used by farmers. The following situations where encountered in the Malta Pilot Site:

- a farmer may own more than one parcel, which due to land fragmentation, parcels can be very far one from another,
- the farmer's parcels may be interspersed among the parcels owned by other farmers,
- irrigation is not always necessary as this depends on the parcel use and the crop type,
- a farmer may own one or more boreholes,
- the farmers' boreholes can be located inside another farmer's parcels,
- the water abstracted from a borehole may be in part supplied to other farmers,
- not all the boreholes are equipped with flowmeters (the installation of flowmeters was still in progress at the time of the project),
- not all the flowmeters were transmitting the data electronically (the installation of transmitting equipment allowing data acquisition was still in progress at the time of the project).

All these kind of situations should be properly analyzed exploiting the EO data in different ways, and particularly, in the case of Malta, analyzing the temporal behavior of the crops during time through NDVI index.

For example, focusing primarily on the agricultural parcels that are not joined with any of the known abstraction points in the area, the multitemporal analysis of Sentinel-2 data easily highlights the situations where the temporal behavior of the NDVI index is typical of some irrigated crop, particularly during spring and summer.

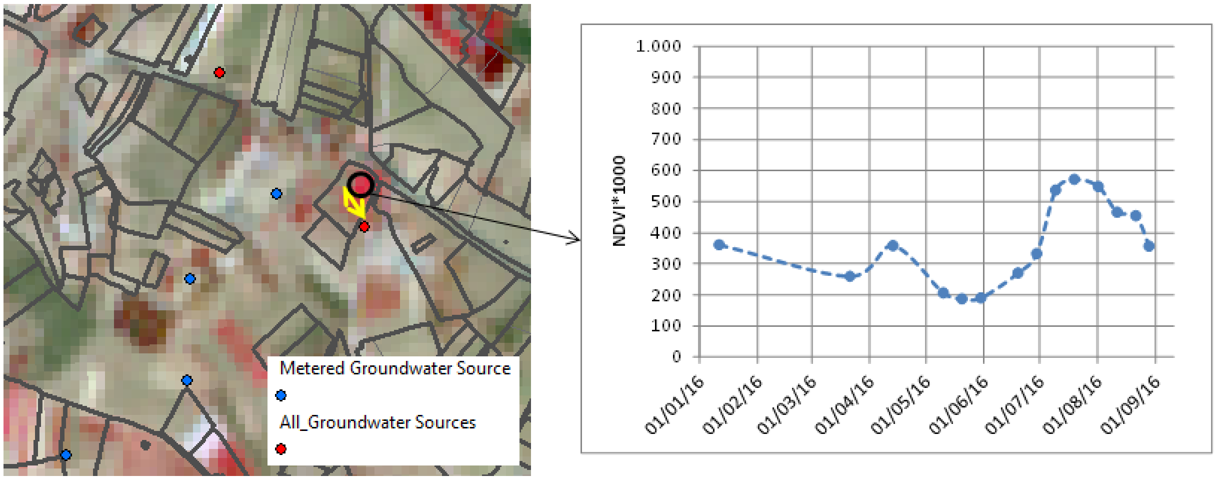
In similar situations, of course, there are different possible causes for the non-joining process between groundwater sources and parcels (e.g., actual not water demanding crops in the parcels, fulfillment of the irrigation water requirement with water transfer with tanks, errors in the registries, unique IDs of the agricultural parcels related to private companies vs boreholes registered by personal ID of the applicant, etc..). These situations often could be resolved only with a "case by case" analysis, by local knowledge, or by specific GIS analysis in order to argue the matching of groundwater source and specific irrigated parcels. Anyway, also in these cases we could have some important benefit from EO data, identifying the fields where water consumption is highly probable.

Key findings: In the cases of lack of matching between known groundwater sources and agricultural parcels, the tested EO approach is useful, particularly in the peculiar context of semi-arid regions, to identify the fields where water consumption is highly probable.

In all the other situations of matching between agricultural parcels and the corresponding (one or more) water abstraction point, EO-data analysis could provide other added-value information.

A first simple case is related to EO multitemporal analysis in agricultural parcels joined with some not yet metered abstraction point.

Figure 24: Example: A single abstraction point, joined with the corresponding parcel (same owner). The abstraction point is not yet metered.



In this case, the agricultural parcel is nominally joined with a corresponding known borehole (that is currently not yet metered): the temporal behavior of NDVI during 2016 clearly shows a very probable presence of a summer crop in the parcel, with a high probable use of water for irrigation.

Key findings: This kind of approach is useful for water monitoring network managers, in order to further implement the metering network.

Further examples of different situations are summarized in the following figures.

Figure 25: A case of an agricultural parcel, joined with the corresponding water abstraction point; in this borehole there was no water abstraction measured in 2016 spring and summer; the NDVI temporal profiles in different plots in the parcels clearly denote different spring and summer crops in the fields

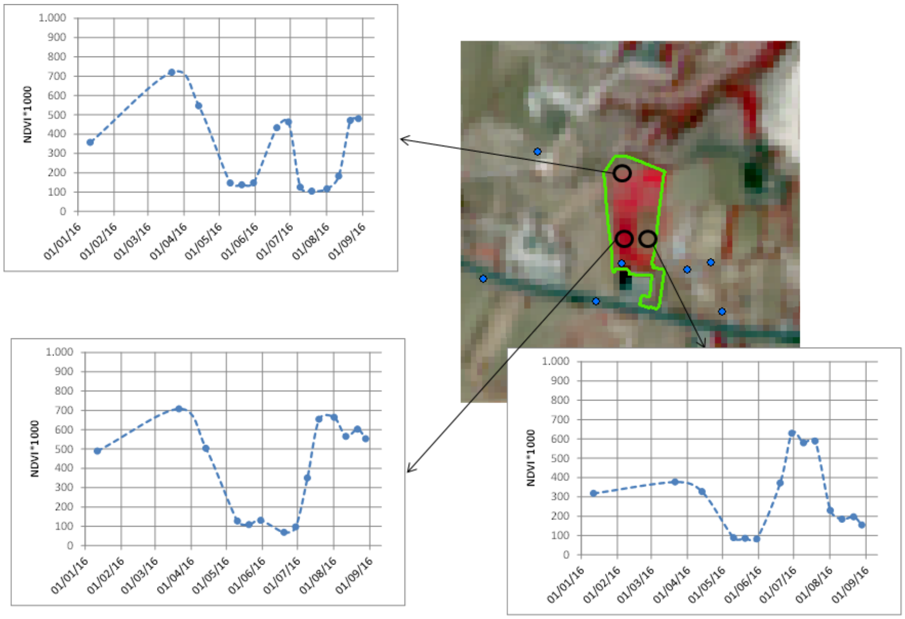
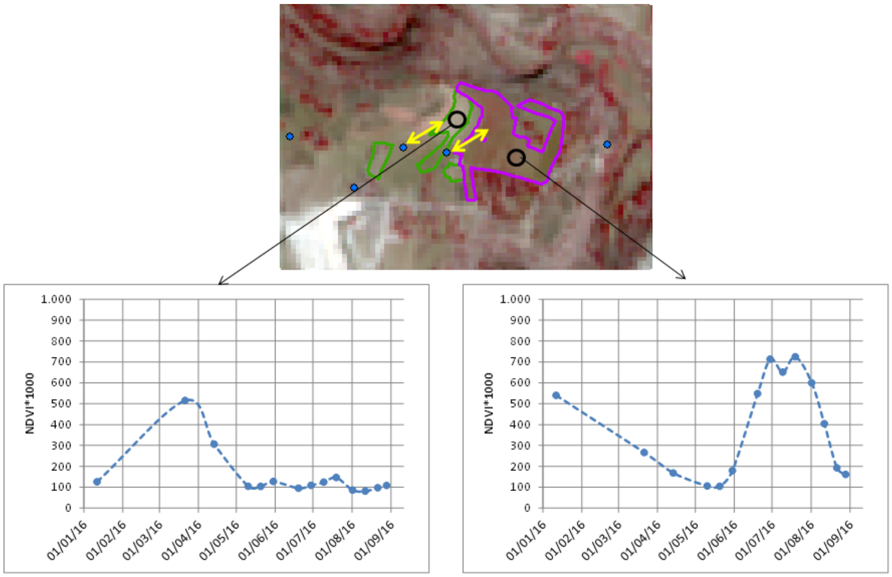


Figure 26: A case of two distinct agricultural parcels, both joined with the relatives water abstraction points; in both boreholes there was no water abstraction measured in 2016 spring and summer; the NDVI temporal profiles in the left plot is typical of a spring crop (with bare soil during summer), while the NDVI temporal profiles in the right plot is typical of a summer crop.



Key findings: Both of the previous situations are typical examples of cases were EO analysis is useful to highlight malfunctioning in the flowmeters, or cases of some other external sources of water in specific agricultural parcels, or, in other similar cases and in different contexts, also for the detection of potentially illegal water abstractions.

In the case of agricultural parcels joined with the corresponding metered abstraction point (one or more than one), the EO analysis could have different possible focuses; the first and simplest case are the quali-quantitative analysis between the water abstraction measurements over time, and the temporal variation of spectral indices in the agricultural parcels. The following figures summarize two cases, where the rate and timing of monthly abstractions are compatible with the NDVI temporal pattern of the relative parcels.

Figure 27: A case of quali-quantitative comparison between water abstractions and NDVI variation in the corresponding agricultural parcel: in this case, the water abstractions during spring 2016 is fully compatible with the NDVI profile, typical of a sping crop (while during summer the response is typical of a summer crop).

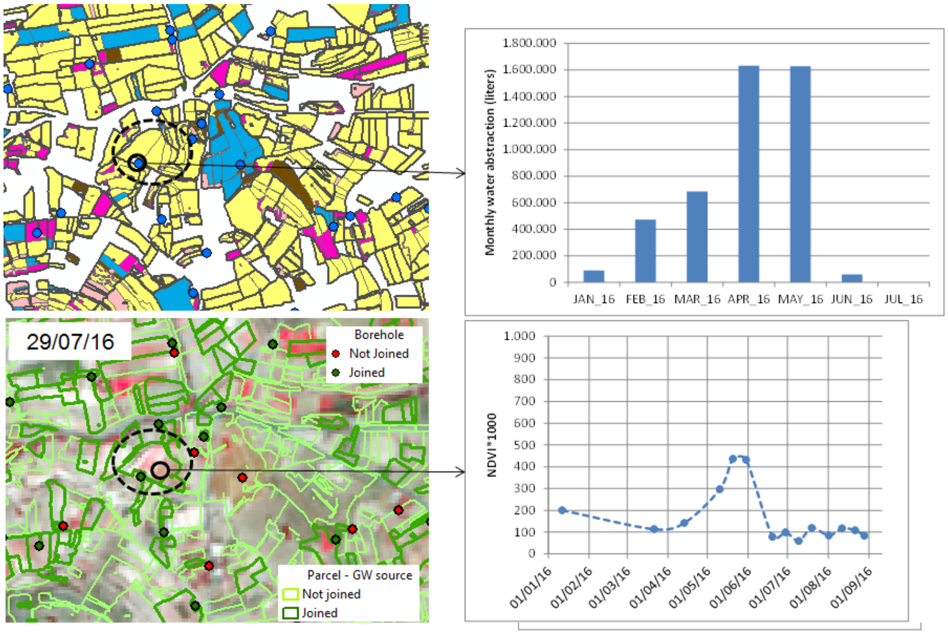
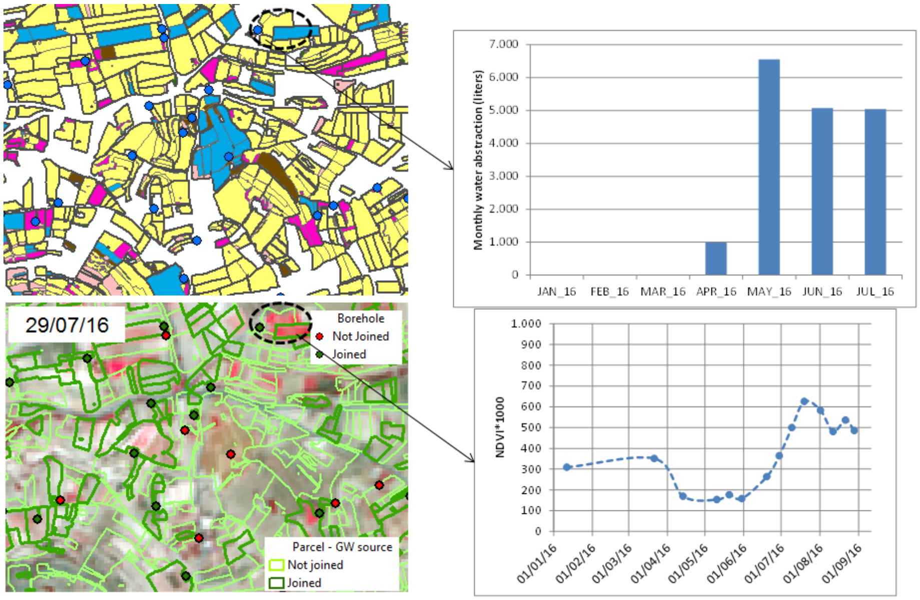


Figure 28: A case of quali-quantitative comparison between water abstractions and NDVI variation in the corresponding agricultural parcel: in this case, the water abstractions during late spring and summer 2016 is fully compatible with the NDVI profile, typical of a summer crop.



Similarly, on the other side, the same approach could be a starting point in order to detect the cases of not matching of water abstractions and NDVI evolution during the growing season.

Key findings: During the pilot feasibility study of Malta, strong knowledge improvements were achieved joining the databases available from different organizations related to groundwater abstractions and agricultural land use.

Key findings: From the EO data point of view, Sentinel-2 data dramatically improved the monitoring capabilities, thanks to the temporal and spatial resolution improvements.

Evaluations of potential inputs for inspections

All the different situations summarized in the previous paragraphs, depending on the different possible situations of matching between parcels, water abstraction location and measurements, etc, could be, with different purposes, object of proper field inspections.

Key findings: The purposes of inspections, depending on the Authority's mandate and on the specific local context, could vary from the management of the monitoring network purposes, to the verification of potentially illegal abstraction, to the quantitative analysis of the water exploitations, etc…

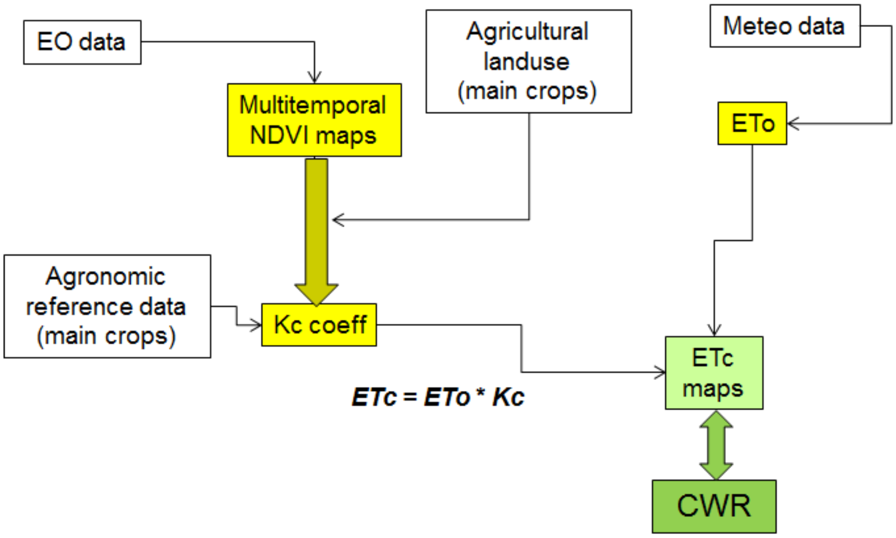
In the case of Malta pilot study, these options were faced only in a theoretical and demonstrative way, with field visits in specific agricultural parcels selected starting from the multitemporal analysis of Sentinel-2 data.

Figure 29: Example of location and pictures from some field visits in the test area in Malta: the parcels were selected after the analysis of potential interests from Sentinel-2 multitemporal data

Crop water requirement (CWR) estimations

The developed and tested approach for Crop Water Requirement (CWR) estimation followed the suggestions of the Copernicus Guidance Document. The general approach, in the Malta pilot study, was set up starting from the characteristics of the available in-situ data, according the following general scheme.

Figure 30: General scheme for CWR estimation process in the Malta pilot study

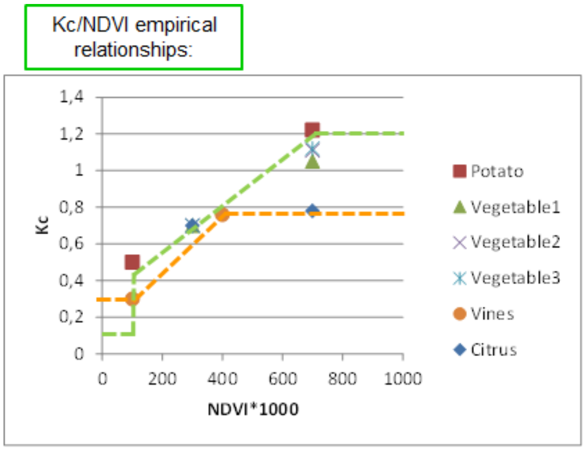


Reference evapotraspiration (ETo) was calculated according to Penmann-Monteith, starting from the available 2016 meteorological data (daily values of temperature, precipitation, wind velocity, solar radiation).

Agronomic reference data were available for the main crops in the area (at least as generic crop types/class): potatoes, vegetables, vineyards, citrus), with the nominal values of crop coefficient (Kc) for the main reference crops development stages.

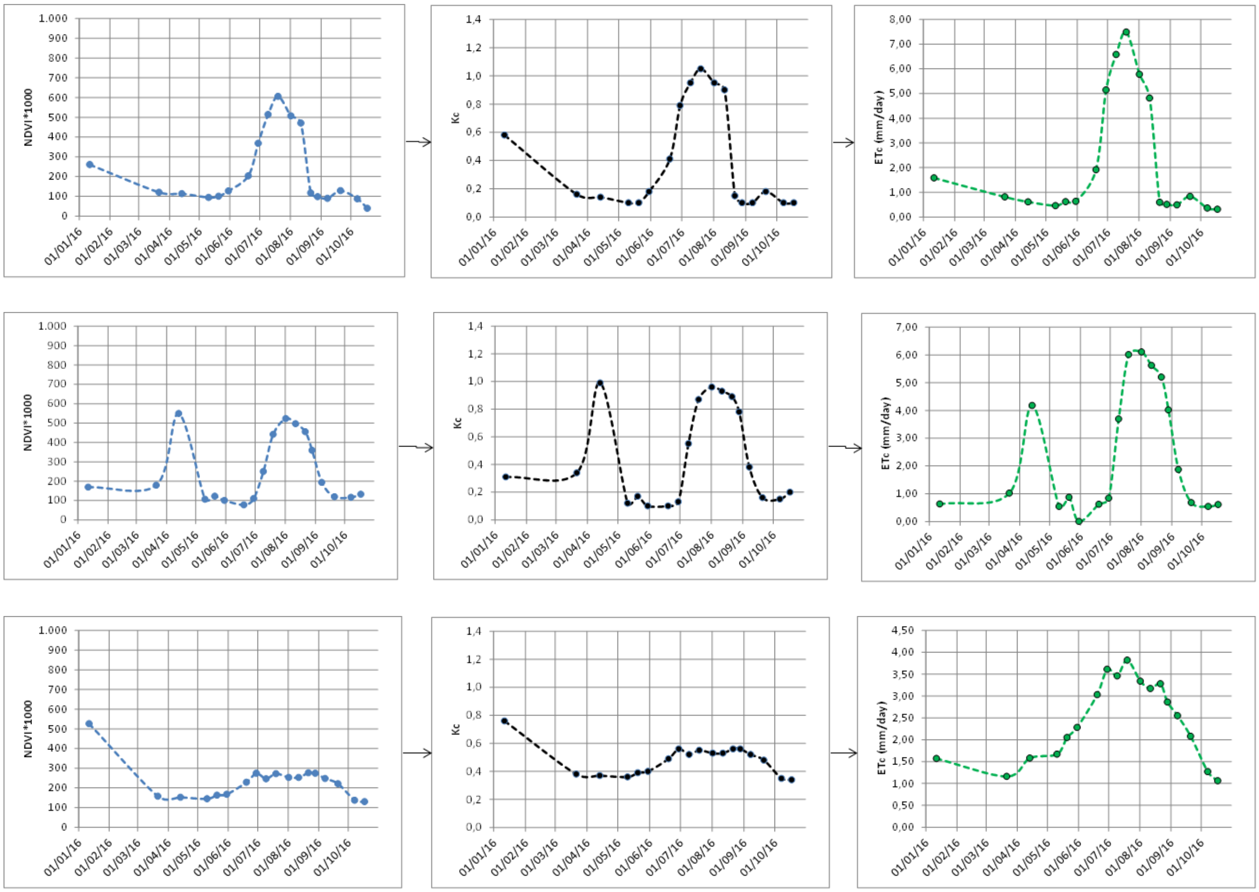
Exploiting the multitemporale availability of Sentinel-2 data during 2016, empirical relationships between NDVI and Kc were set up, for the main generic crop classes in the area (potatoes, vegetables, vineyard, citrus).

Figure 31: Empirical Kc/NDVI relationship applied in the test area in Malta



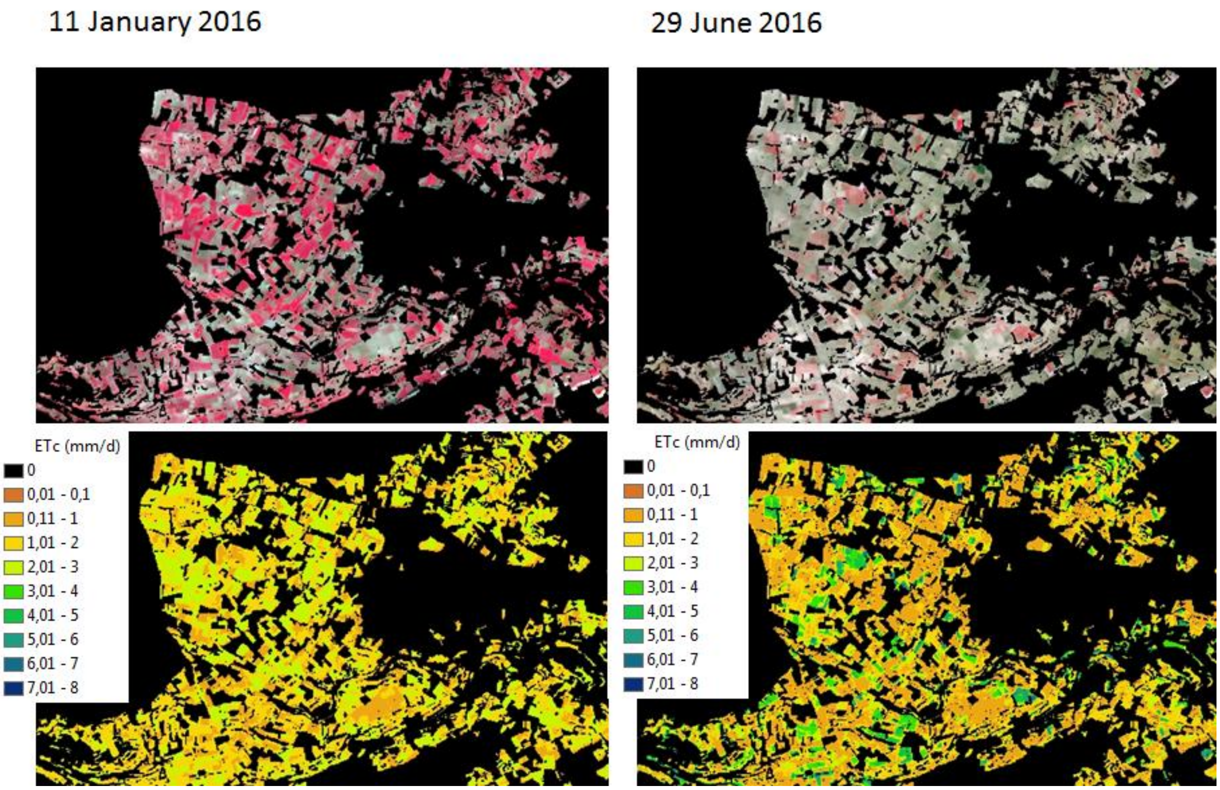
This approach was applied in all the agricultural parcels in the test area, exploiting the whole multitemporal 2016 Sentinel-2 dataset. For each agricultural parcel, is then possible, starting from the NDVI temporal profiles, to estimate the temporal variation of crop coefficient (Kc), and then, matching these values with the reference evapotranspiration (ETo), finally estimate the evapotranspiration under standard conditions (ETc values) of the specific crop type in the parcels: these values, in Malta’s context, are a good proxy of the CWR.

Figure 32: examples, for different agricultural parcels with different crop types, of the progress from NDVI temporal profiles, to Kc temporal variations, and finally to ETc (proxy of the Crop Water Requirements, in mm/day)



The strong point of this approach is obviously that it could be applied extensively, exploiting the EO-data, in the entire study area, for all the available Sentinel-2 acquisitions.

Figure 33: Examples of the comparison of two different Sentinel-2 images over part of the study area, and the corresponding ETc maps (proxy of the crop water requirements, in mm/day).



Key findings: The output of the developed approach are multitemporal maps of CWR estimations. These estimations could be exploited, again with different approaches depending on the different local contexts, for different purposes

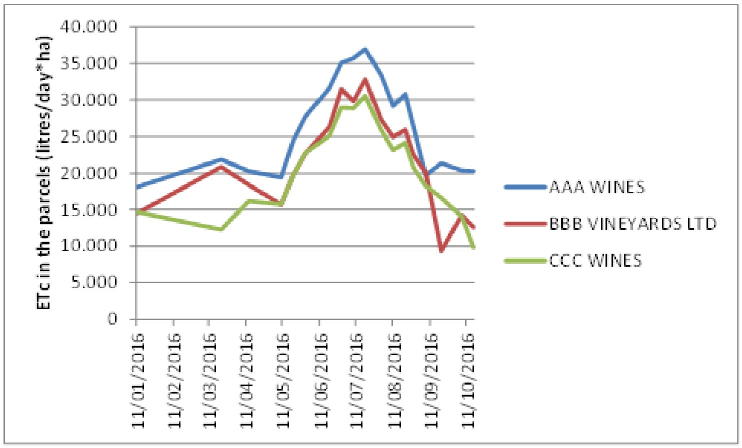
In the Malta use case, the practical applications of CWR estimations were tested in a preliminary way with the following purposes:

- Estimate the water requirements in parcels without proper matching with actual measurements of water abstractions from the corresponding boreholes.
- The identification and comparisons between parcels with similar area and same crop type but very different amount of water consumption.
- Improve in the local comparisons with measured water abstractions in the corresponding agricultural parcels.
- Under proper conditions, with more in-situ data and with a soil modeling approach, set a starting point for actual water irrigation requirement estimations.

- Provide balances over wide areas between total crop water requirements and total actual measured abstractions, in order to improve sustainability analysis on water uses.

For example, at parcel scale, it was possible to compare the values and the temporal pattern of CWR in different agricultural parcels, declared with the same crop (e.g., Vineyard), in order to preliminarily evaluate the water use efficiency.

Figure 34: Example of comparisons of the CWR estimations over time during 2016 in three different parcels with the same crop type (vineyard); the values of estimated CWR are normalized for the total surface of the parcels (litres/day*ha).



Concerning the comparisons, at parcel scale, of the comparisons between CWR and measured water abstractions in the corresponding boreholes, these approach was tested in different parcels, with different dimension and crop type. The following figures summarize some of these applications.

Figure 35: Example of comparisons of the total CWR estimated on a group of agricultural parcel with unique property (with different seasonal crops), and the measured values of water abstractions in the corresponding borehole

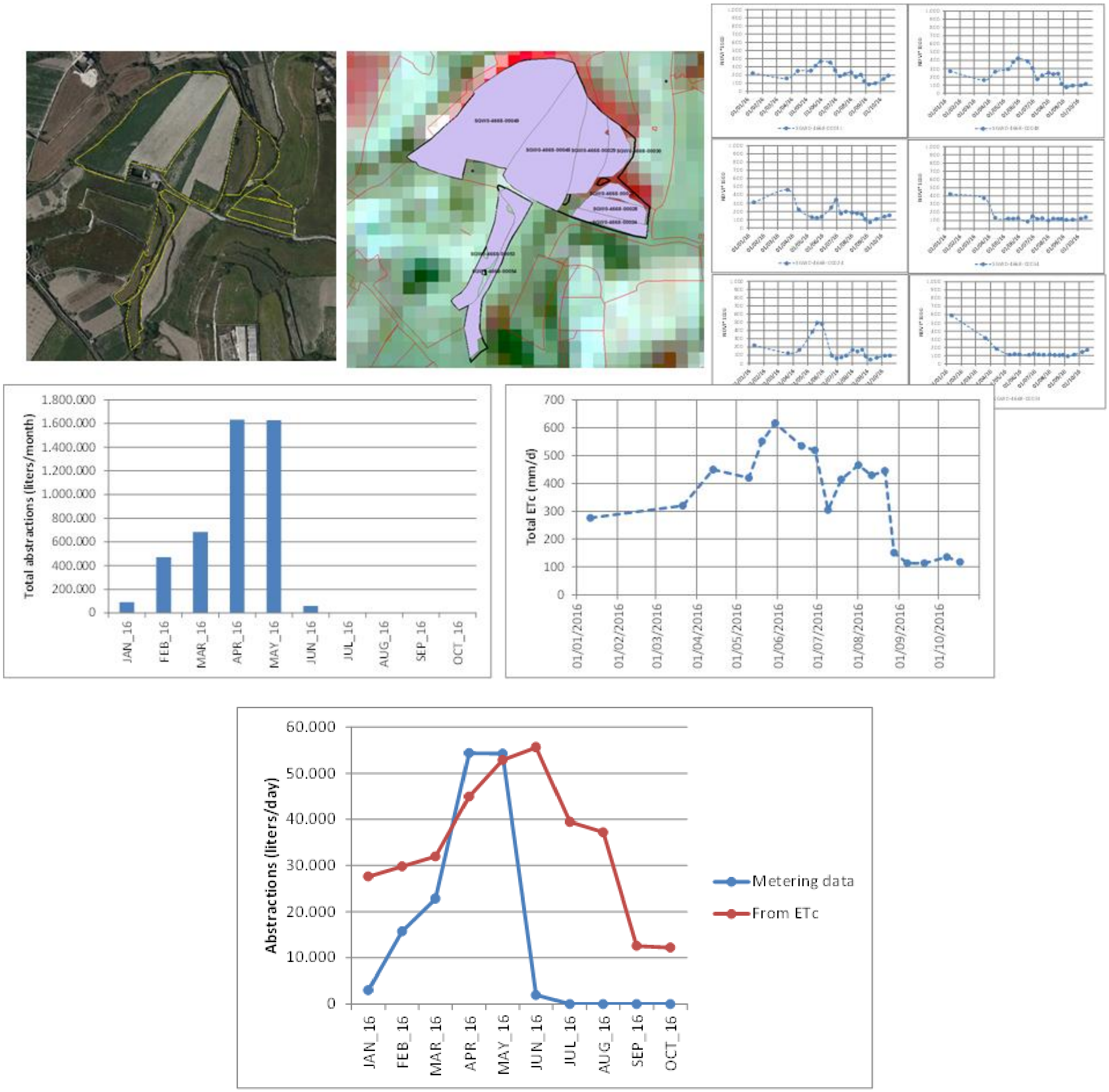


Figure 36: Example of comparisons of the total CWR estimated on a group of agricultural parcel with unique property (with different seasonal crops), and the measured values of water abstractions in the corresponding borehole

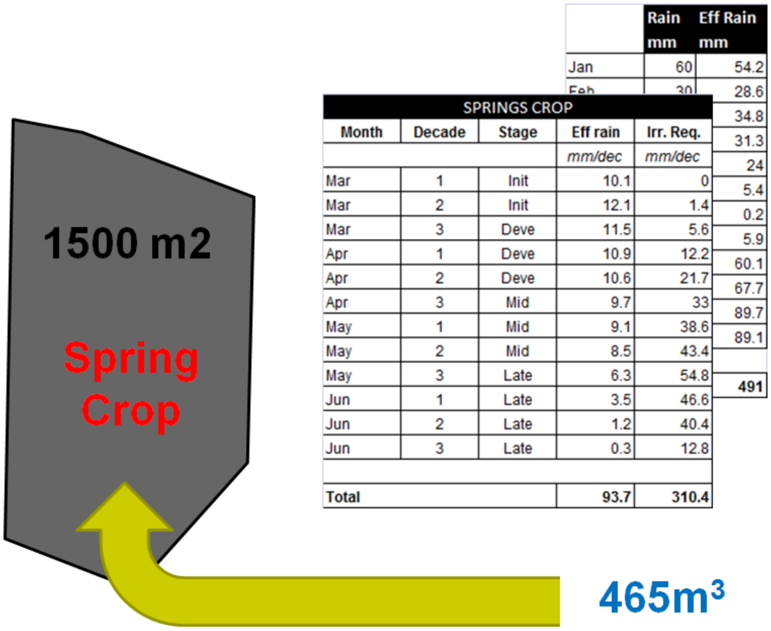
Key findings: This kind of evaluations is in general effective at parcel scale but also over wider areas, aggregating and comparing the total amount of CWR and the total amount of measured abstractions over time; this approach is useful for water uses sustainability analysis, and also in order to localize the single specific situations where statistically are noticed the main differences between estimated CWR and actual measurements, in order to focalize direct verifications in the field.

In the case of the pilot study in Malta, these are the main considerations following this activity:

Generally , it was noticed a general overestimation of the total CWR versus the actual measurements; this was an expected phenomenon, considering that the CWR represent a total potential water demand, that is different from the actual irrigation requirements of the crops. In this uncertainty, a sure role is played by the amount of water delivered from not-metered boreholes or other actually not known sources; locally, the water transfer with tanks is another source of potential misalignment in the comparisons. Moreover, a temporal shifting between the period of maximum abstractions and the maximum estimated CWR was noticed: this is probably due to the effect of the storage of water before the irrigation purposes. Moreover, the tested Kc/NDVI approach could be in the future better calibrate, also with direct measures in the fields.

Finally, during the Malta pilot study some preliminary evaluation about the feasibility to provide more detailed irrigation water requirement estimations, at single parcel scale, were made. The approach integrates the available information regarding meteorological data and reference agronomic data provided by the Food and Agricultural Organization (FAO) with EO multitemporal analysis in order to characterized more in detail the type of crop, and modeling the water requirements in models like CROPWAT.

Figure 37: Example of testing of the model CROPWAT in order to estimate the total irrigation water requirement on a specific agricultural parcel, classified as “spring crop” on the base of EO multitemporal dataset.



	Rain mm	Eff Rain mm
Jan	60	54.2
Feb	30	28.6
		34.8
		31.3
		24
		5.4
		0.2
		5.9
		60.1
		67.7
		89.7
		89.1
		491

SPRINGS CROP

Month	Decade	Stage	Eff rain	Irr. Req.
			mm/dec	*mm/dec*
Mar	1	Init	10.1	0
Mar	2	Init	12.1	1.4
Mar	3	Deve	11.5	5.6
Apr	1	Deve	10.9	12.2
Apr	2	Deve	10.6	21.7
Apr	3	Mid	9.7	33
May	1	Mid	9.1	38.6
May	2	Mid	8.5	43.4
May	3	Late	6.3	54.8
Jun	1	Late	3.5	46.6
Jun	2	Late	1.2	40.4
Jun	3	Late	0.3	12.8
Total			**93.7**	**310.4**

This approch allows for the quantification of the potential irrigation requirements from each parcel based on the identification of general crop classifications derived from the Sentinel-2 Imagery.

2.5. Discussion

The Malta Pilot Case shows very well the tools which are available through Earth Observation to support the identification of potential cases of illegal water abstraction and, more in general, the water resources management, trying to make the most of all the available in-situ data and the Copernicus data.

The case 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 land use, joining GIS analysis and EO data analysis.

EO-data local applications and services 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 is possible, with the following main 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, Sentinel-2 data represent a strong improvement in monitoring capabilities, thanks to temporal and spatial resolution improvements.

In the process of gathering and working on the data of the Malta Pilot site it was clearly evident that EO can have a wide range benefits and should not be limited to just to the detection of illegal water abstractions. Earth Observation can potentially become an important decision support tool which can contribute towards the achievement of the following objectives:

1. Policy formulation – a better understanding of the water use characteristics of the agricultural sector can help with the development of agricultural water policy.
2. Funding/Subsidy Management – EO data coupled with auxiliary data can provide additional information on existing agricultural practices and therefore potentially help with the funding allocation and the management of EU subsidies.
3. Farming Support Services – provide advice to farmers on irrigation practices and crop water use characteristics.
4. Field Inspections – improve and increase the effectives of current operations within existing entities when it comes to field inspections.

3. Use Case 2: Pilot Study Romania

The following table summarizes the contents and the characteristics of the Romania case study.

Table 6. Main contents and characteristic of the Pilot Study Romania

Use case	**Romania Pilot study**
Pilot area	Bihor County
Analysis in WODA and/or WODA2	Feasibility study in WODA (2015) and further evaluations in WODA2 (2016)
Water uses target	Water uses in agriculture, focus for greenhouses detection
Water sources type target	Abstractions from groundwater and potentially also from surface waters
EO-data type and approach	High and medium resolution optical data; agricultural land use class mapping; greenhouses detection
Copernicus EO-data suitable for implementing future operational activities	Sentinel-2
Availability of in-situ data for testing operational services	Land use map, water permits
Type of product / EO-services tested (accordingly to Copernicus Guidance Document)	Crop type maps
Usefulness and potential inputs for inspections	Partially (greenhouses verifications)
Main stakeholders (type)	Water managers, policy makers
Extensibility of the tested approaches to other areas	Continental countries, situations of low in-situ data availability
Level of EO technical requirements	Low
Feasibility of future downstream services	Low-Medium

3.1. Context

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

- The test area is characterized by continental climate
- Average precipitations is 841 mm/year
- Bihor County is characterized by very low irrigated surface percentage (0.04 % of the total surface dedicated to agriculture)
- From the pedological point of view, the area is characterized by soils with very high potential productivity
- In Bihor County the irrigated area are very few, basically due to damage and the clogging of irrigation canals, as well as deterioration or lack pumping equipment

This particular situation causes strong differences between actual and potential irrigation requirements in the area.

3.2. Requirements

Test Application A

The main focus of the feasibility study is on water uses in agriculture, and about the use of multi-temporal optical EO data, primarily in order to derive crop maps, and for the monitoring of potentially irrigated parcels. Starting from the Copernius Guidance Document general scheme, these are the very first steps of applications and services from EO data, reliable in particular in situations and contexts with low amount of in-situ data. The essential steps followed were:

- Multi-temporal Landsat8 data selection and analysis
- Simplified crop map classification
- Detection of potentially irrigated parcels

Test Application B

In the second part of the feasibility study, further qualitative focuses were made about greenhouses detection and about the comparisons with actual water permits related with this specific agricultural land use.

3.3. Materials

3.3.1. In-situ data

In order to develop the Application A, the following were the in-situ data available in the selected test area (Marghita area, Bihor County):

Water permits overview and location

The total known amounts of permitted water in the test area are:

- 0,06 thousands m^3 /year for administrative headquarters
- 1908,59 thousands m^3 /year for Marghita municipality water supply
- 65,80 thousands m^3/year for agricultural use (irrigation)

In the test area there is a total of 17 water permits (some with multiple abstraction points), and some known but non-authorized abstraction points. Water abstraction points in the test area are for the following multiple uses:

- Geothermal water abstraction
- Civil use
- Oil industry
- Car was activities
- Agriculture
- Fishery ponds
- Concrete manufactures
- IPPC (pig farming)
- Wood processing

Most of the abstraction points are situated in the deeper aquifer. In Bihor County the irrigated areas are very few, due to damage and the clogging of irrigation canals, as well as deterioration or lack pumping equipment.

Land use maps, pedological and agronomical information

Unfortunately, no local land use maps were available; for the basic applications, the European CORINE Land Cover database was exploited in this feasibility study. Moreover, no agricultural parcels in the test area were available.

Bihor County is generally characterized by soils with very high potential productivity (chernozems, brown soils, etc..).

Main crop statistics for the test area were provided; the area is characterized by a wide type of crops (mainly wheat, corn, rape, grassland, soybean, triticale, sunflower), and by a significant percentage of potentially irrigated and water demanding crops.

Field inspections

In order to support the development of the Application B, during WODA2 some field verification were performed, in November 2016, by the National Environmental Guard with the support of local agricultural department, in the area of Mihai Bravu village.

3.3.2. Earth Observation and Copernicus data

The Application A was tested during the first part of WODA project (during 2015); at that time, Sentinel-2 satellite from the Copernicus Program was not yet operational, so the basic optical EO data used in the Romania use case was a multi-temporal data set of Landsat8 data, referred to 2014 and 2015 (for more details, see the WODA Final Report 2015).

Bihor County is covered by 2 different scenes of the Landsat8 coverages, and in particular by the scene 186/027. The temporal resolution of Landsat8 data (frequency of acquisition over a single scene) is 16 days; cloud cover in the context of Romania is in general a strong limiting factor, and in 2014 and 2015 no more than 4-5 cloud free Landsat8 images were available in the most significant periods (at least enough to characterize the phenology of the main crops and detect the main crop types). Otherwise, the spatial resolution of Landsat8 data (30x30 meters resolution) isn’t in general a strong limiting factor, considering the average agricultural parcel size in Romania.

For further operative applications, the availability of Sentinel-2 data (10x10 meters pixel size, at least 10 days of temporal resolution, on wider scenes) will be for sure a strong improvement in monitoring capabilities, also in context like Romania and in general in continental countries.

Otherwise, in order to assess the feasibility of the Application B (greenhouses detection and monitoring), developed during both 2015 and 2016, different EO data sources were used (starting from public available high resolution data, to some evaluation with 2016 Sentinel-2 data).

3.4. Methods and Results

3.4.1. Application A: crop maps classifications

The available Landsat8 multi-temporal cloud free data over the test area for 2014 and 2015 were classified in order to derive simplified crop type maps. Focusing for example for the 2014 case, 4 Landsat8 images were available in significant phenological periods (21 March, 6 June, 12 August, 29 September). This multi-temporal Landsat8 data set was used to derived multi-temporal vegetation index (NDVI), and then used to classify the area defined in the CORINE Land Cover database as arable land, pastures or permanent crops.

The general concept of crop mapping, and example of the outputs, are summarized in the following figures.

Figure 38: Landsat8 multi-temporal data set analysis – pasture areas; in a), b), c), d) the four multi-temporal Landsat8 available data are visualized in IRFC false color composite, where red hues refer to vegetation (21/3, 6/6, 12/8, 29/9 respectively). In e), there is the plot of the temporal variation of NDVI over the four date for the a specific pixel (red dot). In this case, the high NDVI index all over the period, from march to September, is typical of pastures. This particular temporal path is exploited in order to classify all the pixel in the image with similar temporal behavior (visualized in green in f) window). .

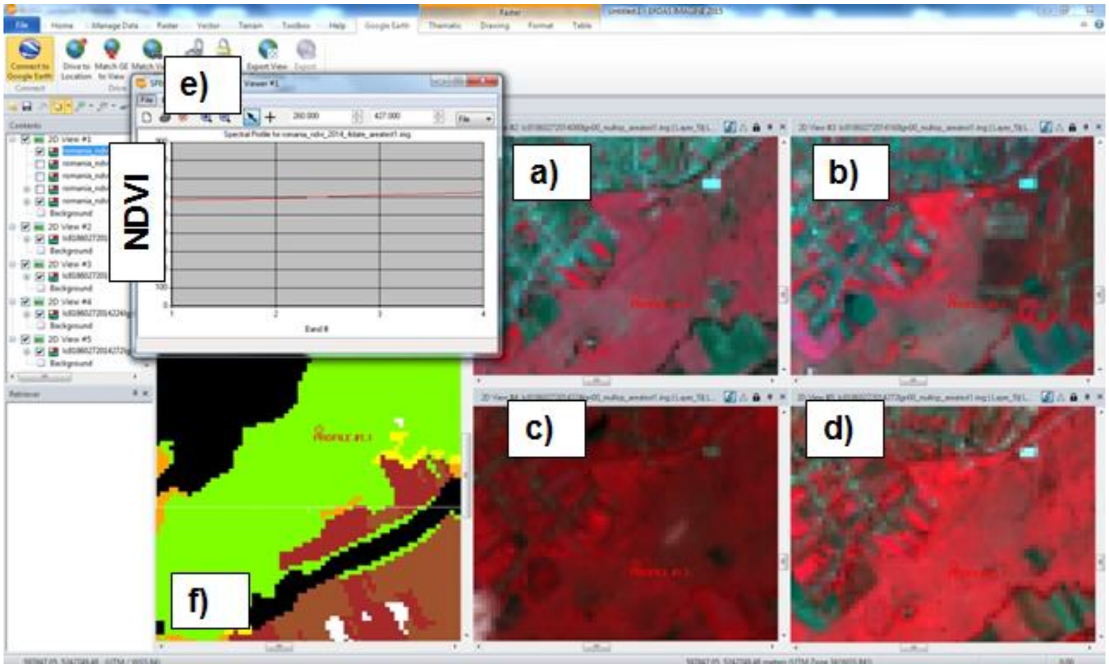


Figure 39: Landsat8 multi-temporal data set analysis – winter crops areas; in a), b), c), d) the four multi-temporal Landsat8 available data are visualized (21/3, 6/6, 12/8, 29/9 respectively). In e), there is the plot of the temporal variation of NDVI over the four date for the a specific pixel (red dot). In this case, the NDVI index is very high (vegetated) in march, lower in June and then very low (not vegetated) in august and September. This temporal path, typical of a winter crop, is exploited in order to classify all the pixel in the image with similar temporal behavior (visualized in orange in f) window) .

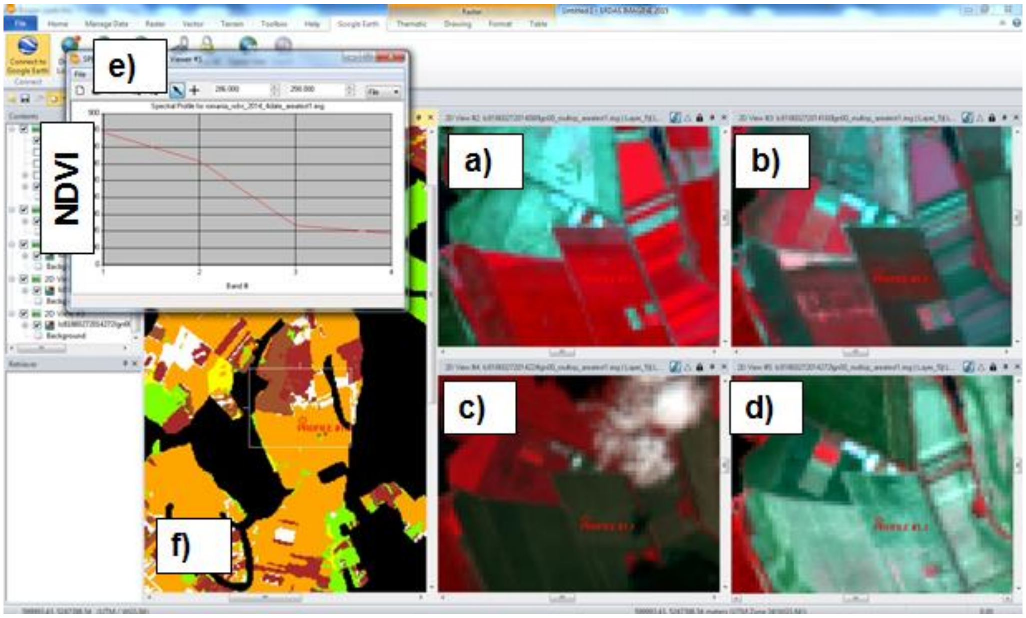
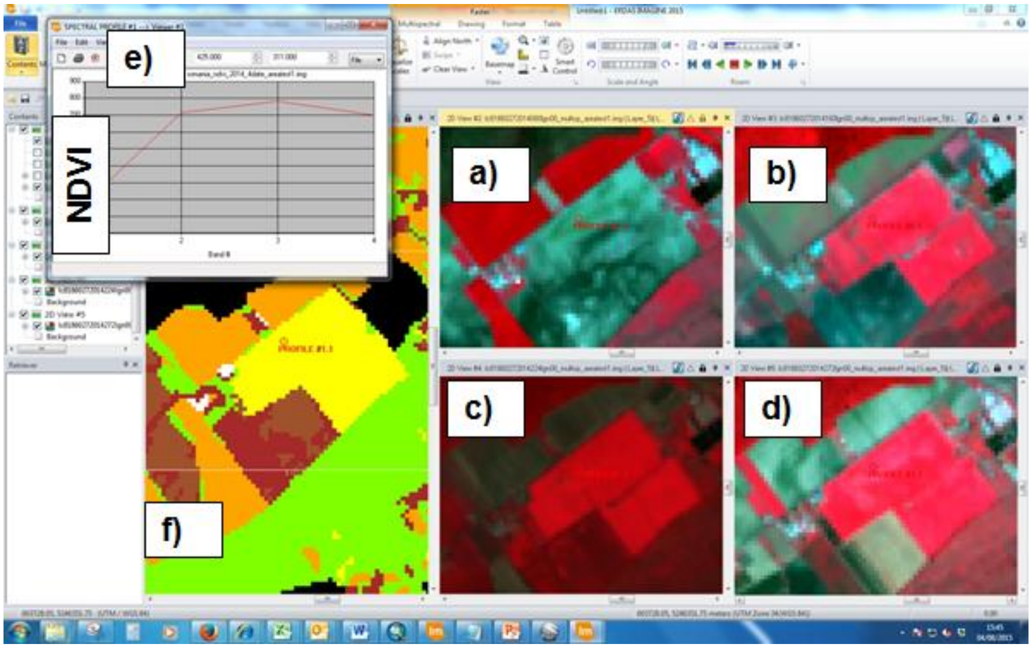


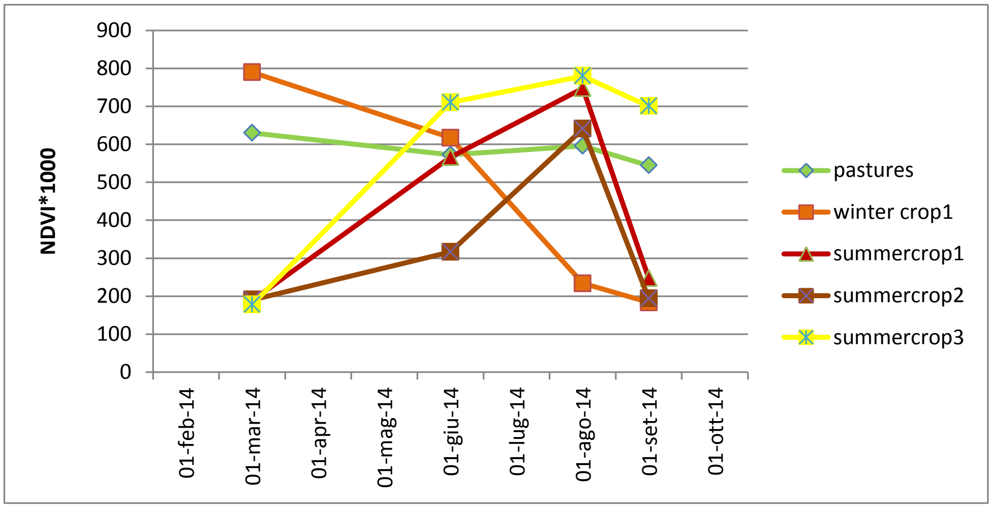
Figure 40: Landsat8 mult- temporal data set analysis – summer crops; in this case, the NDVI index is very low (not vegetated) in march, then NDVI raises in June and in August and in September. This temporal NDVI path could be related to a summer crop, and is exploited in order to classify all the pixel in the image with similar temporal behavior (visualized in brown in f) window) .



This type of basic crop classifications were performed automatically and without any ground truth available, so the outputs are only preliminary classifications in order to characterize the main crops type in the area and extract the potentially irrigated parcels with water demanding crops.

The mean NDVI temporal paths of the different classified crop class area summarized in the next figure.

Figure 41: Mean NDVI temporal paths of the main crop class in the test area



In the test area there were no other auxiliary information in order to improve the characterization of the classified crops, and in particular to differentiate the different "summer crop" classes; these summer crops are those with an higher probability of being water demanding and potentially requiring irrigation. For example, from local checks, also with Google Earth and StreetView software, these summer crop classified generically "type A" and "type B" are in most cases referred to potentially irrigated summer crops like those in Figure 42 (corn, sunflower, ..).

Figure 42: Images, from StreetView, referred to parcels classified as summer crops

Key findings: The main crop map classification provided in this study is an example of a possible first output, useful to detect the potentially water demanding agricultural areas and their evolution over time. Other further EO-products, as outlined in the Copernicus Guidance Document, are strongly limited by the context and also by the low availability of auxiliary in-situ data.

Key findings: From the EO-data point of view, for future developments Sentinel-2 data will provide be a strong improvement in agricultural monitoring capabilities.

3.4.2. Application B: greenhouses mapping and water permits

In the second part of the feasibility study further qualitative focuses were made about water permits for specific agricultural land use (greenhouses) in Bihor County, and after a specific check of water permits in agriculture.

For example, in Arpasel Village there is a single 100 m deep drilling used for the irrigation (drip and manual irrigation system) of flower and vegetable greenhouses with an area of 4,500 square meters. For this drill there is a single Water Permit. Checking the high resolution satellite images available in public software like GoogleEarth, in this single small village, for example, the is a huge quantity of active greenhouses (see Figure 43).

Figure 43: Arpasel village, and zoom over the main active greenhouses (high resolution data available in GoogleEarth)

As first conclusions of these type of verifications carried out in Bihor county it was found that all the greenhouses in the county, except for three, are actually operating illegally (without Water Permit), and there is no database with quantitative information on water abstractions.

Locally, the amount and density of greenhouse is very high (see for example the next figure, relative to Mihai Bravu village in Bihor County).

Figure 44: Mihau Bravu area, Bihor County. Comparison between high resolution satellite image available in GoogleEarth (a) and a Sentinel2 image (1 January 2016) at 10 meters resolution (b).

In the previous example, it’s quite evident the potential application of greenhouse detection and mapping from high resolution satellite images, like those available in public software like GoogleEarth. Moreover, exploiting also lower spatial resolution, but higher temporal revisit satellite data, like Sentinel-2, it could be possible to updated the maps and check periodically the temporal evolution of greenhouses (number, extension, ..), over wide areas.

After these preliminary comparisons and evaluations, some field inspections were performed, in November 2016, by the National Environmental Guard with the support of local agricultural department, in the area of Mihai Bravu, Rosiori and Vaida villages. In this area there are 60 agricultural applicants, the medium size of the parcels is 0,04 ha and are covered by solariums. On these parcels there are vegetables that are grown mostly 2 times per year and even 3 times per year in some particular cases. From these 60 applicants, the National Environmental Guard has inspected 4 of them, and it has been noticed that each owner has 3 to 16 solariums in the village and some plots in field outside the villages. For each address or topographical number, it has been identified a single borehole with an average depth of 12-42 m. The irrigation of both the solariums parcels and the open field is performed using the drip irrigation method. Since drills are not counted it was not possible to check the amount of abstracted water and whether the abstractions are higher or lower than the limits.

Figure 45: Example of one of the report following the inspections to selected greenhouses in November 2016 in Mihai Bravu area; the basemap on the left is the available high resolution layer (aerial orthoimage); on the right, a recent Sentinel-2 image on the same area highlights the presence of a new greenhouse in the same plot, nearby the already known in the same property.

Apart from the considerations about the compliancy of the quantitative water uses, EO data could be useful in order to map single greenhouses and solariums, and also to evaluate their temporal evolution.

The strong point is that this approach could be properly automatized and carried on extensively on wide areas. This approach, moreover, could provide updated information.

Key findings: EO data could provide for the future a potential benefit in order to map and monitor the number and the temporal evolution of greenhouses, and provide potential benefits for their controls and compliance assurance assessment of water uses.

3.5. Discussion

The use case of Romania in Bihor County describes a very peculiar situation: the pilot area is characterized by continental climate, and the irrigated surface is very low due to the damage and the clogging of the irrigation canals, as well as to the deterioration pumping equipment. This particular situation causes strong differences between the actual and potential irrigation requirements in the area.

The main focus of the feasibility study in Romania has been on water uses in agriculture and about the use of multi-temporal optical EO data, primarily in order to derive crop maps, and for the monitoring of potentially irrigated parcels. Other further EO-products, as outlined in the Copernicus Guidance Document, are strongly limited by the context and also by the low availability of auxiliary in-situ data. The main crop map classification provided in this feasibility study is an example of a possible first output, useful to detect the potentially water demanding agricultural areas and their evolution over time.

From the EO-data point of view, with Sentinel-2 data there will be a strong improvement in monitoring capabilities.

As a further analysis, a local potential application was related to greenhouses detection as compared to the water permits. From a quick look at GoogleMap hundreds of greenhouses have been detected, while only few greenhouses have the proper water permit. The mapping of greenhouses is technically feasible (with high resolution data and also, for the bigger ones, with Sentinel-2); EO data could provide in the future a potential benefit in order to map and monitor the number and the temporal evolution of greenhouses, and provide potential benefits for controls and compliance assurance assessment.

Regarding to the monitoring of groundwater over-abstraction both from agricultural uses and other water uses, the SAR Interferometry approach is potentially feasible over the alluvial plains of the Bihor County.

Major efforts for possible evolution in the future are related to the improvements in auxiliary data availability, and related to all the “non-technical” issues (i.e. improvements of relationships and communication with other Authorities, data exchange protocols, the development of common databases about groundwater uses, the technical capacity-building on EO applications, etc…).

4. Use Case 3: Pilot Study Lombardy

The following table summarizes the contents and the characteristics of the Lombardy case study.

Table 7. Main contents and characteristic of the Pilot Study Lombardy

Use case	**Lombardy Pilot study**
Pilot area	Lombardy lowland and alpine valleys
Analysis in WODA and/or WODA2	Feasibility study in WODA (2015)
Water uses target	Water uses in all sectors
Water sources type target	Abstractions from groundwater
EO-data type and approach	Radar data; SAR Interferometry
Copernicus EO-data suitable for implementing future operational activities	Sentinel-1
Availability and quality of in-situ data for testing operational services	Geological maps, pedological maps, aquifers maps and soundings, Groundwater monitoring data, location and amounts of the main groundwater abstractions
Type of product / EO-services tested (accordingly to Copernicus Guidance Document)	EO-Services not object of the Copernicus Guidance Document
Usefulness and potential inputs for inspections	Partially (only for big amounts of groundwater abstraction and in proper geological conditions)
Main stakeholders (type)	Policy makers, Water managers
Extensibility of the tested approaches to other areas	Potentially, all areas with sedimentary basins with big amounts of groundwater abstractions
Level of EO technical requirements	High
Feasibility of future downstream services	High

4.1. Context

The previous two case studies developed in WODA (Malta and Romania) were both related to the use of optical satellite data; the present case study, otherwise, refers to the use of satellite interferometric SAR data, and the its applicability in the geographical context of Lombardy (lowland and alpine valleys).

The general concept of EO monitoring of groundwater over-abstractions through SAR Interferometry is described in the introduction to this document, in Figure 11; taking as reference the DPSIR (Drivers, Pressures, State, Impacts, Responses) scheme, the EO method for the monitoring of the legal water over-abstraction provides the estimation of an environmental impact, i.e. the soil subsidence, caused by a change in the state of the groundwater level, caused in turn by an environmental pressure, i.e. the groundwater over-abstraction. In particular contexts, soil subsidence is a proxy of groundwater over-abstraction; it should be emphasized that satellite SAR interferometry measures with high accuracy the movements of the land (subsidence), which are actually the overall and combined effect of several competing phenomena. The variation of the piezometric levels of underground aquifers (the "state", according to the DPSIR framework) is however only one of the possible causes of the possible observed subsidence; moreover, the piezometric variations may be subject to water over-abstractions and unbalances between abstractions and recharges of groundwater resources.

4.2. Requirements

The technical feasibility of ground movements monitoring with satellite SAR Interferometry, with high accuracy, is widely proven in literature and in numerous operational monitoring applications; within the WODA project and through this feasibility study, the objective was to assess the observability, in the geological context of Lombardy lowland, of subsidence induced by groundwater abstraction (and possibly over-abstraction). This kind of phenomenon has already been observed and monitored in the past in other regions, even proximal to Lombardy (for example, in Emilia Romagna), but this approach is not yet applied operationally in Lombardy's context.

In addition to this technical feasibility evaluation (focused on the observability of the phenomenon), we also want to investigate the "operative" feasibility, in terms of actual availability of SAR data and interferometric time series, and of auxiliary data availability for the correct interpretation of the observed ground movements.

The feasibility analysis was structured in the following different components:

- assessment of the availability of auxiliary information in order to properly interpret the observed ground movements, and in order to relate them correctly, among other possible reasons, to the groundwater abstraction

- assessment of the current and future satellite data availability and SAR interferometric time series in Lombardy's lowland,
- observability analysis of the phenomenon in the geological context of the Lombardy's lowland, with some specific ground movement analysis from the available SAR interferometric data, compared with the available information about groundwater abstractions.

4.3. Materials

3.6.1. In-situ data

In the following section a brief review of the main available in-situ data, in order to support the analysis and interpretation of ground movements, is summarized (for a more complete description, see the WODA Final Report 2015).

Theoretically, with constant extraction of groundwater, the observable effect to the ground, in terms of subsidence, is highly variable in function of many factors, in particular depending on different geological conditions, on sediments granulometry, on the thickness of the aquifer, etc...

The proper knowledge, as thorough as possible, of these aspects is therefore an essential prerequisite for the proper interpretation of observable ground movements by SAR interferometry technique.

Geo-litology and sediments structure

The main type of information available were geological maps (1:250.000 scale, with delineation of the main lithologies), pedological maps (scale 1:50.000, thematised by the main soil type and prevalent granulometry in the upper stratus), geological surveys database with sediments stratigraphy. In particular, the Subsoil database in Lombardy ("Banca Dati Sottosuolo") is composed of a total of 12306 points with geological surveys (of which 8015 related to stratigraphy of wells, and 3985 relating to direct surveys). For each point of the database stratigraphic analysis with horizons definition and granulometry analysis are available.

Aquifers and Ground Water Bodies definition and monitoring

Regarding the knowledge of the aquifers and their spatial development, the reference database is the "Geology of aquifers" regional database, available through the Regional Geoportal. In this database, for different defined aquifers groups (Group A, B, C, D), the information relating to extension of the aquifers, depth of the basal surfaces, thickness of sandy deposits, recharge areas, are available.

Regarding the Groundwater bodies (GWB) definition and classification, and their qualitative and quantitative monitoring as required by the Water Framework Directive (WFD), in Lombardy 23 groundwater bodies (GWB) are defined. Focusing the attention only on the quantitative aspects, from the point of view of the classification of the status of groundwater bodies as specified in the Framework Directive, it must be stressed that currently all the defined GWB are classified in Good status. The defined water bodies are monitored through the ARPA monitoring network (groundwater quality and quantity network). The frequency and length of the time series of quantitative piezometric measurements is variable (generally monthly measures).

Quantitative information about actual groundwater abstractions

Generally, in Lombardy there aren't direct and systematic measurements about the amount of actual groundwater abstractions (such measures are planned and available only on a small part of the major abstraction points). The reference database about active licenses and concessions for the extraction of groundwater in Lombardy is represented by CUI (*Catasto Utenze Idriche*, Water Users Cadastre), that is currently being updated and under revision (towards the new SIPUI regional database). The CUI database is characterized by a certain degree of inhomogeneity in terms of type and completeness of the information (in particular referring to the distinction between large and small concessions, characterized by different authorization process and competences).

At the moment, the considerable lack of homogeneity of the available information about actual groundwater abstraction measurements and also about groundwater concessions appears a strong criticality, although this will be probably largely overcome by the future evolutions in water utilities databases.

Potentially interfering phenomena location

For the purposes of the correct interpretation of the observable ground movements, and in particular to properly attribute the main causes of local subsidence, we need to know as much as possible also about localization and extent of other possible interfering phenomena. The main anthropogenic phenomena that potentially generate observable ground movements are the different exploitations of the subsoil: part of this information is available through the updated maps (source MISE, Ministry for the Economic Development) that shows the areas currently with active concession for exploitation, research or storage of mineral resources (oil and gas) in Lombardy. Among them, those with the greatest interest and potential impact in terms of observable ground movements, are the concessions for the production (extraction) and underground storage of natural gas.

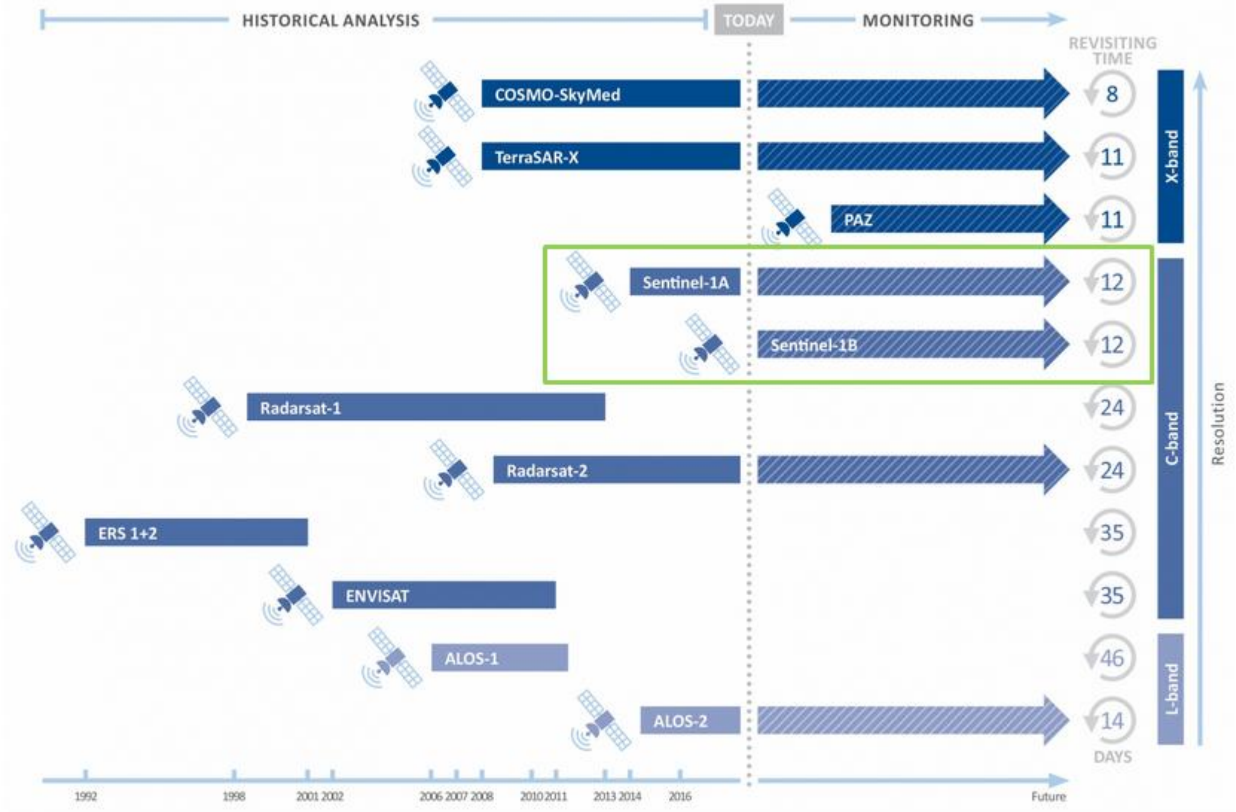
Other types of ground movements could be for example related to the local compaction of sediments, observable in particular in the recently built urban areas, or even related to the thermal expansion of the buildings; to minimize these "interfering signals", which in fact represent a disturbance to the proper interpretation of SAR interferometric series, the analysis should be always supported by local knowledge of the areas (e.g., land use maps, or more detailed information extracted from topographic databases).

3.6.2. Earth Observation and Copernicus data

This section of the document refers to the evaluations about the current and future availability of SAR satellite data and of SAR interferometric time series, relatively to Lombardy Region (for a more complete description, see the WODA Final Report 2015).

From the SAR satellite data availability point of view, the following figure summarizes the essential characteristics (length of time series, revisit time, bandwidth) of the main SAR constellations that operated in the past decades, or are currently in operation, or are expected in the next years.

Figure 46: Essential scheme of the main SAR satellites (image courtesy: TRE-Altamira); highlighted in the green box, the two SAR satellite from the Copernicus Program (Sentinel-1A and Sentinel-1B)



The main SAR satellites that worked in the past, useful for historical analysis of ground movements, are the European satellites ERS1 and ERS2 (1992-2000 time series) and ENVISAT (2002-2008 time series) and the Canadian Radarsat1 (1999-2012 time series). Right now, different SAR constellations are fully operating with different characteristics, like Cosmo-SkyMed (ASI), TerraSAR-X (DLR), and in particular the first SAR satellite from the ESA COPERNICUS Program (Sentinel-1A, operating from April 2014); in 2016 also Sentinel-1B was launched, and is currently operating, providing half of the time revisit of this constellation (from 12 days to 6 days).

Key findings: the characteristics of the SAR satellites constellation from the Copernicus Program (Sentinel-1A and Sentinel-1B), in terms of accuracy, swath of the scenes, temporal revisit and accessibility to data, are potentially very effective in order to monitor subsidence over wide areas

Key findings: From the operational point of view, it should be emphasized that, for the purpose of the actual usability of SAR data for the monitoring of ground movements, more than the "simple" availability and accessibility of data, the main limiting factor is SAR data processing (particularly onerous from the computational point of view) in order to derive the interferometric time series.

Key findings: In order to facilitate the operative exploitation of Sentinel-1A and Sentinel-1B, new operative Core Services are needed, at European or National level, aimed to the creation of operative SAR interferometry analysis production and dissemination.

The following paragraphs briefly describe the essential characteristics of the SAR interferometric time series currently available in Lombardy.

SAR Interferometric time series provided by Environmental Ministry

A first baseline is represented by the SAR interferometric time series provided at national level by the Environmental Ministry, in the framework of the National Remote Sensing Plan (PST). The data are related to the processing of ERS1, ERS2 and ENVISAT data, and are available through the National Geoportal and specific map services. In particular, Lombardy is covered almost entirely by time series for 1992-2000 period (ERS) and 2003-2008 period (ENVISAT).

Through specific map services it’s possible to check the individual PS (Permanent Scatterers) identified in the different areas. One limitation of these series is that the identified Permanent Scatterers are generally themed only by the average vertical displacements (mm/year) during the period, thus highlighting only mean movements during the available time series; disaggregated data referred to single satellite acquisitions are not available, which would enable a more complete interpretation of observed subsidence movements (for example, possible acceleration in specific periods, seasonal fluctuations, etc ..).

Regional SAR Interferometric time series

At Regional level, other SAR interferometric time series are available, commissioned by ARPA or Lombardy Region, in particular in the framework of landslide monitoring activities. The temporal coverage and the type of SAR satellite data is different (in particular ERS and Radarsat series, and, in more recent years and in smaller areas, even with COSMO-SkyMed data); the territorial coverage of these data is mostly related to the mountainous and hilly areas of the Lombardy.

Some of these SAR Interferometric time series cover, almost partially, the higher part of Lombardy's lowland or the main alpine valleys (characterized in general by the presence of local aquifers); moreover for these data the specific information of the ground movements observed in every satellite acquisition, for the single Permanent Scatterer, is generally available; for these reasons, these data provide potentially a good level of information.

SAR interferometric time series at the Underground Gas Storage (UGS)

A further source of available information, evaluated in this feasibility study, are the interferometric series available for some of the Underground Gas Storages (UGS) facilities active in Lombardy. Currently in Lombardy six different UGS concessions are active; for four of them ground movements and subsidence is monitored with SAR Interferometry; these data are required to the Environmental Ministry and to ARPA. The six currently active UGS concessions in Lombardy are distributed in different provinces in the lowland of Lombardy. In these monitoring areas, currently available interferometric series are referred to Radarsat data, with time series available since 2003, and with the acquisition frequency of 24 days.

For the purposes of this feasibility study, such data are of interest, as well as from the methodological point of view, exclusively in the marginal portions of the monitored areas, where the observable ground movements are not caused by the gas storage activities.

4.4. Methods and Results

The following sections are related to some examples in Lombardy, where SAR interpherometric time-series analysis, jointly with the available in-situ data analysis, led to the detection of areas with specific ground movements over time, potentially related to groundwater abstractions, despite significant differences about spatial extension and temporal development of the phenomena, and possible other interfering causes.

Oltrepò Pavese area

A first potential interest area for the observed ground movements, is represented by the Oltrepò Pavese (Pavia Province). Since from the first SAR interferometric series analysis carried out under the PST with ERS (1992-2000) and ENVISAT (2003-2008), locally the Oltrepò Pavese plain showed some areas affected by local subsidence (see next figures)

Figure 47: Extract, from the National Geoportal, of the SAR interferometric analysis from PST (ERS series 1992-2000), in a portion of Oltrepò Pavese; single Permanent scatterers (PS) points are themed as a function of their average speed of displacement (mm/y) along the line of sight of the satellite during the period of analysis; yellow-red colors denote local subsidence.

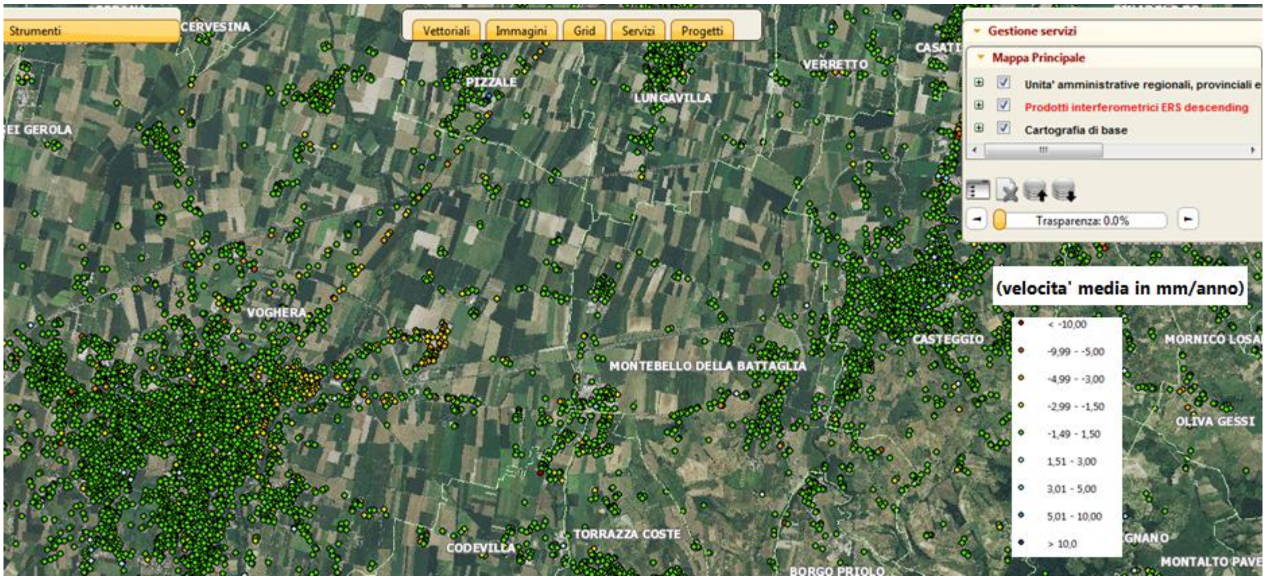
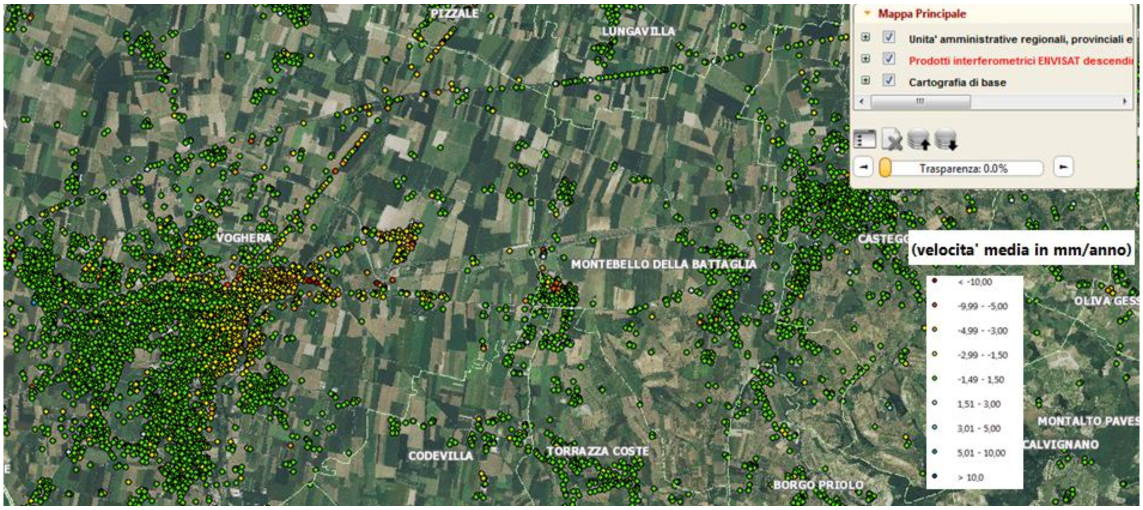
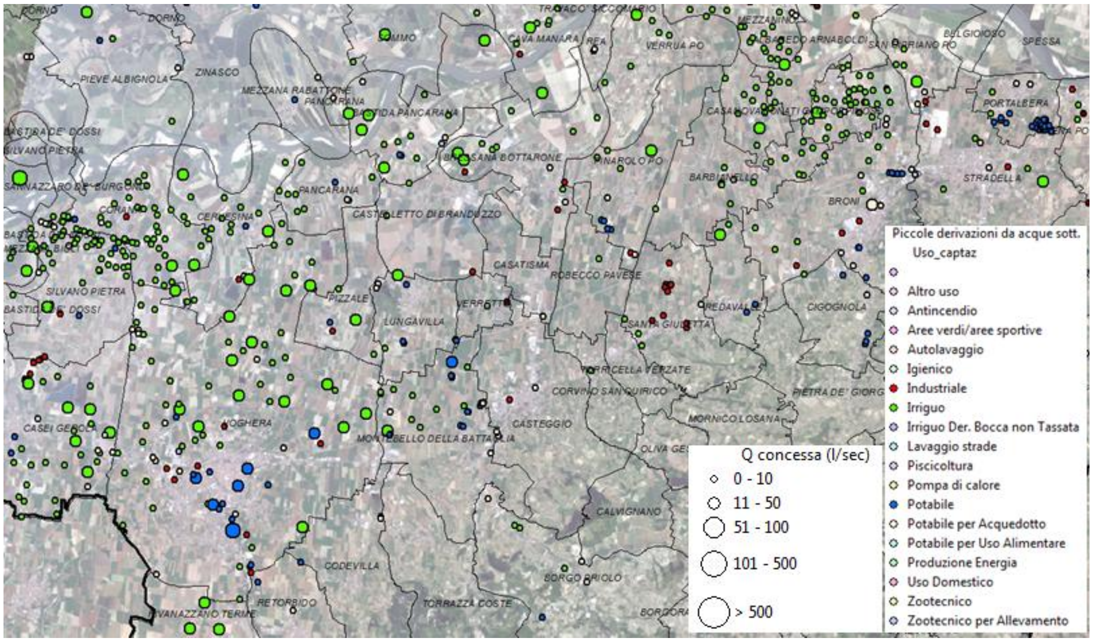


Figure 48: Extract, from the National Geoportal, of the SAR interferometric analysis from PST (ENVISAT series 2003-2008), in a portion of Oltrepò Pavese; single Permanent scatterers (PS) points are themed as a function of their average speed of displacement (mm/y) along the line of sight of the satellite during the period of analysis; yellow-red colors denote local subsidence.



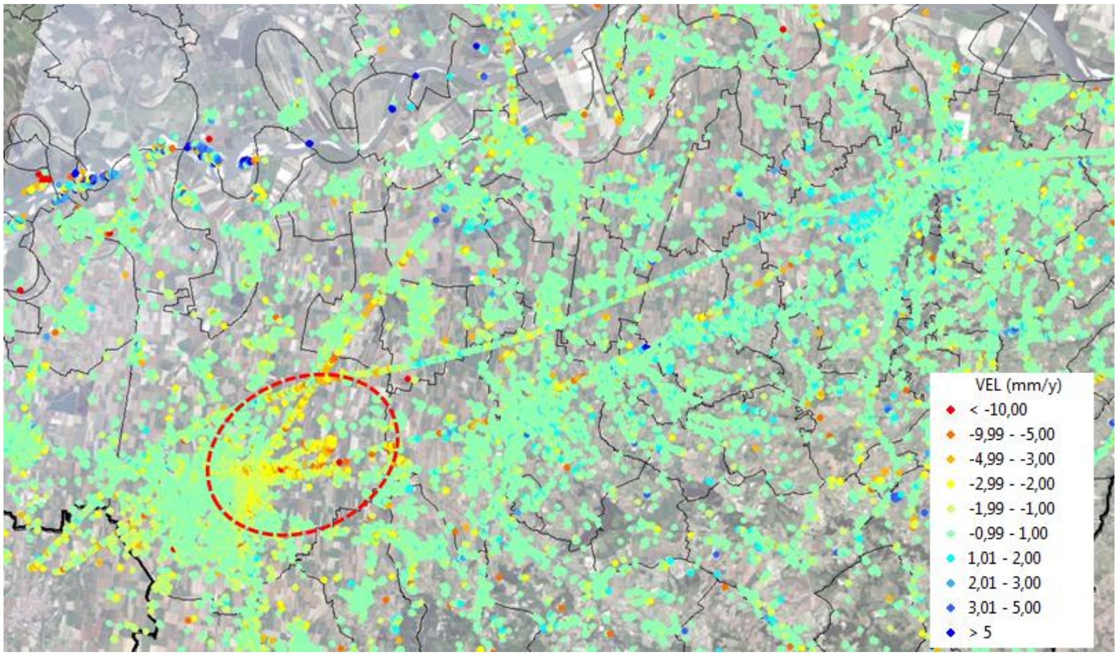
The Oltrepò Pavese area, from the point of view of water resources, has very specific characteristics compared to the average Lombardy conditions: water uses from superficial network in this area are very limited, while most of the uses (especially for irrigation) are secured by groundwater. For example, the following is an extract from the CUI (regional water uses cadaster), with the georeferencing of active groundwater concessions (all classified as “small concessions”), themed by use type and amount.

Figure 49: Extract, from the CUI, of the active groundwater concessions in the Oltrepò Pavese area (all classified as “small concessions”), themed by water use type and water concession (l/sec).



This area of interest is also partly covered by a more recent SAR interferometric time series, from Radarsat (2003-2010 period), in which the disaggregated data referred to the movements of individual PS in the individual acquisition dates are available (extract in Figure 50).

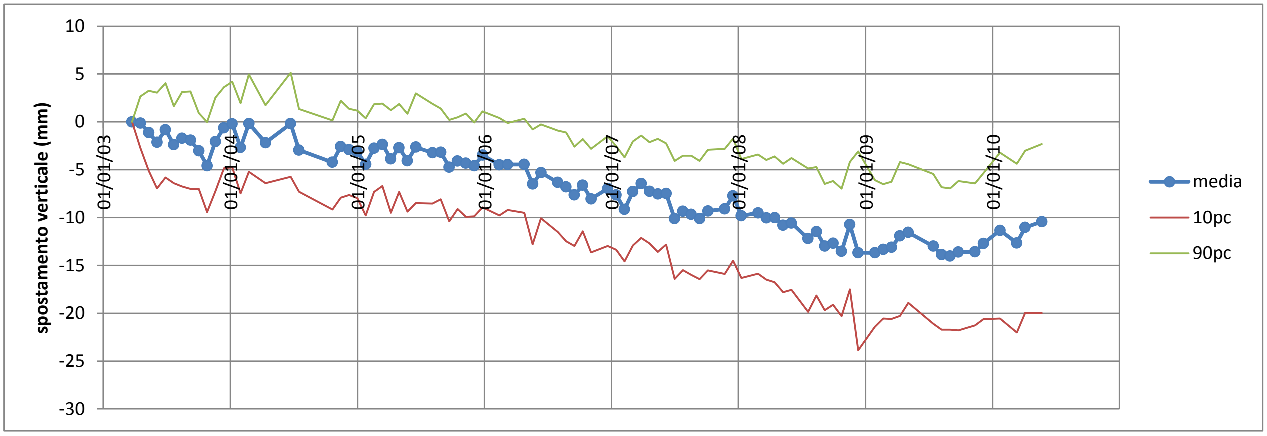
Figure 50: Extract of SAR interferometric analysis from Radarsat time series 2003-2010), in a portion of Oltrepò Pavese; single Permanent scatterers (PS) points are themed as a function of their average speed of displacement (mm/y) along the line of sight of the satellite during the period of analysis; yellow-red colors denote local subsidence.



Even in this case, and over this period of analysis, localized areas of light subsidence are observed; in particular, an area (e.g. ellipse in red in the previous figure) of local subsidence near the town of Voghera is highlighted, that could be caused by the combination of different potential causes; among them, it can be excluded the gas extraction (the nearby Casteggio Concession, now exhausted, is several km to the east); most likely a concomitant cause could be the sediments compaction effects (in particular for the PS points in slight subsidence aligned along transport infrastructures); the distributed “background signal" of subsidence trend appears likely related to groundwater abstractions (in the area there are several active concessions in particular for civil and irrigation uses).

Analyzing the Permanent Scatterers data from the statistical point of view, the group of PS in this area shows a substantially linear trend of slight subsidence in the investigated period, with no significant seasonal trend.

Figure 51: Statistical analysis of the vertical displacement trend of the PS points near Voghera; this group of PS shows a slight tendency to subsidence, with slightly higher rate in 2007-2008, without particular seasonal variations.



From the regional groundwater monitoring network point of view, unfortunately there are no close and significant stations nearby this local subsidence area, and in particular not relatively to the period covered by SAR data. In this area the groundwater body (GWB), called MPOP ISS, is classified in "Good" quantitative status, but it should be emphasized that the GWB covers a very wide area, while the observable effects of potential "unbalance" of groundwater resources, caused by potential over-exploitation, could be very localized.

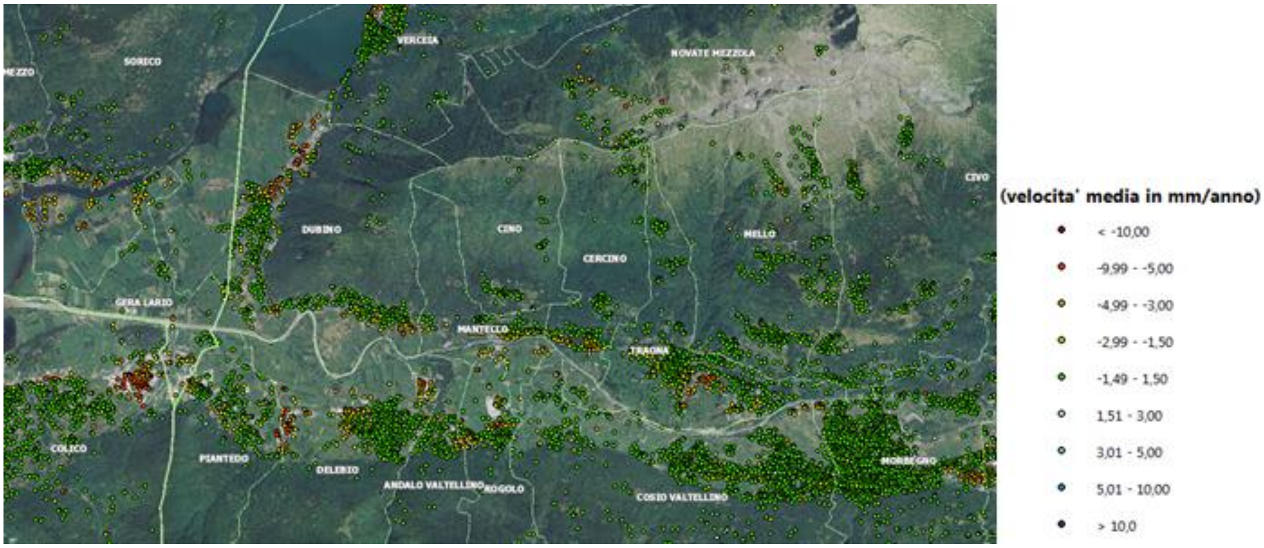
Key findings: In similar contexts, the monitoring of observed subsidence phenomena appears potentially interesting for improve the knowledge and for the long-term management of water resources, as well in potential support to the authorization process for renewal or new concessions of permissions for water abstractions.

Local Phenomena

A second type of investigation and potentially interesting area for observed ground movements, is represented by localized areas in the main alpine valleys.

The next figure shows the case of lower Valtellina valley (Sondrio Province), in which, already in the PST SAR interferometric series, very localized areas of long-term subsidence were observed.

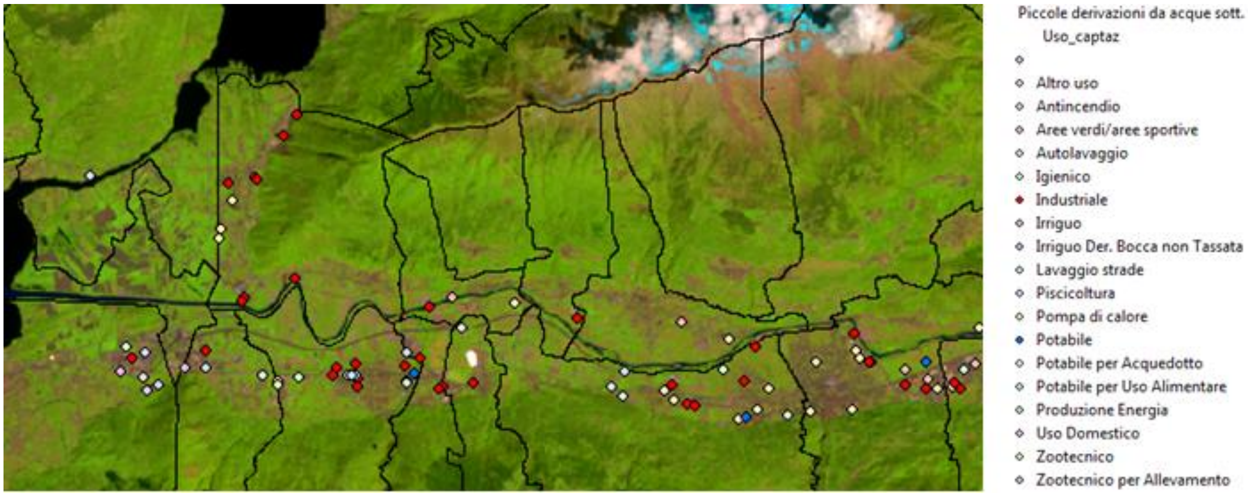
Figure 52: Extract of the Permanent Scatterers points identified by SAR interferometry (PST, ENVISAT series 2003-2008), in a portion of the Valtellina lower vally; PS points are themed the average speed of displacement (mm/y) along the axis of sight of the satellite during the period of analysis.



In these areas, the highest subsidence rates are generally observed nearby the urbanized areas with mainly industrial and commercial land use (often areas of recent construction): likely in these cases an important interfering phenomenon is represented by the sediments compaction, moreover in these valley areas more "young" from a geological point of view.

Key findings: From the perspective of groundwater resources monitoring, generally these areas are characterized by local and superficial aquifers: for these GWB, also, currently is often not possible to determine the quantitative status under the Framework Directive. Often, in correspondence of the local subsidence areas, there are also concentrated the most active licenses for groundwater abstractions.

Figure 53: Overlapping, in the lower part of Valtellina valley, of the georeferenced concessions for groundwater abstractions, themed for main use (e.g: red: industrial uses).



In this case, in particular, there are many water concessions for industrial use, localized in the areas subject to slight subsidence. This type of very localized phenomenon of subsidence takes place in different similar contexts alpine valley or high plains.

Key findings: In many cases, the concomitant presence of concessions for groundwater abstractions (often for industrial use) suggests a potential situation of cause/effect relationship (at least in terms of one of the contributing causes).

The following example refers to a similar situation in the Val Cavallina valley (Bergamo Province), nearby the Endine lake.

Figure 54: Overlapping, in Val Cavallina valley, of the georeferenced concessions for groundwater abstractions, themed for main use (e.g.: red: industrial uses).

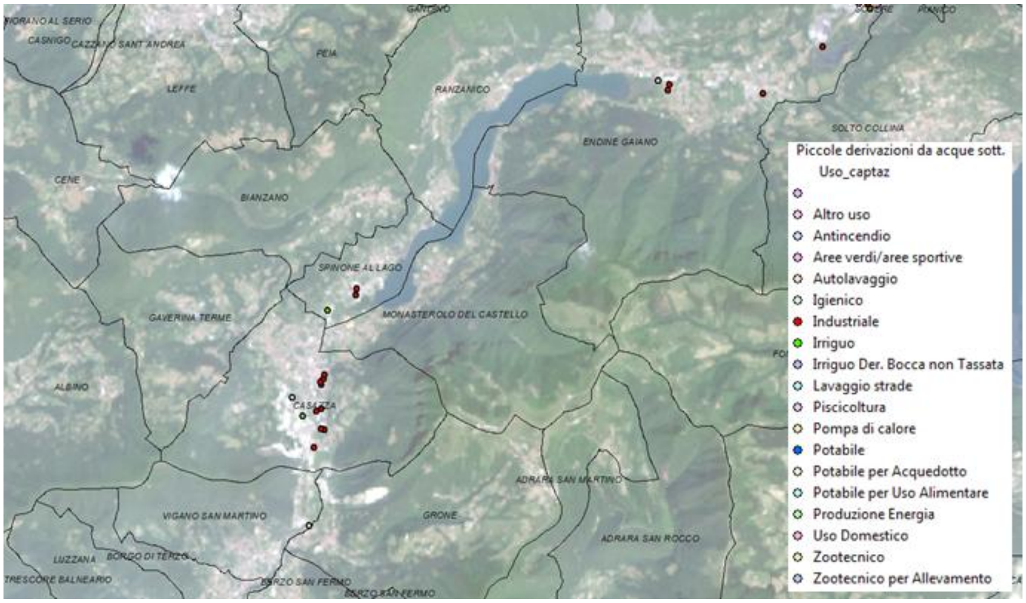
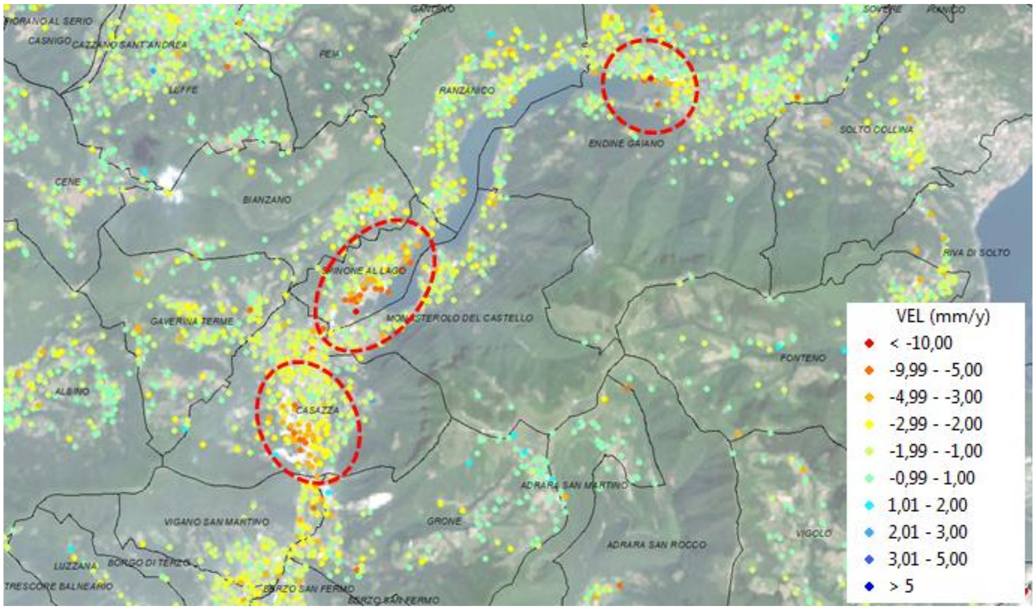
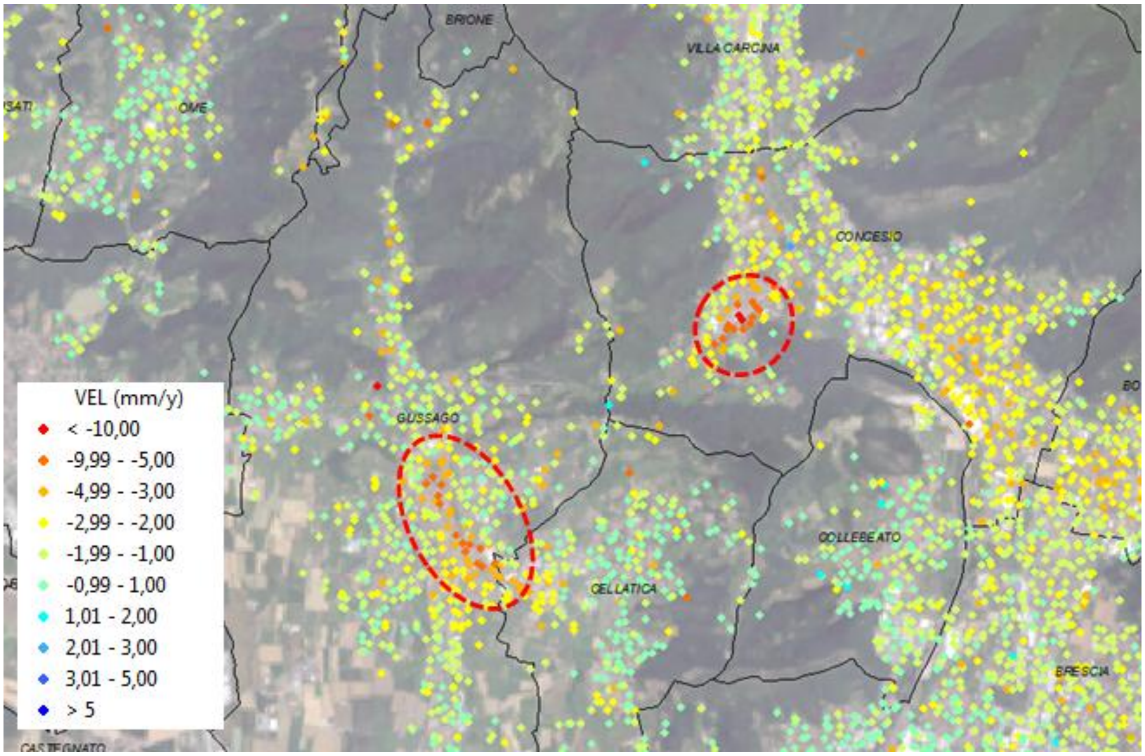


Figure 55: Extract of the Permanent Scatterers points identified by SAR interferometry (Radarsat time series 2003-2010), in a portion of the Val Cavallina valley; PS points are themed the average speed of displacement (mm/y) along the axis of sight of the satellite during the period of analysis.



In similar contexts, local subsidence could be detected and localized, but there are no enough information about actual local abstractions and water concessions data; in the next figures, an example of two situations of very localized subsidence in the valley of Val Sabbia (Concesio) and in the high plain of Brescia (Gussago).

Figure 56: Extract of the Permanent Scatterers points identified by SAR interferometry (Radarsat time series 2003-2010), in the valley of Val Sabbia and the high plain of Brescia; PS points are themed the average speed of displacement (mm/y) along the axis of sight of the satellite during the period of analysis.



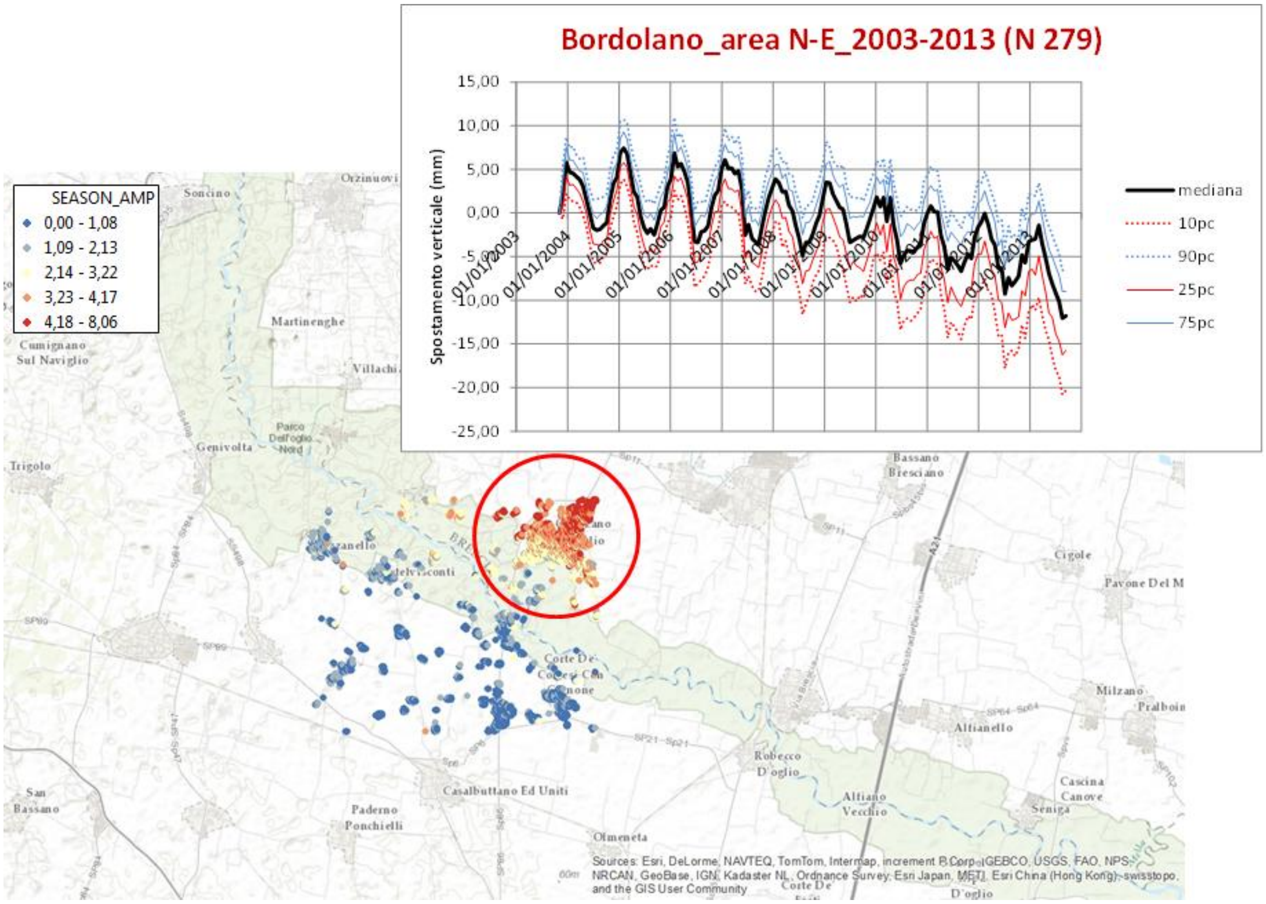
Lowland Lombardy (Bordolano area)

In this case the available SAR interferometric time series is part of the monitoring data provided by the dealer of one of the underground gas storage sites (UGS) active in Lombardy, specifically the Bordolano site (Cremona and Brescia Province). This UGS site is not yet productive (i.e. a complete input/output cycle has not yet been completed), but for the purposes of the ex-ante evaluation interferometric series (from Radarsat) have been made available; these data are very complete, with disaggregated data for individual PS, and ground movement data relative to each satellite scenes analyzed (one every 24 days, in the 2003-2013 period).

From the point of view of the interferometric analysis, the area nearby the UGS is not affected by significant ground movements, except for the marginal portion of the monitored scene (extreme North-East, in the province of Brescia). In this area the identified PS points show, in addition to a light long-term subsidence trend, a particular seasonal oscillation, with very evident minimums (higher subsidence) in summer (

Figure 57).

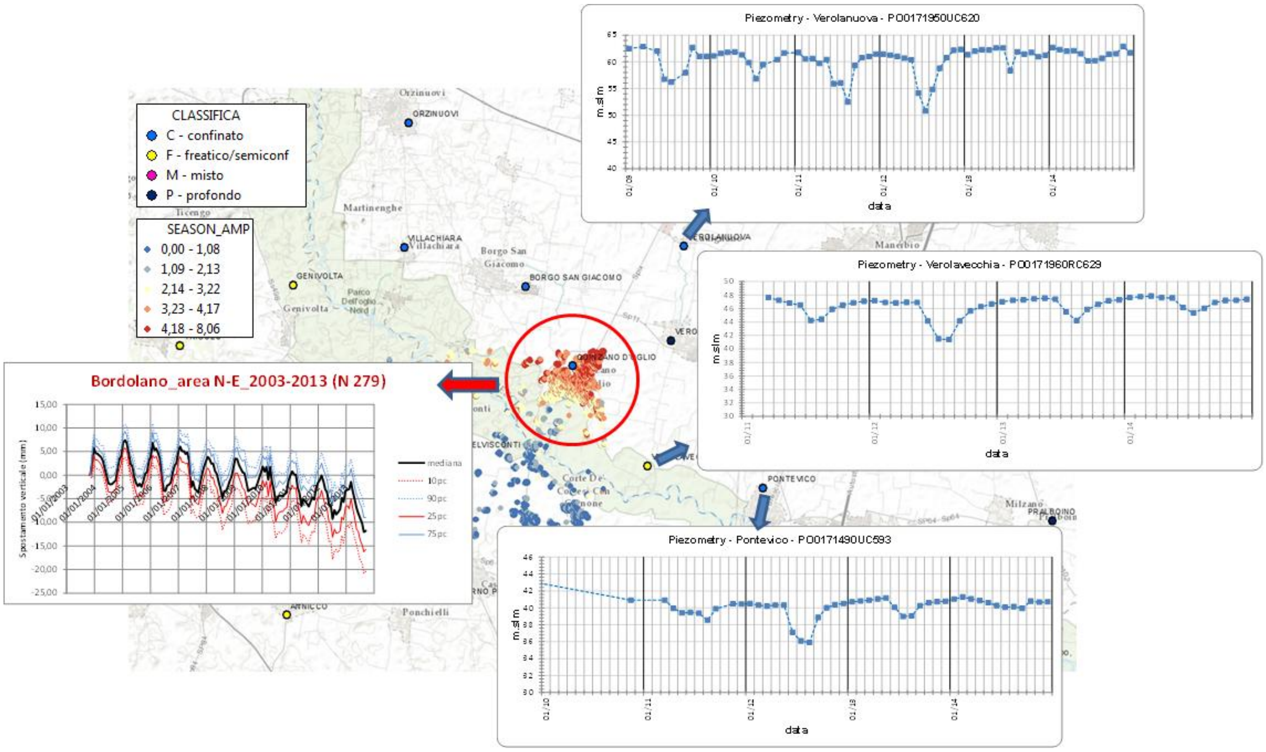
Figure 57: Focus over the area monitored with SAR interferometry near the UGS Bordolano site, and highlighting of the statistical trend of the group of PS points in the portion N-E of the scene; these point are affected by slight long-term subsidence and a seasonal variation.



Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

This part of the lowland is particularly complex from the geological point of view, with succession of different sedimentary formations and the presence of different aquifers (at different depths and with different confinement degree); the area is characterized by intensive agriculture, with irrigation predominantly covered by surface water but also by groundwater (particularly in periods of scarcity of surface water resources); moreover, the area is characterized by high population density and by a great number of highly water demanding livestock farms. In the next figure, in addition to the graph related to the statistical trend of ground movements in the N-E portion of the scene, the trends of piezometric levels derived from three nearby groundwater monitoring stations are shown.

Figure 58: Statistical summary of the ground movement in the N-E portion of the scene, and trends of piezometric levels derived from three nearby groundwater monitoring stations



The piezometric time series measured at the three wells nearby the area of interest show, in addition to a substantially constant trend in the long term, several summer minimums, probably caused by the increased water abstractions in the summer period (in particular for irrigation and zootechnic water requirements); the summer decreases in the water table are also more evident in particular in the summer of 2012, which was particularly dry.

Key findings: In this case, the cause/effect relationship between groundwater abstractions and local subsidence (although localized and not irreversible) appears very likely, although it must be stressed that there could be other interfering phenomena (related in particular to the observed long term-trend of subsidence).

4.5. Discussion

This paragraph describes the use case Lombardy carried out in the framework of the Project WODA; this particular feasibility study refers to the potential use of satellite SAR interferometric data for the identification of potential groundwater over-abstractions in the geographical context of Lombardy.

SAR Interferometry methodology measures with high accuracy ground movements (subsidence), which in fact is the overall effect potentially of several competing phenomena: for this reason, a first part of the analysis was focused on the overview of the auxiliary and supporting data that should be exploited in order to correctly interpret SAR interferometric series.

Another overall objective of the feasibility study was to assess the observability of subsidence in the geographical context of Lombardy (in the lowland and in the alpine valleys), potentially induced by groundwater abstraction and over-abstraction in most contexts the potential observability of the phenomenon appears guaranteed by actually operating SAR constellations.

In different contexts of Lombardy, some observed local subsidence appear, although with very different degrees in terms of scale and frequency, connected to groundwater abstractions; in order to further assess whether and in what situations these findings correspond to actual over-extraction (in terms of unbalances, in the long term, between abstraction and recharge) more complete analysis are necessary, as well as more complete availability SAR interferometric series on wider areas, updating the analysis and integrating them with different sources of information.

The Lombardy use case is well representative of many areas in Europe characterized by sedimentary basins and high rates of groundwater abstractions, in which the EO approach investigated in this study could provide important contributions in monitoring capabilities; in general, improving the monitoring capabilities of the observed effects of local subsidence appears of interest for the purposes of knowledge improvement and of long-term management of the water resources, as well as in potential support to the authorization process for renewal or new concessions of permissions for water abstractions.

5. Conclusions

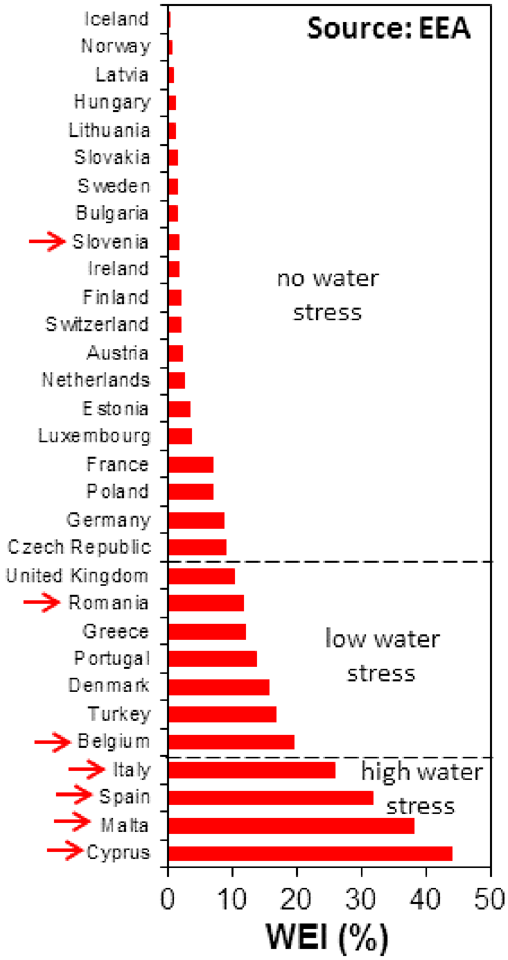
Eight European partners have actively participated to project WODA. Apart from the partners of Malta, Slovenia and Cyprus which are national boards, the other partners are local boards. As a consequence their territories are smaller than the respective countries, that is: regions (the case of Flanders in Belgium, Emilia Romagna and Lombardy in Italy), counties (the case of Bihor County in Romania) and basins (the case of Basin of Miño-Sil, Ourese in Spain). To what extent are the WODA partners' territories statistically significant of the European Union context? From a merely geographic and demographic point of view we can consider them a representative sample. In fact, the total area of the partners' territories is nearly 115000 Km^2, corresponding to the 2.60% of the whole European Union, while the total population of the partners' territories is about 25 million, corresponding to the 5.11% of the European Union population.

Table 8. Geographic and demographic representativeness of the WODA partners as compared to European Union (population data range from 2008 to 2014).

WODA partner	Area (Km^2)	Population
Environment, Nature and Energy Department. Flemish Government. Region of Flanders. Belgium.	13 682	6 161 000
Water Development Department. Ministry of Agriculture, Natural Resources and Environment. Cyprus.	9 250	858 000
ARPA (Regional Environmental Protection Agency) Emilia Romagna. Region of Emilia Romagna. Italy	22 451	4 450 541
ARPA (Regional Environmental Protection Agency) Lombardia. Region of Lombardy. Italy.	23 869	9 973 397
Sustainable Energy and Water Conservation Unit. Ministry for Energy and Health. Malta.	316	425 384
National Environmental Guard - Bihor County Commissariat. Bihor County. Romania.	7 535	549 752
Inspectorate of the RS for Environment and Spatial Planning, Ministry for the Environment and Spatial Planning. Slovenia.	20 273	2 062 874
Consejero técnico. Confederación Hidrográfica del Miño-Sil. Ourese. Spain.	17 582	825 851
Total	**114 958**	**25 306 799**
% over European Union	**2.60%**	**5.11%**

From the point of view of quantitative water resources, we can consider the WODA partners' territories very significant of the main European Union issues. Water Exploitation Index (WEI) gives an indication of how the total water demand puts pressure on the water resource. The WODA partners' countries are well representative of the problems of water over-exploitation in Europe (Figure 59). Following the EEA statistics, 20 countries don't have water stress, 7 have low stress (among WODA partners: Belgium and Romania) and 4 have high stress (among WODA partners: Cyprus, Malta, Spain, Italy).

Figure 59. Distribution of Water Exploitation Index (WEI) in European countries; red arrows indicate WODA partners (source: EEA,2001)



$$\mathrm{WEI} = \frac{\text{mean total demand for freshwater}}{\text{long-term average freshwater resources}}$$

All the WODA partners' territories (included Slovenia, the less critical from the water over-exploitation point of view) have experienced several important water scarcity and drought events during the last decade (Table 9).

Table 9. Involvement of WODA partners' territories in main water scarcity and drought events during the last decade (elaborated by ARPA Lombardia from EEA statistics).

WODA partner	Main water scarcity and drought events						
	2002	2003	2005	2007	2008	2011	2012
Environment, Nature and Energy Department. Flemish Government. Belgium.		√	√			√	√
Water Development Department. Ministry of Agriculture, Natural Resources and Environment. Cyprus.	√			√	√		
ARPA (Regional Environmental Protection Agency) Emilia Romagna. Italy.		√		√	√	√	
ARPA (Regional Environmental Protection Agency) Lombardia. Italy.		√		√	√	√	
Sustainable Energy and Water Conservation Unit. Ministry for Energy and Health. Malta.	√	√		√	√		
National Environmental Guard - Bihor County Commissariat. Romania.		√		√	√	√	√
Inspectorate of the RS for Environment and Spatial Planning, Ministry for the Environment and Spatial Planning. Slovenia.		√				√	√
Consejero técnico. Confederación Hidrográfica del Miño-Sil. Ourese. Spain.		√	√	√	√		√

We think therefore that the considerations we can derive from the WODA questionnaire and the pilot feasibility studies could be reasonably taken into account at a wider scale.

The aims of the questionnaire were:

- To provide IMPEL and the Commission with first-hand information on illegal water abstraction and legal over-abstraction.

- To set the basis for further feasibility studies: many information contained into the questionnaire can be used to address a feasibility study: define the priorities, choose the methodology,…

- Extrapolation of the results: the issues from the feasibility studies can be extrapolated to the partners who didn't carry out the feasibility study using the information of the questionnaire as a baseline.

The information collected through the WODA questionnaire is very reach: 95 questions about 5 topics: the competences of the partner, the context (geographical, hydro-climatic and socio-economic), the water abstraction practices, the availability and consistency of data, the Earth Observation experiences of the partner.

if we had to summarize the outcome of the questionnaire just into keywords, we could use: diversity, complexity and information quality. We explain these keywords:

- Diversity. The partners' organizations are very different. The administrative levels range from national, regional, county up to basin (paragraph 8.3.1). The same for the competence sectors (paragraph 8.3.2): some partners' competences are concentrated on water resources, others are encompassing environment, agriculture, energy and sustainable development. These differences are even more evident when coming to the competences on water resources (paragraph 8.3.3): some organizations are highly specialized (e.g. management of industrial water uses or inspections of permits,….), others have wider competences ranging from monitoring, permits release, inspections, development of water policies, etc. etc. up to research and development. The administrative level and the competences of an organization affect the types and complexity of its relationships with other organizations.

- Complexity. The water abstraction management criteria are complex and very different (paragraph 8.5) among partners both in term of permits, fees, monitoring and inspections criteria. Permits may be released on the basis of the declared amount of water abstracted and/or the water use, and/or the type of plant/infrastructure,… Fees criteria may be related to the permitted/ measured abstraction and/or use,… Monitoring is not very widespread: in some cases there are not flowmeters at all, in other cases the installation of flowmeters is progress. The inspection methods are in some cases based more on administrative data, in others on field visits. The number and frequency of field visits is highly variable among partners, depending at a large extent on the number of available field inspectors.

- Information quality. In general the information about permits is organized in an information system but the abstraction points are not always georeferenced. The so called auxiliary data, i.e. the data necessary for the processing and interpretation of EO data: agricultural parcels, meteorological, phenological, crop data, etc. etc. are not always available. The pilot feasibility studies of WODA have demonstrated that in cases where the data owner was different from the WODA partner the acquisition of data turned out to be very difficult and time consuming.

The Copernicus Guidance highlights some factors limiting the application of EO to the detection of illegal water abstraction in agriculture, the most relevant being:

1) The presence of a wet climate, because it is difficult to separate the contribution of precipitations from those of irrigation.

2) The irrigation from surface water (or a mix of groundwater and surface water), because abstraction from surface water is in general more difficult to measure.

3) The small dimension of parcels, because it makes difficult the observation from satellite.

4) The lack of information (or low quality of information) about permits, location of abstraction points, auxiliary data,…. because it limits the capability to interpret, calibrate and validate the information extracted from satellite images.

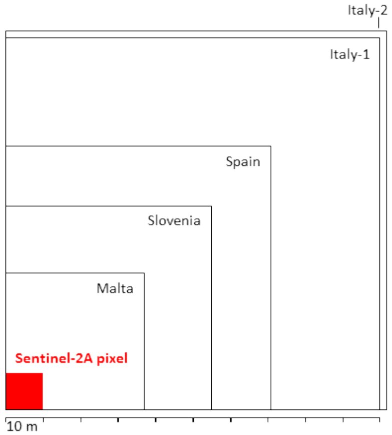
5) The lack of knowledge on EO.

The WODA questionnaire addresses all these limiting factors. Regarding to the first and second point, some partners territories, like Lombardy, have climate and irrigation systems not favourable to the use of EO for the detection of illegal water abstraction. However, even in these situations, EO can provide a very useful contribution in supporting the water management policies and the assessment of water scarcity and drought event. In general, if the focus is not restricted only on illegal water abstraction but is open to water management issues and to the water over-abstraction, than EO turn to be a very powerful tool.

Regarding to the small dimension of parcels, the questionnaire provides useful information (Table 20 and Figure 74). The diversity among partners is, as always, great. The average parcel size ranges

From 1400 m^2 in Malta to 10400 m^2 in Lombardy, i.e. a factor of 10 of difference. The case of Malta is well representative of other Mediterranean areas as Cyprus and Greece. The Copernicus Sentinel-2A satellite, launched on 23 June 2015, is currently providing multi-spectral images at 10 metre resolution in the region of visible and near-infrared (the pixel resolution of the short wave infrared bands is 20 m) of excellent quality, completely free and available within one day from the acquisition. The geometric resolution of Sentinel-2A is suitable for crop mapping and for the discrimination between irrigated and non-irrigated parcels even in Malta.

Figure 60. The red square shows the pixel of Sentinel-2A multi-spectral in the visible and near-infrared bands, compared with the average parcel size in the partners' territories.

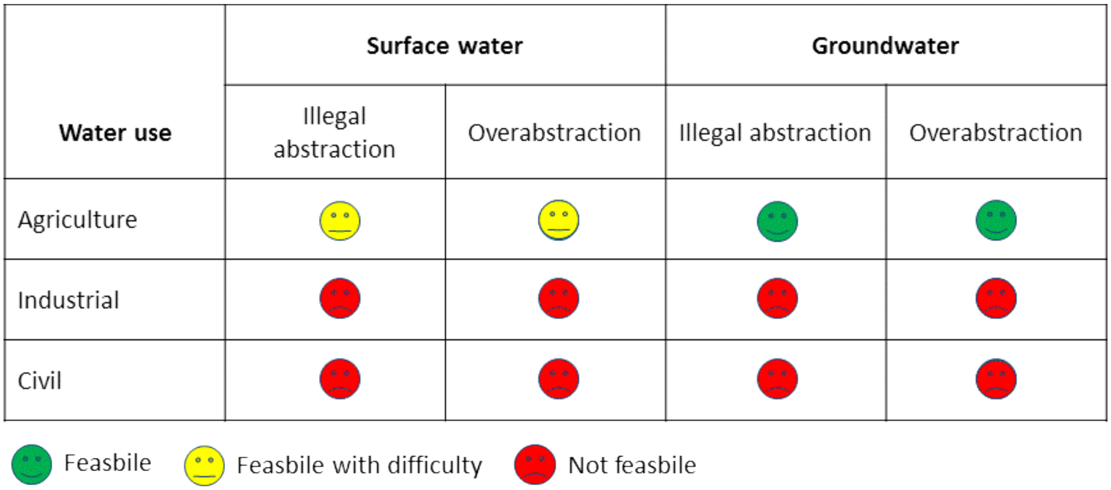


The information problem emerges very clearly both from the questionnaire and from the pilot feasibility studies and is probably the most important limiting factor to the application of EO. To explain the problem we describe some cases:

- Abstraction points are not always georeferenced.
- Auxiliary data are partially available or they are not updated.

- The information exists in databases but it is spread among different organizations. The fragmentation of the competences among different organizations can generate the dispersion of the information. There are therefore different data owners. Data have to be requested to the data owners through bureaucratic procedures which are in general time consuming. But the most difficult hindrance to overcome is of a technical nature: being that databases belonging to different organizations were designed independently from each other and without following general standards, common key identifiers do not exist, thus the join of tables belonging to different databases doesn't work properly. in some cases it is partially successful but in the worst cases it turns out to be impossible. The Directive 2007/2/EC INSPIRE lays down the framework for the sharing of the environmental information through systems interoperability. If the Directive were fully implemented these problems should be at a large extent solved. In fact, the Directive is still under implementation by many organizations. The pilot feasibility study on Malta has demonstrated how the integration of the registers available from different organizations can provide value-added information very useful to understand the actual state of water abstraction

Figure 61. Feasibility of use of satellite optical remote sensing in detecting illegal water abstraction and monitoring legal water over-abstraction.



Water use	Surface water		Groundwater	
	Illegal abstraction	Overabstraction	Illegal abstraction	Overabstraction
Agriculture	🟡	🟡	🟢	🟢
Industrial	🔴	🔴	🔴	🔴
Civil	🔴	🔴	🔴	🔴

🟢 Feasbile 🟡 Feasbile with difficulty 🔴 Not feasbile

Figure 62. Feasibility of use of satellite SAR interferometry in detecting illegal water abstraction and monitoring legal water over-abstraction.

Water use	**Surface water**		**Groundwater**	
	Illegal abstraction	Overabstraction	Illegal abstraction	Overabstraction
Agriculture	🔴	🔴	🟡	🟢
Industrial	🔴	🔴	🟡	🟢
Civil	🔴	🔴	🟡	🟢

🟢 Feasbile 🟡 Feasbile with difficulty 🔴 Not feasbile

Figure 63. Feasibility of the combined use of satellite optical remote sensing and SAR interferometry in detecting illegal water abstraction and monitoring legal water over-abstraction.

Water use	**Surface water**		**Groundwater**	
	Illegal abstraction	Overabstraction	Illegal abstraction	Overabstraction
Agriculture	🟡	🟡	🟢	🟢
Industrial	🔴	🔴	🟡	🟢
Civil	🔴	🔴	🟡	🟢

🟢 Feasbile 🟡 Feasbile with difficulty 🔴 Not feasbile

The aim of the pilot feasibility studies of WODA was to assess the technical feasibility of use of EO in specific partners contexts, taking as reference the Copernicus Guide and underlining the main drawbacks and limiting factors.

The pilot feasibility study of Malta has further highlighted the problem of complexity. In this case complexity refers to the way water is abstracted and used by farmers. The following situations are very common on the pilot site of Malta:

- a farmer may own more parcels,
- the farmer's parcels may be interspersed among the parcels owned by other farmers,
- depending on the parcel use and the crop type, a parcel may require or not irrigation,
- a farmer may own one or more boreholes,
- the farmers' boreholes may not stand inside farmer's parcels,
- the water abstracted from a borehole may be in part supplied to other farmers,
- not all the boreholes are equipped with flowmeters (the installation of flowmeters is in progress),
- not all the flowmeters are transmitting the data (the acquisition of data is in progress).

During the pilot feasibility study of Malta, knowledge improvements were achieved joining the databases available from different organizations related to groundwater abstractions and agricultural land use. For the cases of agricultural parcels correctly joined with flowmeters data, better quantitative analysis are expected, e.g.:

- discrimination among 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, Sentinel-2 data will dramatically improve the monitoring capabilities, thanks to the temporal and spatial resolution improvements respect to Landsat8.

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

- full exploitation of Sentinel-2 data,
- improvements in quantitative analysis, towards water uses sustainability analysis,
- improvements on auxiliary data availability and integration through data exchange protocols,
- EO capacity building.

The pilot feasibility study of Romania in Bihor County describes a situation very different from Malta. The pilot area is characterized by continental climate. The irrigated surface is very low due to the damage and the clogging of the irrigation canals, as well as to the deterioration pumping equipment occurred in the 90s during fall of the former political regime. This particular situation causes strong differences between the actual and potential irrigation requirements in the area. The main focus of the feasibility study in Romania has been on water uses in agriculture and about the use of multi-temporal optical EO data, primarily in order to derive crop maps, and for the monitoring of potentially irrigated parcels. The main crop map classification provided in this feasibility study is an example of a possible first output, useful to detect the potentially water demanding agricultural areas and their evolution over time. From a quick look at GoogleMap hundreds of greenhouses have been detected. Only three greenhouses have the proper water permit. Sentinel-2 images will allow an easy automated detection of the greenhouses and their evolution. Regarding to the monitoring of groundwater over-abstraction both from agricultural uses and other water uses, the SAR Interferometry approach is potentially feasible over the alluvial plains of the Bihor County.

The pilot feasibility study of Lombardy is different from the above two studies because it refers to the use of SAR interferometry for the monitoring of groundwater over-abstraction. SAR interferometry measures with millimeter accuracy the ground movements (e.g. subsidence), which in fact are the effect of several concurrent phenomena: for this reason, a first part of the analysis was focused on the review of the auxiliary data that should be exploited in order to correctly interpret SAR interferometric data.

The detection of the subsidence induced by potential groundwater over-abstraction has been tested in Lombardy in different areas of the lowland and in alpine valleys using SAR interferometric data available from previous monitoring campaigns. Some local subsidence phenomena arise from the analysis of data, although with very different degrees in terms of geographic scale and time frequency, connected to groundwater abstractions. In order to further assess whether these findings correspond to actual over-extraction (in terms of unbalances, in the long term, between abstraction and recharge) further analysis are necessary, as well as more complete SAR interferometric series on wider areas.

6. References

- FAO Irrigation and Drainage Paper No. 56. Crop Evapotranspiration. Guidelines for computing crop water requirements.

- Applying Earth Observation to support the detection of non-authorised water abstractions, Proposed Guidance Document, DG Environment, 2014.

- Applying Earth Observation to support the detection of non-authorised water abstractions, Discussion paper on the development of Copernicus tools and services, 2014.

- WODA Terms of Reference and previous reports are available on Basecamp: http://www.impel.eu/projects/water-over-abstraction-and-illegal-abstraction-detection-and-assessment-woda/

7. Annex I. WODA Questionnaire

8.1 Aims of the questionnaire

The aims of the WDOA Questionnaire are the following:

1) General information
   As in other projects promoted by IMPEL, it is quite a practice to collect information about how different aspects of the problem (in this case: illegal and over abstraction of water) are assessed by each partner. Being that the project partners are competent and experienced on different and specific aspects of the problem, the information they provide is very helpful for IMPEL and the Commission to get a realistic overview of the problem.

2) Providing a starting point for a possible pilot feasibility study
   Many information contained into the questionnaire will be used to address the feasibility studies: define the priorities, choose the methodology,…

3) Extrapolation of the results
   The issues from the feasibility studies will be extrapolated to the partners who don't carry out the feasibility study using the information of the questionnaire as a baseline.

8.2 Participants

Table 10. List of WODA partners who answered the questionnaire

Partner short name used in the document	Partner full name
Belgium	Environment, Nature and Energy Department. Flemish Government. Belgium.
Cyprus	Water Development Department. Ministry of Agriculture, Natural Resources and Environment. Nicosia. Cyprus.
Italy-1	ARPA (Regional Environmental Protection Agency) Emilia Romagna. Italy.
Italy-2	ARPA (Regional Environmental Protection Agency) Lombardia. Italy.
Malta	Sustainable Energy and Water Conservation Unit. Ministry for Energy and Health. Malta.
Romania	National Environmental Guard - Bihor County Commissariat. Romania.
Slovenia	Inspectorate of the RS for Environment and Spatial Planning, Ministry for the Environment and Spatial Planning. Slovenia.
Spain	Consejero técnico. Confederación Hidrográfica del Miño-Sil. Ourese. Spain.

8.3 Competences of your organization

8.3.1 Administrative level

Table 11. Administrative level (question 2).

	Nation	*Region*	*Province*	*County*	*Municipality*	*Basin*
Belgium		√				
Cyprus	√					
Italy-1		√				
Italy-2		√				
Malta	√					
Romania				√		
Slovenia	√					
Spain						√

8.3.2 Sectors

Table 12. Sectors (question 3).

	Water resources	*Environment*	*Agriculture*	*Energy*	*Sustainable development*
Belgium		√		√	
Cyprus	√	√			
Italy-1	√	√	√	√	√
Italy-2	√	√	√		√
Malta	√				
Romania		√			
Slovenia	√	√			
Spain	√	√			√

8.3.3 Competences related to water resources

Table 13. Competences related to water resources (question 4).

	Surface water	*Groundwater*	*Monitoring water quantity*	*Monitoring water quality*	*Release of water permits*	*Inspection on water permits*	*Assessment/ analysis of water requirements*	*Development of water policies*	*Support to development of water policies*	*Development of River Basin Management Plans*	*Support to development of River Basin Management Plans*	*Advice tor irrigation*	*Early warning on unsustainable water uses*	*Management of drought events*	*Support to management of drought events*	*Research and development*
Belgium	√	√				√			√							
Cyprus	√	√	√	√	√	√	√		√	√	√			√		
Italy-1	√	√	√	√			√		√		√	√			√	√
Italy-2	√	√	√	√			√		√		√		√		√	
Malta		√	√	√				√	√	√						
Romania	√	√				√										
Slovenia	√	√				√			√							
Spain	√	√	√	√	√	√	√	√	√	√	√		√	√	√	

8.3.4 Relationship with other organizations

Description of the relevant organizations (if any) with which the WODA partner normally cooperate in his activities related to water resources.

Table 14. Relationship with other organizations (question 5).

Belgium	VMM: Vlaamse Milieumaatschappij (Flemish Environment Agency).
Cyprus	Department of Environment.
Italy-1	Water procurement and management consortia, River and hydrographic district authorities, Region Emilia-Romagna.
Italy-2	Lombardy Region, River Authorities, Provinces, irrigation Consortia, great lakes Consortia.
Malta	The partner's unit mainly works with the following government entities: Water Services Corporation (The national water utility company), Malta Resources Authority (The national resource regulator), Ministry for Gozo (Regional Ministry responsible for the island of Gozo), Ministry for Transport and Infrastructure (Collaborations on policy development and projects), Ministry for Sustainable Development, Environment.
Romania	Crisuri Water Basin Administration. "Romanian Waters" national administration. National Agency of Mineral Resources. Bihor Department of Agriculture. INCDIF-ISPIF, National Institute of Research and Development for land improvement, Bucharest.
Slovenia	Ministry for environment and spatial planning, Slovenian Environment Agency (EPA), Institute for Water of Republic of Slovenia, Financial administration RS, competent authorities for water quality monitoring, river and marine supervisory services,..
Spain	Other river-basin organisations. Regional and local authorities. European Union. Water consulting firms.

8.4 Context

8.4.1 Geography

Table 15. Geography (questions 7 – 9).

	Surface (Km^2)	Minimum elevation (metres above sea level)	Maximum elevation (metres above sea level)
Belgium	(1) 13 682	0	288
Cyprus	(2) 9 250	0	1 950
Italy-1	22 451	-4	2 165
Italy-2	23 869	5	4 020
Malta	316	1	252
Romania	7 535	85	1 849
Slovenia	20 273	0	2 864
Spain	17 582	0	2 190

Notes:

(1) Flanders.

(2) Includes the occupied part of Cyprus.

Figure 64. Surface of the territories of the WODA partners

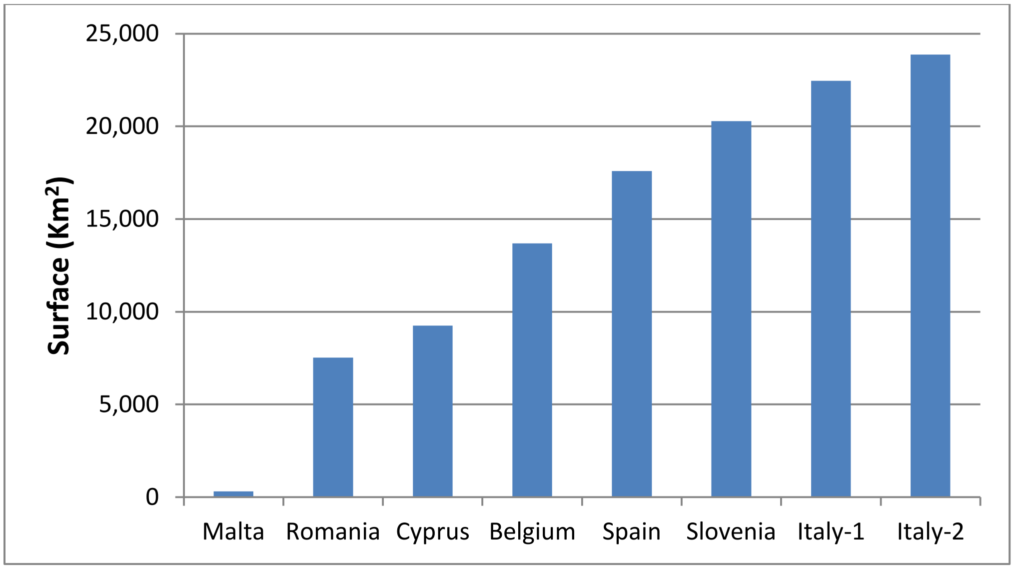


Figure 65. Elevation range (maximum elevation – minimum elevation) of the territories of the WODA partners.

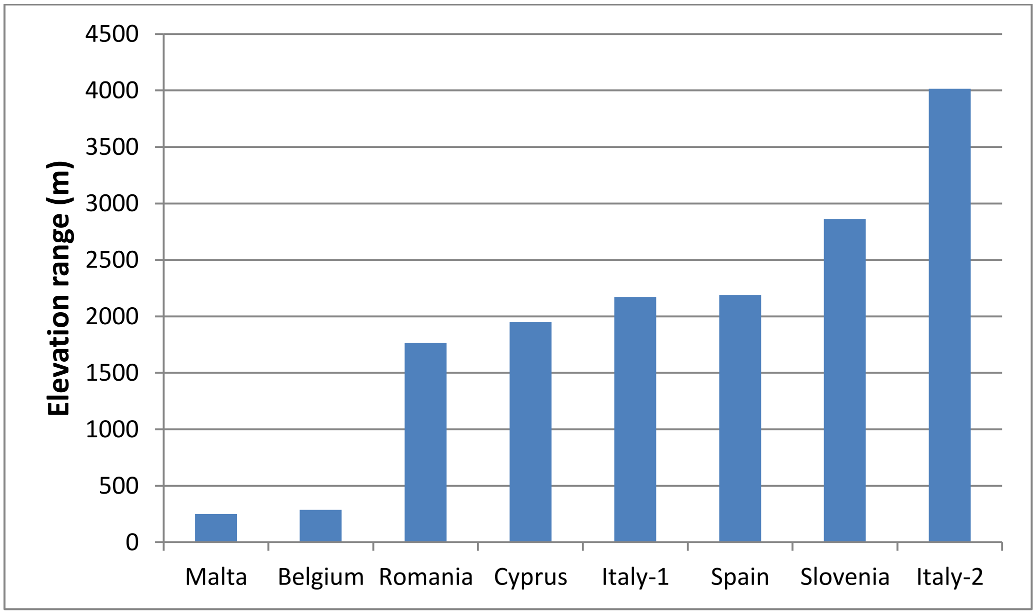


Figure 66. Distribution of the elevation range of the territories of the WODA partners versus their surfaces. Scales are logarithmic

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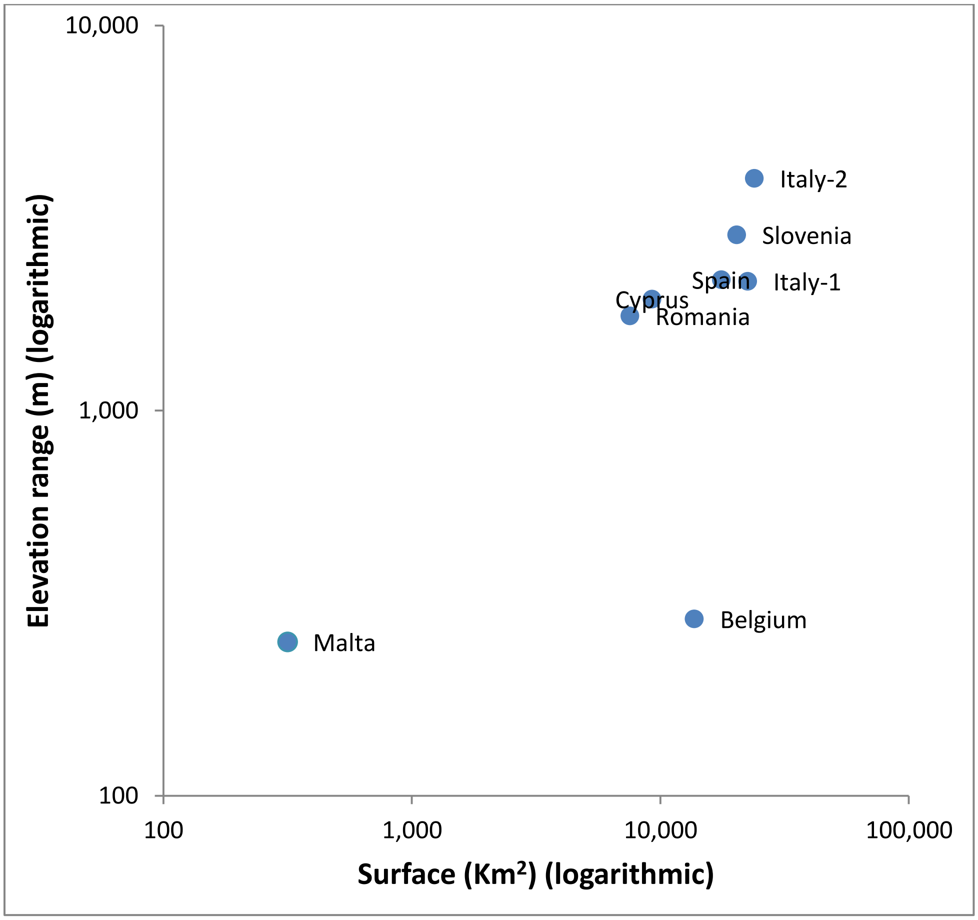


8.4.2 Climate

Table 16. Climate (questions 10 – 12).

	Year(s) of reference of data	*Average precipitations (mm/year)*	*Comments*
Belgium	1981 - 2010	852	Average for Belgium, website www.meteo.be.
Cyprus	1981 - 2010	465	Uneven distribution. More rainfall in the western part and less in the eastern part of the island.
Italy-1	2010	900	Precipitation ranges from 600 (eastern plain) to 2200 mm (western Apennine ridge).
Italy-2	2013	1 300	Strong inter-annual variations (e.g. 2013 extremes from 60 mm/month in June and July to 200 mm/month in May), and geographic differences in the Region from North to South as well as from West to East (e.g. 2013 ranges from weather stations were from 800 mm/y up to over 2200 mm/y).
Malta	1940s till present	550	
Romania	2014	841	
Slovenia	2014	1 957	Many years average precipitations (1991-2010): 1.462 mm/l .
Spain	1940 - 2012	1 229	

Figure 67.Average precipitations.

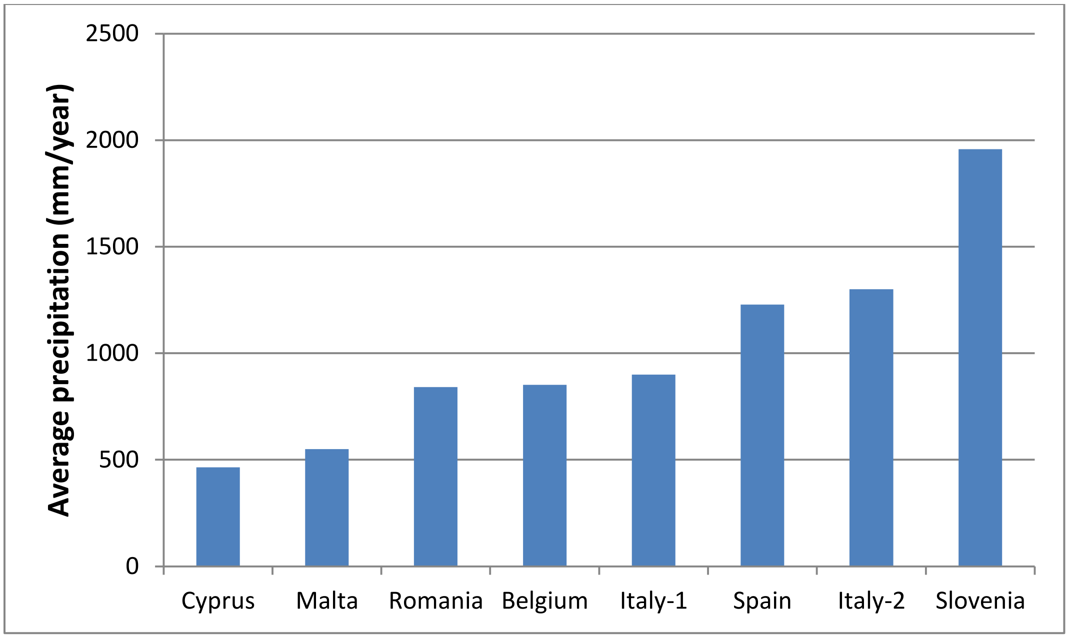
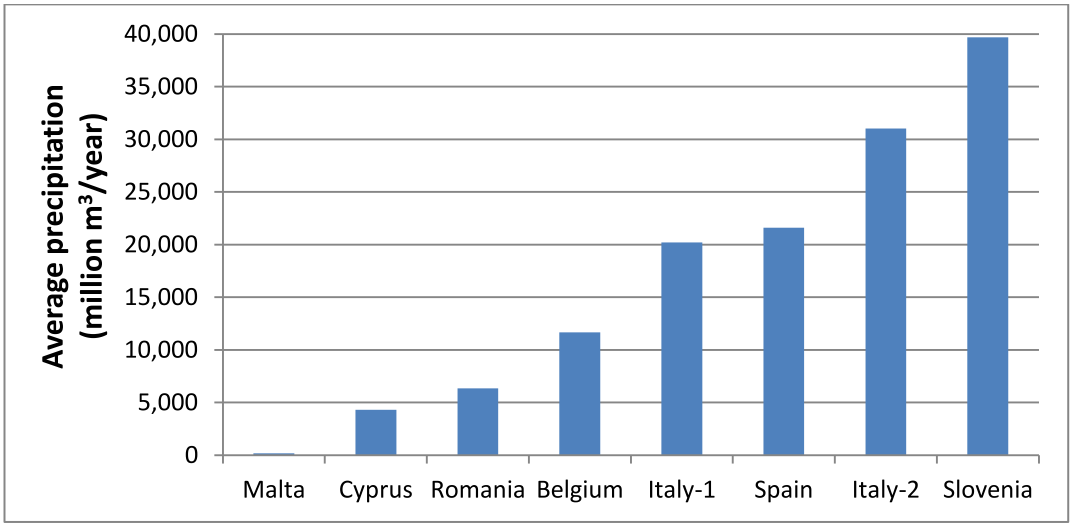


Figure 68. Average precipitations in million m^3 per year.



8.4.3 Population

Table 17. Population (question 13 – 14).

	Year(s) of reference of data	Population
Belgium	2008	(1) 6 161 000
Cyprus	2013	(2)858 000
Italy-1	2014	4 450 541
Italy-2	2014	9 973 397
Malta	2014	425 384
Romania	2012	549 752
Slovenia	2014	2 062 874
Spain	2013	825 851

Notes:

(1) Flanders.

(2) Government controlled areas.

Figure 69. Population.

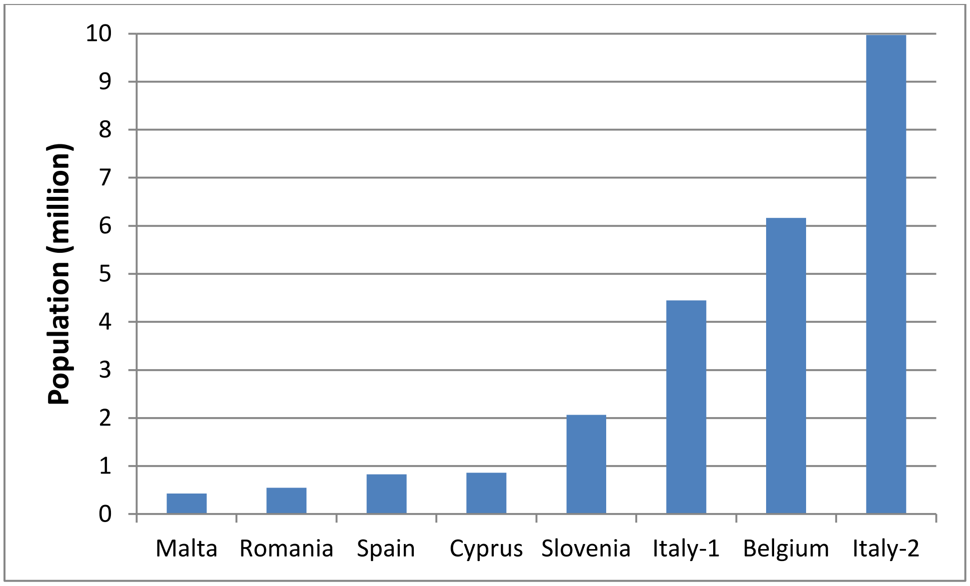
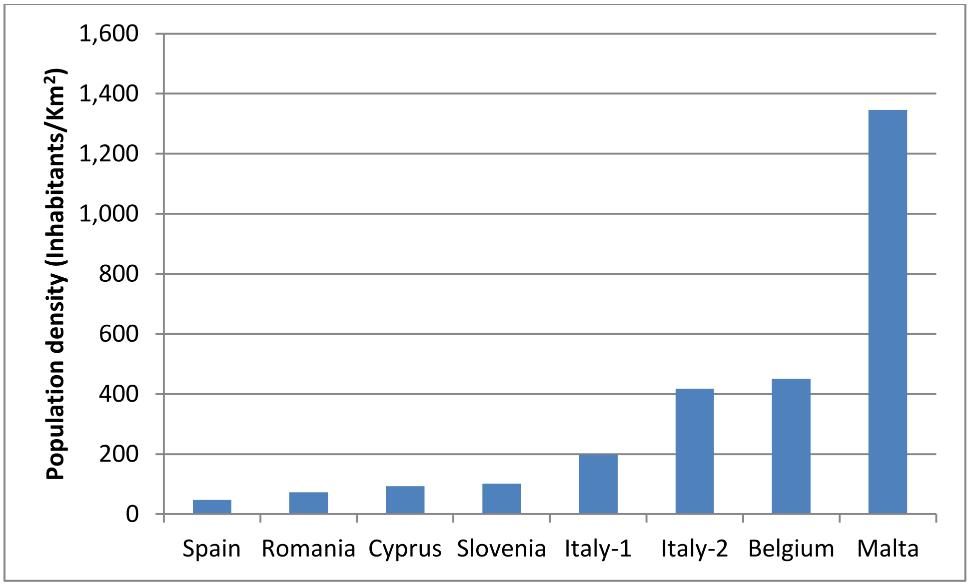


Figure 70. Population density.



8.4.4 Industry

Table 18. Industry (questions 15 – 17).

	Year(s) of reference of data	*Number of plants regulated by Directive IED (Industrial Emissions Directive 2010/75/EU)*	*Comments*
Belgium	2015	1 620	'installations' (industry and agricultural).
Cyprus	2014	77	
Italy-1	2010	850	
Italy-2	2014	1 750	1750 are total IED regulated plants (among them: 732 are IED 6.6, zoothecnical plants); also, strong pressure from non IED industrial plants (e.g: total of more than 800.000 active industrial plants, about 100.000 of them are in manufacture sector), and non IED 6.6 zoothecnical plants (e.g.: total of more than 21.000 farms, with about 1.500.000 cattles and 4.700.000 pigs).
Malta	2014	27	
Romania	2014	29	Out of the total 29 units, 13 units perform poultry and pig growth activities, 5 units perform chemical treatment of metal or plastic surfaces and their processing, 1 waste deposit, 1 thermal power plant, 2 unit produce ceramic products, 2 food industry units, 1 medicine factory, 2 units perform organic compounds production, 1 unit for cement production and 1 oil refinery.
Slovenia	2014	200	Water permit not included in IED permit (separate permit).
Spain	2015	136	Estimated data. 105 is the real number of plants in Galicia´s area of the River Basin District Authority (13.538 km^2 approx).

Figure 71. Number of plants regulated by Directive IED (Industrial Emissions Directive 2010/75/EU).

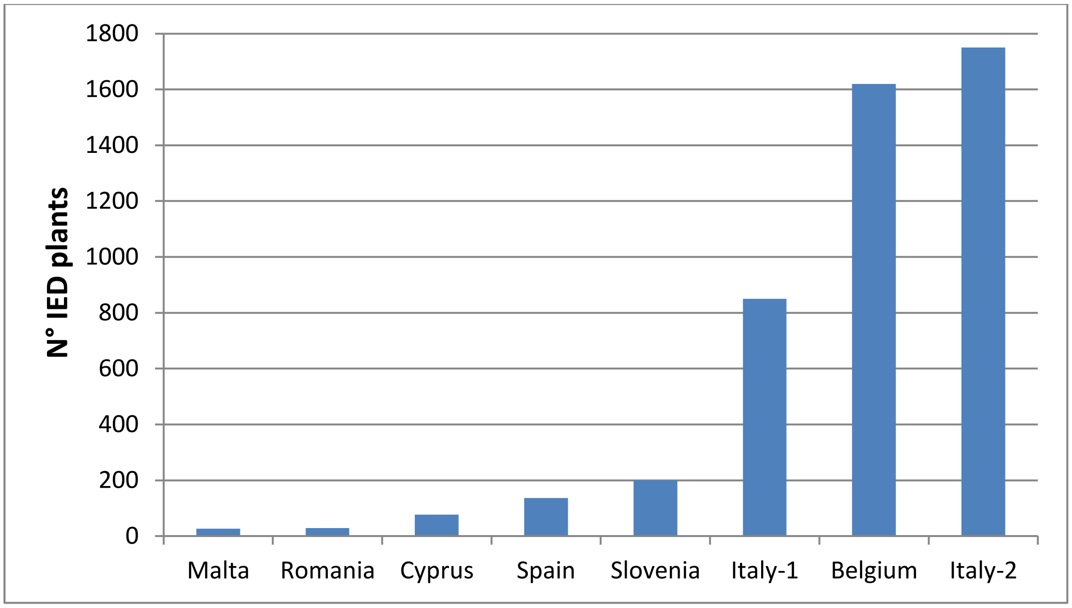
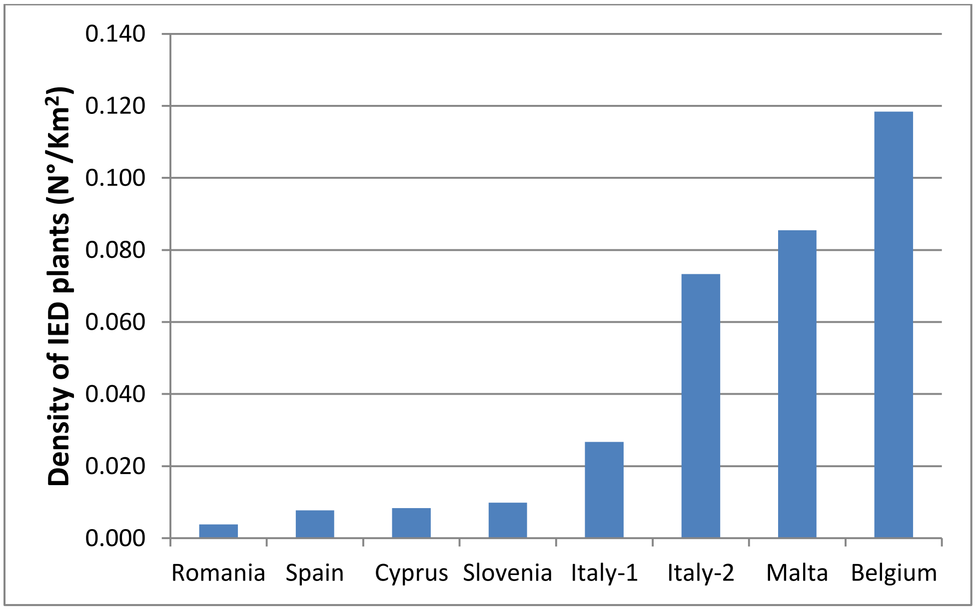


Figure 72. Density of IED plants per Km^2.



8.4.5 Agriculture

Table 19. Agriculture (questions 18 – 24).

	Year(s) of reference of data	Total surface dedicated to agriculture (Km^2)	Main crops	Irrigated surfaces (% over the total surface dedicated to agriculture)	Main irrigation systems in use	Average parcel size (m^2)	Comments
Belgium	2013	6221	Pasture, maize, Wheat, sugar beets, horticulture	2.40%	Irrigation, drip irrigation, sprinkling	na	Department of agriculture
Cyprus							
Italy-1	2010	10 600	Wheat, maize, pasture, horticulture, vineyards and fruit orchards	24.00%	Sprinkler irrigation, drip irrigation, furrow irrigation	10 000	
Italy-2	2010	9 868	Corn (> 50%), rice (approx. 20%), then other cereals (winter wheat, …), permanent crops, pasture.	78.00%	Flow 59%, submersion (rice) 15%, aspersion-spray 25%, drop 1%.	10 400	10400 m^2 is the total LPIS average size (all crops); average corn and rice parcels size is about 15000 m^2.
Malta	2013	129	Forage crops, potatoes, vegetables.	27.00%	Drip Irrigation	1 376	
Romania	2014	4 871	Straw cereals 1013 km^2, hoe cereals 856 km^2, oil plants 490 km^2, forage plants 221 km^2, potatoes 65 km^2, field vegetables 65 km^2, industrial plants 24.2 km^2.	0.04%	Sprinkling, weeping of protected crops (glass-houses, solariums)	na	

	Year(s) of reference of data	***Total surface dedicated to agriculture (Km^2)***	***Main crops***	***Irrigated surfaces (% over the total surface dedicated to agriculture)***	***Main irrigation systems in use***	***Average parcel size (m^2)***	***Comments***
Slovenia	2013	4 770	Lawns, agriculture (corn, wheat), permanent plantations, vegetable.	1.60%	Drip irrigation, spray irrigation, flow irrigation,	3 000	
Spain	2012	3 618	Forage crops, grain cereals, potatoes, vineyard, non-citrus fruit trees.	5.84%	Flood irrigation, spray irrigation.	5 000	

Figure 73. Agricultural surface irrigated and non irrigated and other non agricultural surfaces.

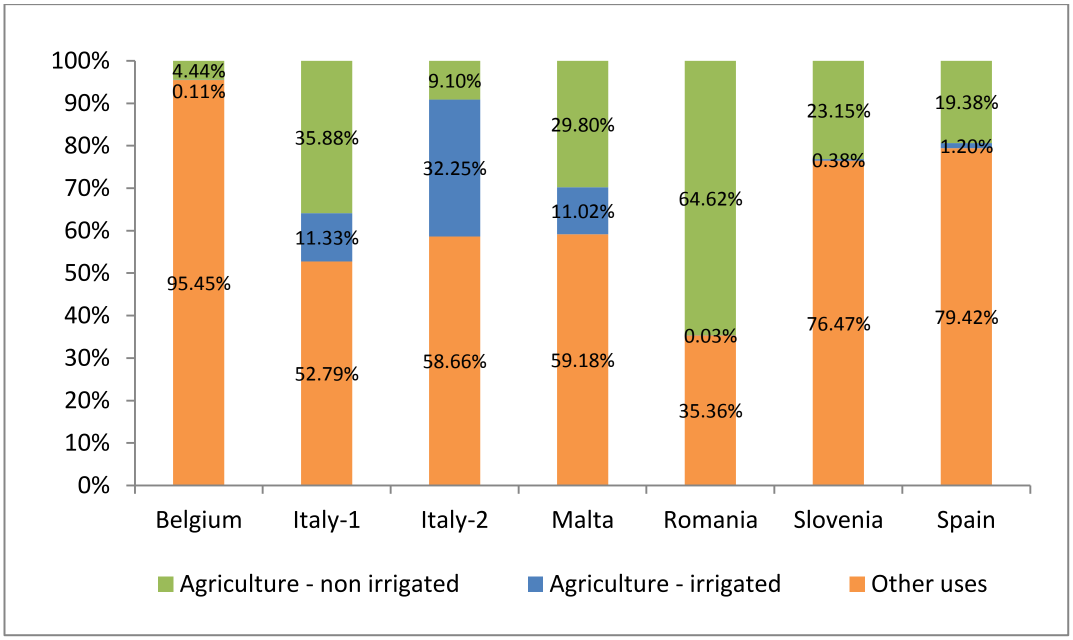
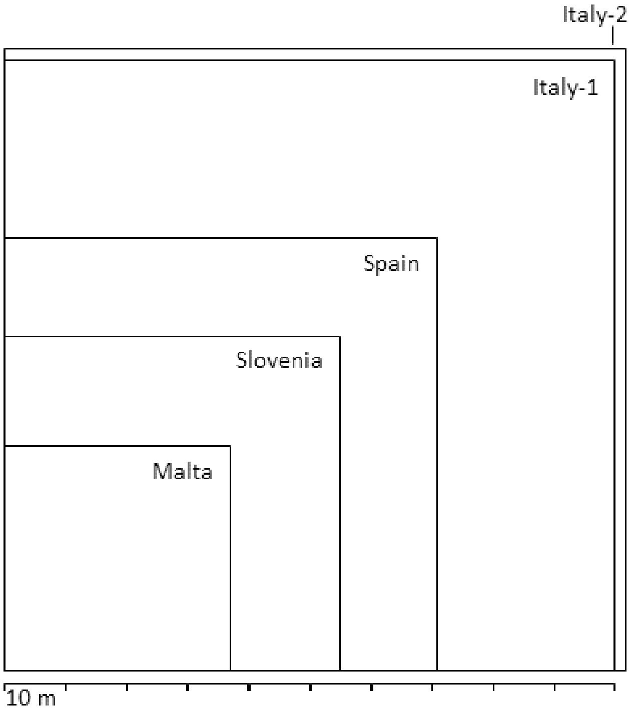


Table 20. Average parcel sizes.

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

Figure 74. Average parcel sizes.



8.5 Water abstraction

8.5.1 Surface water abstraction

Table 21. Surface water abstraction – Total abstraction (questions 25 – 26).

	Year(s) of reference data	*Surface water total abstraction (million m^3/year)*
Belgium	2012	350
Cyprus	2013	115
Italy-1	2010	1 547
Italy-2	2014	120 750
Malta		(1)
Romania	2014	49
Slovenia	2012 if not stated otherwise in specific answer	(2)998
Spain	2014	72 914

Notes:

(1) There are no significant surface water bodies which can be exploited.

(2) The quantity does not include the uses that are exempt from payment for water reimbursement fee (as explained in question 34). Water use for energy production is not included in the above figure, as reported in other units (MWh).

Table 22. Surface water abstraction – Abstraction per use (questions 27 – 32).

	Surface water abstraction for civil uses (%)	*Surface water abstraction for industrial uses (%)*	*Surface water abstraction for hydropower (%)*	*Surface water abstraction for agriculture (%)*	*Other uses (%)*	*Number of permits (for all uses)*
Belgium	45.00%	43.00%	8.00%		4.00%	(1)
Cyprus	50.00%	4.00%	0.00%	46.00%	0.00%	15 000
Italy-1	14.00%	4.00%	na	81.00%	0.00%	
Italy-2	0.08%	2.16%	74.85%	22.49%	0.42%	3 643
Malta						
Romania	7.55%	41.69%	na	50%	na	(2)689
Slovenia	(3)19.00%	(3)4.00%	(3)58.00%	(3)17.00%	(3)2.00%	(4)1 769
Spain	0.09%	0.05%	92.37%	0.45%	7.04%	3 481

Notes:

(1) This is only information for the 'navigable' waterways.

(2) Represents the cumulative total number of permits for both groundwater and surface water.

(3) Information is given for surface water and groundwater together. Civil use: 97% of drinking water is from groundwater and 3% from surface water. Agriculture: 96% from surface and 4% from ground water.

(4) Permits and concessions (no. in May 2014).

Figure 75. Abstraction (%) of surface water per use.

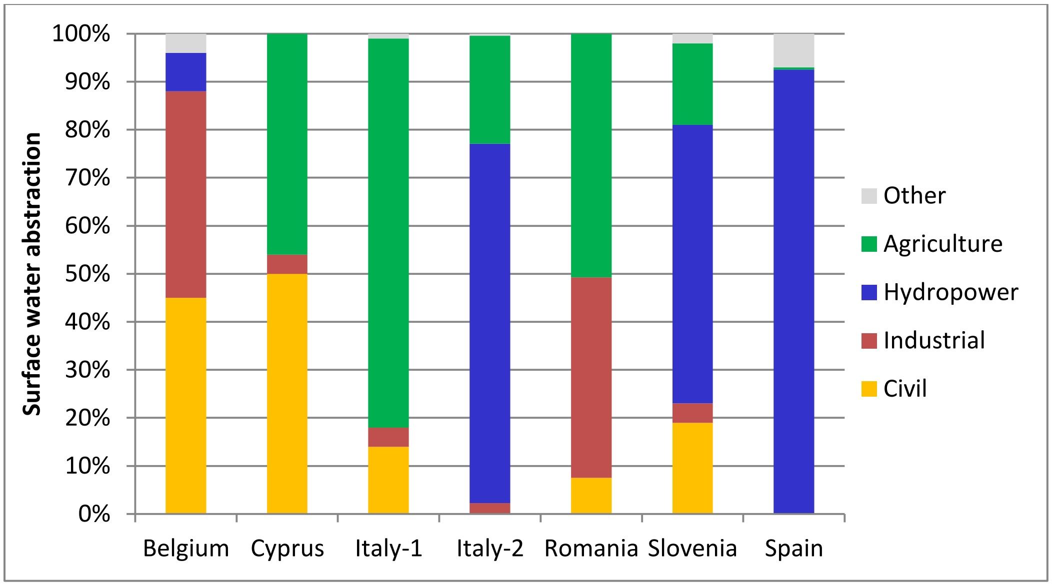


Table 23. Surface water abstraction – Permit criteria (question 33).

	Description of permit criteria
Belgium	A permit is required for abstractions from more than 500 m^3/year, except for abstraction from non-navigable waters. For abstractions less than 500 m^3/year: only a declaration is required.
Cyprus	A permit is required for all types of users.
Italy-1	Unknown to ARPA Emilia Romagna.
Italy-2	Permit is required for all types of user. Distinction in definition, competence and authorization process for “big” or “small” abstractions. the threshold is different, varying from different type of use: use for irrigation: 1000 l/s or 500 ha of irrigated surface. Civil use: 100 l/s. industrial use: 100 l/s hydroelectric use: 3000 kW (average nominal power).
Malta	
Romania	Permit is needed for the following: • any abstraction with flow > 0.2 liters/second; • any construction that modifies the natural water flow regime; • any water treatmemt and waste water treatment plants; • any constructions against the destructive actions of water; • any mineral extraction installation; • any waste deposits; • any panting and deforestration of woody vegetation.
Slovenia	Water law defines that for all water uses exceeding the limits of common use, use of alluvial and underground water is necessary to obtain the water rights on the basis of a water permit, concession or record special water use. The limits setting the obligation to obtain permit or concession will be defined in Regulation on recorder special use of water that is

	Description of permit criteria
	under preparation. Until than every water use exceeding the limits of general use undergoes permitting procedure. A common use includes in particular the use of water for drinking, bathing, diving, skating or other personal needs if such use does not require the use of specific equipment (water pumps, siphon and the like) or construction of a facility for which the permission must be obtained, in accordance with the regulations on spatial planning and construction facilities.
Spain	Permit needed for any flow.

Table 24. Surface water abstraction – Fees criteria (question 34).

	Description of fees criteria
Belgium	In 2012: total fee income of surface water abstraction: 20.45 million euro Fee for 2014: ≤ 500 m^3/year: free 500 m^3/year-1 million m^3/year: 0,069755588 €/m^3 1-10 million m^3/year: 0,040458273 €/m^3 10-100 million m^3/year: 0,02135874 €/m^3 ≥ 100 million m^3/year: 0,004219328 €/m^3
Cyprus	• Agriculture 17c/m^3. • Industry 19c/m^3. • Golf courses, football fields 34c/m^3. • Consumption over allocation 56c/m^3. • Recycled water for agriculture 7c/m^3. • Recycled water for greens 15-21c/m^3. • Potable water 77c/m^3.
Italy-1	
Italy-2	The annual fees are defined by the Region of Lombardy, and are differentiated by use: to calculate the fee, the measure unit for all uses is a flow of 100 l/s (locally this quantity is named "*modulo*"), except for a type of irrigation use (without direct reimbursement " *irriguo a bocca non tassata*"- the most common type of water abstraction for irrigation) for which the measure unit is the hectare (ha) of irrigated area, and for the hydroelectrical use, for which the fee is based on the kilowatt (kW) of average nominal power. The fees are: • drinking water: 2264,5 euro/*modulo* (or 2264,5 euro/100 l/s); • irrigation: 0,53 euro/ha of irrigated surface; • hydroelectric: 15,44 euro/kW (small abstractions, < 3000 kW) o 31,09 euro/kW (big abstractions, > 3000 kW); • industrial: 17480,33 euro/*modulo* (< 3 m^3/sec) o 35237,82 euro/*modulo* (>3 m^3/sec); • other (livestock, hygiene, fire protection, street cleaning, heat pumps, …) : 1132,22 euro/*modulo*.
Malta	
Romania	The Romanian Waters National Administration applies the system of contributions, payments, bonus and penalties specific for water resource management to all water users. The system of contributions, payments, bonuses and penalties are based on the principle that the beneficiary and pollutant pays in accordance with the provided activities as well as on the principle of rational use of water resources. Depending on the use of the water resources bonus can be granted to users who demonstrate concern for the use and protection of water quality or penalties for users identified with deviations from the contractual provisions both in case of exceeding the abstraction limit and discharge pollutants quantities into the water resources.
Slovenia	The water user is liable for the payment of water use as payment for water rights and water reimbursement fee. Payment for water rights: • for granted concession;

	Description of fees criteria
	• for granted water permit (not yet established). Payment for water reimbursement fee - for all granted water rights, with the exemptions as follows: • The use of water from the water source for drinking water supply less than 50 people, if the annual amount of water resource abstraction does not exceed 2,500 m^3 and the water source is not included in the system of public drinking water supply. • The use of water for irrigation of agricultural land, if the annual amount of water resource abstraction does not exceed 5,000 m^3. • The use of water for irrigation of land, non-agricultural land if the annual amount of water resource abstraction does not exceed 50 m^3. • For the production of electricity in hydroelectric power plants up to 10 MW, if the potential energy of water, which is available for the production of electricity in accordance with the acquired water rights annually does not exceed 10 MWh. • Water mill saws or similar devices, where the potential energy of water which is available for mechanical handling in accordance with the acquired right of the water, annually, more than 10 MWh. • To generate heat when energy is available for the withdrawal of heat from the water, does not exceed 10 MWh. • Breeding salmonid species of fish, if available annual amount of water for removal from the water source does not exceed 50,000 m^3. • Breeding cyprinids, where good surface water intended for rearing fish, does not exceed 10,000 m^2. • For fishing in commercial ponds where good surface water intended for the commercial fishing does not exceed 1,000 m^2.
Spain	Fixed fee at the request of the permit.

Table 25. Surface water abstraction – Monitoring method (question 35).

	Description of monitoring method
Belgium	Flowmeters and self-monitoring and time registration.
Cyprus	Flowmeters
Italy-1	Monitoring is very limited, only where water flows in pipes.
Italy-2	Surface water abstraction monitoring is performed by Irrigation Consortia. For all major abstraction data are available in near real-time. The measurements are limited to abstractions from major rivers, while it is not systematic on the minor branches and even less for the actual flow distributed to the users.
Malta	
Romania	
Slovenia	The water permit shall also prescribe the installation of measuring devices for monitoring quantities of abstracted water.
Spain	Flowmeters. Self-monitoring.

Table 26. Surface water abstraction – Information system (questions 36 – 38).

	Are permits organized in an information system ?	***Are abstraction points georeferenced ?***	***Comments***
Belgium	Yes	Yes	
Cyprus	Yes	Yes	
Italy-1			
Italy-2	Yes	Yes	Abstraction points are partially georeferenced. Concerning management of irrigation water: 58% of irrigated surfaces is irrigated by water provided with fixed delivery rounds, while another 20% with on demand delivery; the rest of the area is irrigated with water from direct supply , nearly 15% from surface water and 7% from groundwater.
Malta			
Romania	Yes	No	
Slovenia	Yes	Yes	Information on water use in Slovenia is available in three databases. The first is water book, the other is a database of entities liable to pay water reimbursement fees and the third is database on water rights on the basis of concessions. Water book contains, inter alia, information on the extent of water rights (information on the quantities of permitted use). Water reimbursement fees are in accordance with the Regulation on water reimbursement fees based in majority of services related to water use on the actual water abstraction. For certain services, the basis for payment is quantity of permitted use and not the actual use of water. Entities liable to pay water reimbursement fees which are in accordance with Article 7 of the Regulation on water reimbursement fees exempted from payment (look question 34) and entities whose payment is lower than the administrative costs of billing water reimbursement are not included in the data in questions 26-30. Information in questions 26-30, on the abstraction of water in 2012 are provided on the basis of data on payments of water reimbursement fee. Information is given for surface water and groundwater together. We are providing some additional data on the relationship of usage of ground and surface water in different sectors. Question 27: civil use: 97% of drinking water is from ground water and 3% from surface water. Question 30: abstraction for irrigation: 96% from surface and 4% from ground water.
Spain	Yes	Yes	

8.5.1.1 Illegal surface water abstraction

The partners from Cyprus, Romania, Slovenia and Spain carry out inspections on illegal surface water abstraction.

Table 27. Illegal surface water abstraction – Inspection method (questions 40 – 43).

	Description of inspection method	***Permits inspected per year (% over the number of permits)***	***Cases of illegal surface water abstraction (% over the number of inspected permits)***	***Your assessment of the inspection method***
Cyprus	All flowmeters are sealed. Visual inspection for any interference. Water consumed has to agree with the area and crop type requirements.	100	Very few (illegal tapping on pipelines).	Strong points: visual, stands in court. Weak points: expensive (flowmeters, personnel)
Romania	There is an annual inspection plan that includes only the companies which conduct activities with environmental impact. Other companies are verified based on unplanned inspections. It is verified how the completed construction works on water / under execution on water are operated and maintained/made in accordance with the water management permit. It is also verified how the water users meet their legal obligations regarding the modifications of manufacturing technologies in order to reduce the water consumption, waste water volume and the operation of the waste water treatment plants.	na	na	Weak point: there is no consolidated database available that contains information from all government institutions that relate to the environment, agriculture and industry.
Slovenia	Criteria for defining priorities of inspections: • the water quantity or frequency of use, • the ecologically acceptable rate of flow, • sensitive areas of water flows and particular,	About 120 in special inspection action control	About 20% without water permit (action	Strong points: small territory of RS enables inspectors to be

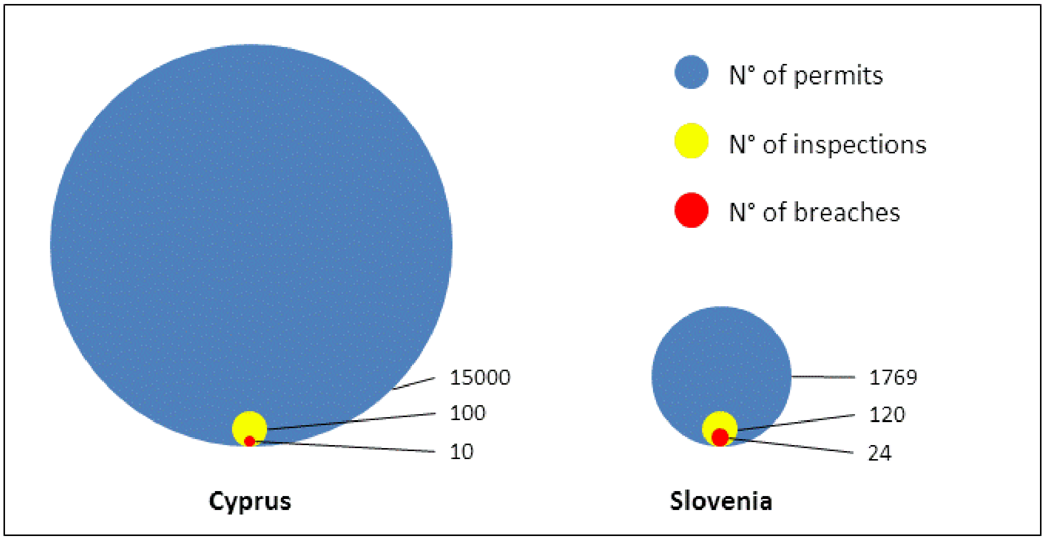
Description of inspection method	*Permits inspected per year (% over the number of permits)*	*Cases of illegal surface water abstraction (% over the number of inspected permits)*	*Your assessment of the inspection method*
• specific conditions of use indicated in a concession or water permit: a1) if concession is needed to be granted: • the production of electricity in a hydroelectric power plant, if it is connected to the public electricity network; • a port, if the investor is a person under public law; • the removal of alluvium, except for the provision of public services pursuant to this Act; • the cultivation of water organisms for the market. a2) if water permit is needed to be granted: • technological purposes; • the irrigation of agricultural land or other areas; • the production of electricity in hydroelectric power plants directly connected to the public electricity network; • propelling water mills, saws or similar installations; • a port, if the investor is a person under public law; • the provision of ski pistes with snow; • the erection of a floating installation pursuant to regulations on maritime navigation and navigational safety on inland waters; • other types of use that exceed general use pursuant to this Act for which a concession does need to be granted; b) monitoring techniques: permanent visual control of river and marine supervisory services, inspection control of permitted installations (conditions in water permits, evidences, control of measurement equipment, yearly reports to the national EPA) Data bases: • Inspection data base: potential larger users of water in industry, larger irrigation	in 2013 (1769 granted permits for abstraction of surface water).	control in 2013).	better informed about potential new water abstractors (information through reported irregularities, media information, about all issued water permits and rejected applications inspectorate is informed by the permit authority). Weak points: not enough inspectors, poor measurement equipment, difficult to control water permit conditions (sometimes not specific enough). Criticalities: surface water abstraction for technological purposes, irrigation in agriculture, in hydroelectric power plants, for cultivation of water organisms – difficult to detect illegal water abstraction without any notification and to prove how much water was illegal abstracted.

	Description of inspection method	*Permits inspected per year (% over the number of permits)*	*Cases of illegal surface water abstraction (% over the number of inspected permits)*	*Your assessment of the inspection method*
	systems, use of artificial snow, hydroelectric power plants. • Using data from the Ministry/Agency: water permit and concession applications, rejected applications. • AJPES data (registered economic activities in RS), Water book data. • Media data.			
Spain	Surveillance.	No data	No data	More technical and human resources are needed.

Table 28. Inspections on surface water permits(are represented the partners whose datasets are complete).

Surface water	**Cyprus**			**Slovenia**		
	N°	**% referred to permits**	**% referred to inspections**	**N°**	**% referred to permits**	**% referred to inspections**
Permits	15 000	100.00%		1 769	100.00%	
Inspections	100	0.67%	100.00%	120	6.78%	100.00%
Breaches	10	0.07%	10.00%	24	1.36%	20.00%

Figure 76. Inspections on surface water permits (are represented the partners whose datasets are complete; the surface of circles is proportional to the number permits, inspections and breaches).



Among the partners that don’t carry out carry out inspections on illegal surface water abstraction, the following think it is an issue in their territory.

Table 29. Illegal surface water abstraction – Opinion of WODA partners that don’t carry out inspections (question 44).

Italy-1	No data available but agricultural surface water abstraction is deemed well above actual needs.
Italy-2	Regarding potential illegal surface water abstraction, probably the most critical issues to investigate are firstly agricultural sector and then industry sector.

8.5.1.2 Legal surface water over-abstraction

The partners from Cyprus, Slovenia and Spain carry out inspections on legal surface water over-abstraction.

Table 30. Legal surface water over-abstraction – Monitoring method (questions 46 - 48).

	Description of the monitoring method	***Description of results***	***Your assessment of the monitoring method***
Cyprus	Each user/plot has an allocation each year (agricultural year). The flowmeter is visited at least twice (start and end of period).	Accurately measure the over-consumption.	Strong points: Visual, stands in court. Weak points: expensive (flowmeters, personnel).
Romania			
Slovenia	The water permit shall also prescribe the installation of measuring devices for monitoring quantities of abstracted water: • Water abstraction in l/s and in m3/year on specific GKK location. • Permanent control of current and total quantity of water abstraction every hour and record of date and time of measurement. • Conditions for Qes. • Once per month operator must control and register abstracted quantity of water. • Rules of procedures. • Other conditions (duration of permit - max for 30 years).	in 2013 inspection action 1 detected over–abstraction from surface waters (27 included in control)	Permit conditions could be more specific, precise ? (interested in permit conditions in other EU member states). Criticalities: Surface water abstraction for technological purposes, in hydroelectric power plants - possible disconnection of meters from time to time, how to detect bypasses ; how to ensure and measure the minimum ecological flow (hydroelectric power plants or, cultivation of water organisms).
Spain	• Meter reading. Monitoring.	Inplementation in process. The monitoring is in the initial state.	The process is initiating. According to initial studies, results are satisfactory.

Table 31. Legal surface water over-abstraction – Opinion of WODA Partners who don’t carry out monitoring (question 50).

Italy-1	Agriculture and industry.
Italy-2	The most critical issue in the mountain areas is hydropower (lack of respect of ecological flow). The most critical issue in the lowland is related to agriculture.
Romania	Over-abstraction is not an issue in Bihor county.

8.5.2 Groundwater abstraction

Table 32. Groundwater abstraction – Total abstraction (questions 50 – 51).

	Year(s) of reference data	*Groundwater total abstraction (million m^3/year)*
Belgium	2012	399
Cyprus	2013	140
Italy-1	2010	652
Italy-2	2006	8 356
Malta	2003 and 2015	29
Romania	2014	30
Slovenia	2012 if not stated otherwise in specific answer	193
Spain	2014	80

Table 33. Groundwater abstraction – Abstraction per use (questions 52 – 56).

	Groundwater abstraction for civil uses (%)	*Groundwater abstraction for industrial uses (%)*	*Grounwater abstraction for agriculture (%)*	*Other uses (%)*	*Number of permits (for all uses)*
Belgium	63.20%	17.10%	16.70%	3.00%	(1)23 000
Cyprus	30.00%	40.00%	66.00%	0.00%	(2)130 000
Italy-1	44.00%	19.00%	37.00%	0.00%	na
Italy-2	41.40%	17.80%	38.50%	2.30%	(3)6 700
Malta	3.40%	3.40%	93.00%	1.70%	7 900
Romania	66.83%	30.25%	2.92%	na	(6)689

	Groundwater abstraction for civil uses (%)	***Groundwater abstraction for industrial uses (%)***	***Grounwater abstraction for agriculture (%)***	***Other uses (%)***	***Number of permits (for all uses)***
Slovenia	(4)	(4)	(4)	(4)	(5)35 976
Spain	32.97%	7.19%	51.76%	8.08%	11 530

Notes:

(1) Approximated.

(2) During the last 50 years (estimated 40% active today).

(3) Refers to permits for irrigation. The total number of permits is not available.

(4) Information is given for surface water and groundwater together. See Table 22. Civil use: 97% of drinking water is from groundwater and 3% from surface water. Agriculture: 96% from surface and 4% from ground water.

(5) Permits and concessions (no. in May 2014)

(6) Represents the cumulative total number of permits for both groundwater and surface water.

Figure 77. Groundwater abstraction (%) per use.

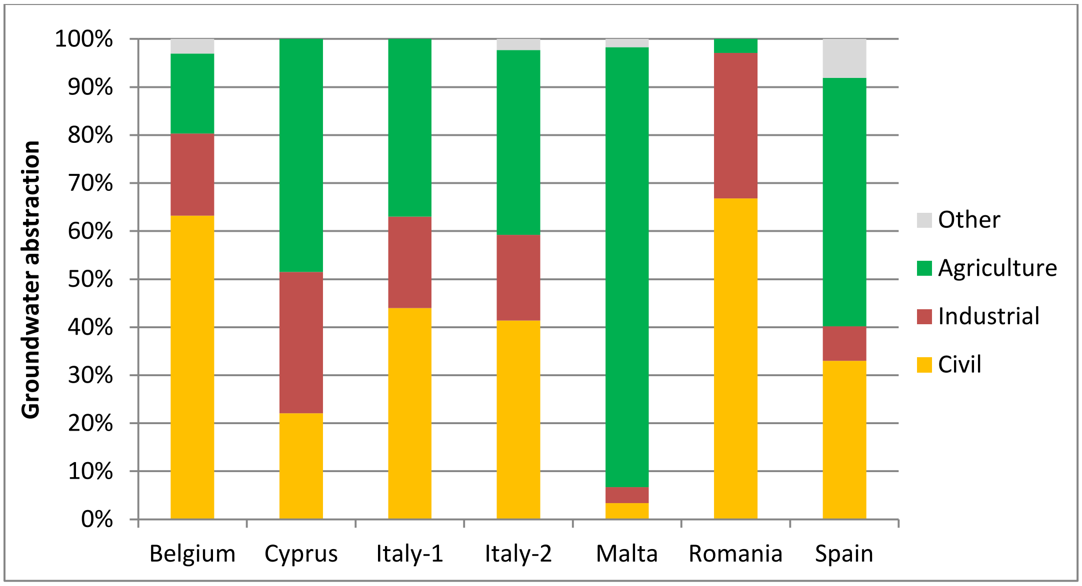


Table 34. Groundwater abstraction – Permit criteria (question 57).

	Description of permit criteria
Belgium	For vulnerable groundwater layers, a permit is needed in every case (category 2 if the abstraction is between 0 and 30 000 m³/year, category 1 if the abstraction exceeds 30 00m³/year. In non vulnerable groundwater layers, a permit is needed if the abstraction exceeds 5.000 m³/year (category 2 between 5. 000 and 30 .000 m³/year, category 1 if > 30.000 m3/year is abstracted. From the 23000 permits for groundwater abstraction we have 600 permits for abstraction of > 30.000 m^3/year and 134 permits for abstraction > 500.000 m^3/year.
Cyprus	All abstraction points need a license.
Italy-1	
Italy-2	Permit is required for all types of user. Distinction in definition, competence and authorization process for "big" or "small" abstractions. the threshold is different, varying from different type of use: use for irrigation: 1000 l/s or 500 ha of irrigated surface. Civil use: 100 l/s. industrial use: 100 l/s.
Malta	Owners of private groundwater sources are not given a permit but are obliged to register their groundwater source. Registering a groundwater source does not entitle the owner to abstract groundwater.
Romania	Permit is needed for any abstraction with a flow greater than 0.2 litre/second. Other criteria might be applicable just as defined for surface waters.
Slovenia	Water law defines that for all water uses exceeding the limits of common use, use of alluvial and underground water is necessary to obtain the water rights on the basis of a water permit, concession or record special water use. The limits setting the obligation to obtain permit or concession will be defined in Regulation on recorder special use of

	Description of permit criteria
	water that is under preparation. Until than every water use exceeding the limits of general use undergoes permitting procedure. A common use includes in particular the use of water for drinking, bathing, diving, skating or other personal needs if such use does not require the use of specific equipment (water pumps, siphon and the like) or construction of a facility for which the permission must be obtained, in accordance with the regulations on spatial planning and construction facilities.
Spain	Owner > 7.000 m^3/year Non-owner: Any value.

Table 35. Groundwater abstraction – Fees criteria (question 58).

	Description of fees criteria
Belgium	Fee since 1997: 3 categories: • groundwater abstraction for the production of drinkingwater (public sector): 7.5 eurocent/m^3; • category groundwater abstraction in non vulnerable groundwater layers > 500 m^3/y and < 30.000 m^3/y: 5-6 eurocent/m^3; • category groundwater abstraction in vulnerable groundwater layers and > 30.000 m^3/y in non vulnerable groundwater layers: a minimum (fee/m³ is increasing with increasing amount of abstracted groundwater) of 6.2 eurocent/m^3 + local specific factor.
Cyprus	In progress. To be charged for resource and environment costs (about 2- 5 c/m3)
Italy-1	As for surface water.
Italy-2	The annual fees are defined by the Region of Lombardy and are differentiated by use: to calculate the fee, the measure unit for all uses is a flow of 100 l/s (locally this quantity is named "*modulo*"), except for a type of irrigation use (without direct reimbursement " *irriguo a bocca non tassata*"- the most common type of water abstraction for irrigation) for which the measure unit is the hectare (ha) of irrigated area. The fees are: • drinking water: 2264,5 euro/*modulo* (or 2264,5 euro/100 l/s); • irrigation: 0,53 euro/ha of irrigated surface; • industrial: 17480,33 euro/*modulo* (< 3 m^3/sec) o 35237,82 euro/*modulo* (>3 m^3/sec); • other (livestock, hygiene, fire protection, street cleaning, heat pumps, …) : 1132,22 euro/*modulo*.
Malta	Owners of private groundwater sources pay a onetime registration fee. The fee is a standard fee that applies to all users. Apart from that owners of private groundwater sources also incur the annual operation and maintenance costs.
Romania	
Slovenia	The water user is liable for the payment of water use as payment for water rights and water reimbursement fee. Payment for water rights: • for granted concession; • for granted water permit (not yet established). Payment for water reimbursement fee - for all granted water rights, with the exemptions as follows: • the use of water from the water source for drinking water supply less than 50 people, if the annual amount of water resource abstraction does not exceed 2,500 m^3 and the water source is not included in the system of public drinking water supply; • the use of water for irrigation of agricultural land, if the annual amount of water resource abstraction does not exceed 5,000 m^3; • the use of water for irrigation of land, non-agricultural land if the annual amount of water resource abstraction does not exceed 50 m^3.
Spain	Fixed fee at the request of the permit.

Table 36. Groundwater abstraction – Monitoring method (question 59).

	Description of monitoring method
Belgium	The Flemish permit data are not referenced to fee data. Monitoring via administrative data (yearly reports from the companies), company visits, information from seeling of flowmeters, linking data from different organisations,…
Cyprus	Flowmeter on each borehole.
Italy-1	
Italy-2	When granting permission (in particular for major abstractions) it is typically prescribed by the competent authority to install flowmeters for self-monitoring. Also, controls could be performed by competent authorities, using also ARPA for technical support.
Malta	Monitoring of groundwater abstraction is still its initial phases. Flow meters are currently being installed on all significant groundwater sources. These flow meters are equipped with an RF module that remotely transmits the data being collected.
Romania	Quantitative monitoring of groundwater bodies. Qualitative monitoring of groundwater bodies: • surveillance program with a total of 276 sections throughout the hydrographic basin, • operational program with a total of 65 sections throughout the hydrographic basin.
Slovenia	The water permit shall also prescribe the installation of measuring devices for monitoring quantities of abstracted water.
Spain	Flowmeters. Selfmonitoring.

Table 37. Groundwater abstraction – Information system (questions 60 – 62).

	Are permits organized in an information system ?	***Are abstraction points georeferenced ?***	***Comments***
Belgium	Yes	Yes	Permits can be publicly consulted: http://dov.vlaanderen.be/, administration has access to more detailed data.
Cyprus	Yes	Yes	
Italy-1			
Italy-2	Yes	Yes	Abstraction points are partially georeferenced.

	Are permits organized in an information system ?	***Are abstraction points georeferenced ?***	***Comments***
Malta	Yes	Yes	
Romania	Yes	No	
Slovenia	Yes	Yes	Information in questions 26-30 and in questions 52-55, on the abstraction of water in 2012 are provided on the basis of data on payments of water reimbursement fee. Information is given for surface water and groundwater together. We are providing some additional data on the relationship of usage of ground and surface water in different sectors. Civil use: 97% of drinking water is from ground water and 3% from surface water. Abstraction for irrigation: 96% from surface and 4% from ground water.
Spain	Yes	Yes	

8.5.2.1 Illegal groundwater abstraction

The partners from Belgium, Cyprus, Romania, Slovenia and Spain carry out inspections on illegal surface water abstraction.

Table 38. Illegal groundwater abstraction – Inspection method (questions 64 – 67).

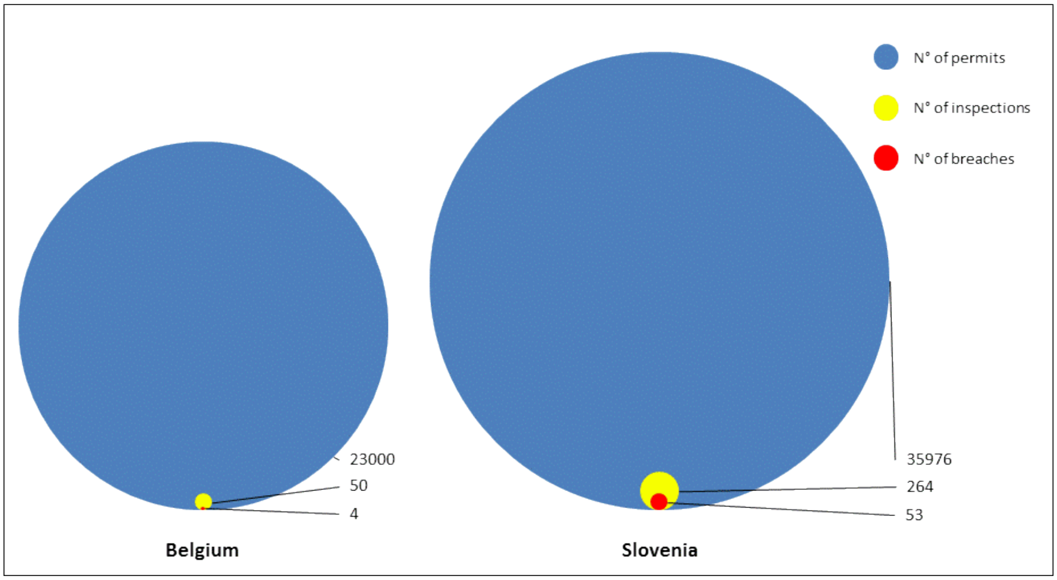
	Description of inspection method	***Permits inspected per year (% over the number of permits)***	***Cases of illegal groundwater abstraction (% over the number of inspected permits)***	***Your assessment of the inspection method***
Belgium	Administrative data (yearly reports from the companies), company visits, information from other organisations, linking data from different organisations with our own data,…	An average of 50/ year (from the 730 category 1 permits).	8% in 2014 (39 company visits).	We use checklists to ensure that every aspect of legislation is inspected. We actualize the checklist when weak points are observed.
Cyprus	Every borehole must have a licence (maximum amount of water to be extracted per year, flowmeter). Site visits.	>5000 m^3/year, visited twice per year.		<u>Strong points</u>: Visual, stands in court. <u>Weak points</u>: Expensive (flowmeters, personnel).
Romania	As for surface water.	na	na	Very difficult since there is no information available other than the water permit. There is a weak collaboration between the National Environmental Guard and the Romanian Waters National Administration. Low number of human resources within the National Environmental Guard compared to the number of locations to be inspected.

	Description of inspection method	***Permits inspected per year (% over the number of permits)***	***Cases of illegal groundwater abstraction (% over the number of inspected permits)***	***Your assessment of the inspection method***
Slovenia	a) criteria for the selection of permits to be inspected - use of inspection data base - potential larger water abstractors: a1) if concession is needed to be granted: -the production of beverages; -the needs of bathing areas and such like, if the use involves mineral, thermal or thermo-mineral water; a2) if water permit is needed to be granted: • The private supply of drinking water or the supply of drinking water provided as a commercial public service; • Technological purposes; • The activity of bathing areas and natural health spas pursuant to healthcare regulations; • the extraction of heat; • the irrigation of agricultural land or other areas; • the provision of ski pistes with snow; • other types of use that exceed general use pursuant to this Act for which a concession does need to granted; b) monitoring techniques: inspection control of permitted installations (evidences, measurement equipment, yearly reports to EPA),inspection control of non permitted installations, reported irregularities.	About 264 in inspection action control in 2013 (35976 granted permits for abstraction of groundwater) * 50 environmental inspectors carry out inspections in the whole field of environmental protections (water management, emissions to water, air, noise, waste management, nature protection, management of genetically modified organisms).	About 20% without water permit (action control in 2013).	<u>Strong points</u>: small territory of RS enables inspectors to be better informed about potential new water abstractors (many information through reported irregularities, media information, about all issued water permits and rejected applications inspectorate is informed by the permit authority) <u>Weak points</u>: not enough inspectors, pure measurement equipment, how to detect possible bypasses <u>Criticalities</u>: Groundwater abstraction for technological purposes, irrigation of agriculture or other areas - possible disconnection of meters from time to time, how to know if all boreholes are registered, possible bypasses.
Spain	Surveillance.	No data	No data	

Table 39. Inspections on groundwater permits (are represented the partners whose datasets are complete).

Groundwater	Belgium			Slovenia		
	N°	% referred to permits	% referred to inspections	N°	% referred to permits	% referred to inspections
Permits	23 000	100.00%		35 976	100.00%	
Inspections	50	0.22%	100.00%	264	0.73%	100.00%
Breaches	4	0.02%	8.00%	53	0.15%	20.00%

Figure 78. Inspections on groundwater permits (are represented the partners whose datasets are complete; the surface of circles is proportional to the number permits, inspections and breaches).



Among the partners that don’t carry out carry out inspections on illegal surface water abstraction, the following think it is an issue in their territory.

Table 40. Illegal groundwater abstraction – Opinion of WODA partners who don’t carry out inspections (question 68).

Italy-1	For sure unreported wells are used in agricultural areas, no data available.

Italy-2	The most critical issues to investigate are firstly agricultural sector and then industry sector.
Malta	Inspections on illegal groundwater abstraction are carried out by the Malta Resources Authority. It is noted that when an illegal groundwater abstraction source is encountered, the case is immediately referred to the police, which may instigate criminal proceedings. Site inspections are undertaken in all cases where the presence of illegal groundwater abstraction sources is reported to the regulatory authorities or the police.

8.5.2.2 Legal groundwater over-abstraction

The partners from Cyprus, Slovenia and Spain carry out inspections on legal groundwater over-abstraction.

Table 41. Legal groundwater over-abstraction – Monitoring method (question 70 – 72) .

	Description of the monitoring method	***Description of results***	***Your assessment of the monitoring method***
Belgium	The checklists together with the company visits reveal illegal abstraction and over-abstraction. Permits include a maximum that can be extracted. Flowmeters and logbooks are checked to reveal over-abstraction.	In 2014, 2 of the 39 company visits revealed over-abstraction.	We use checklists to ensure that every aspect of legislation is inspected. We actualize the checklist when weak points are observed.
Cyprus	Every borehole must have a licence (maximum amount of water to be extracted per year, flowmeter). Site visits.		Strong points: visual, stands in court. Weak points: expensive (flowmeters, personnel).
Italy-2	In general, in support to competent authorities, for major abstraction controls.		
Slovenia	The water permit shall also prescribe the installation of measuring devices for monitoring quantities of abstracted water: • water abstraction in l/s and in m3/year on specific GKK location; • at outlet of borehole a measurement	Abstraction from groundwater (60 included in control).	Permit conditions could be more specific, precise ? (interested in other permit conditions).

	Description of the monitoring method	*Description of results*	*Your assessment of the monitoring method*
	equipment must be installed for current and total control of abstracted water; both measurement must be performed every hour; • all data (daily and hourly) must be recorded on borehole and observable borehole (if prescribed in specific cases); • monitoring of groundwater level is obligatory; • yearly diagram of all measurements must be sent to EPA; • on observable borehole operator must allow EPA to perform national monitoring measurements; • other rules of procedure; • other conditions (duration of permit - max for 30 years).		
Spain		Implementation in process. The monitoring is in the initial state.	

Table 42. Legal groundwater over-abstraction – Opinion of WODA Partners who don't carry out monitoring (question 73).

Cyprus	Not an issue
Italy-1	For sure we are exploiting subsurface water (even fossil aquifers) unsustainably, in recent years though higher than normal precipitation partially compensated this.
Italy-2	Regarding potential legal groundwater abstraction, probably the most critical issues to investigate are firstly agricultural sector and then industry sector. The number of known wells for irrigation is high and shows a quite high increase in the years, creating problems for the control of the total abstraction. The monitoring of the actual abstraction is not systematic and consequently the available values are derived mainly from estimates.
Malta	At this stage accurate statistics for groundwater abstraction in Malta are not available. It is however to be noted that all significant private groundwater abstraction sources are in the process of being metered for the purpose of monitoring groundwater abstraction. This process, once finalised, will enable the undertaking of a comparative analysis between the volume of groundwater abstracted from legal groundwater sources and the estimated total demand of the sectors and the development of statistics.
Romania	na
Slovenia	Groundwater abstraction for technological purposes, thermal-heating, irrigation systems,…- possible disconnection of meters from time to time, bypasses?

Spain	I think legal groundwater over-abstraction isn't an issue in my territory.

8.6 Criticalities

8.6.1 Drought events

Table 43. Drought events (questions 74 – 76).

	Has your territory been subject to relevant drought events since 2000 ?	*Which types of effects ?*	*Comments*
Belgium	No		In the abstraction permits is included that in periods of prolonged drought the abstraction can be limited or suspended temporarily.
Cyprus	Yes	Not enough water to sustain the permanent crops. No water available for seasonal crops.	
Italy-1	Yes	Damages to crops, lower yields, difficulties in drinking water distribution, and for hydropower plants.	Climatic variability is rising, droughts need monitoring and management, this type of service is now implemented at the regional and river catchment level, ARPA Emilia Romagna provides data and assistance.
Italy-2	Yes	in general: water user conflicts were reported; damages to yield, minimum ecological flow rate not respected, local problems in drinking water supplies, lower hydropower production, lower touristic fruition (lake areas).	
Malta	Yes	Malta is in a prolonged state of drought. This is further exacerbated by the effects of climate change which are leading to a reduction in rainfall and increasing temperatures. These conditions limit the availability of water given the high evapotranspiration rates, which in turn reduces the amount of water available to replenish the aquifer.	
Romania	Yes	Corn, canola and barley crops impacted by droughts (production decreased between 20-25%).	
Slovenia	Yes	Agricultural droughts. Shortages in drinking water	Major damage due to droughts events has occurred 12 times since 1990, of which 9 times

	Has your territory been subject to relevant drought events since 2000 ?	***Which types of effects ?***	***Comments***
		supply in south eastern part of Slovenia.	since 2000. Droughts in 2000, 2001, 2003, 2006, 2007, 2012 and 2013 reached the dimensions of a natural disaster. The estimated direct damage exceeded 0.3 ‰ of revenues of the state budget, which is a necessary condition for assistance in accordance with the natural disasters law. Agricultural droughts that are becoming more frequent and more intense over the last ten years. The incidence varies in time and regionally from year to year. The fact is that in addition to affecting the most vulnerable regions of north-eastern and south-western Slovenia it affects also other parts of Slovenia. Shortages in drinking water supply in south eastern part of Slovenia during summer months are combination of increased demand due to high touristic season and droughts.
Spain	Yes	Water users conflicts.	

8.6.2 Soil subsidence

Table 44. Soil subsidence (questions 77 – 80).

	Have soil subsidence been noticed in your territory	*Maximum rate of subsidence (mm/year)*	*Which causes ?*	*Comments*
Belgium	Yes		Ex coalmine sites.	Local issue in the county of Limburg.
Cyprus	No			
Italy-1	Yes	Over 30 mm/year during the period: 2006-2011	Groundwater over-abstraction, hydrocarbon abstraction (natural gas, shale gas, oil,...), tectonics.	
Italy-2	Yes	10	Groundwater over-abstraction, hydrocarbon abstraction (natural gas, oil,...), Underground Gas Storage (UGS) facilities, landslides, compaction.	Subsidence is often a very local phenomenon. Subsidence may also be due to several concurrent causes; in some case, there is no evidence of subsidence in the long term, but there are evidences of seasonal variations.
Malta	No			
Romania	No			
Slovenia	No			
Spain	No			

8.6.3 Other criticalities

Table 45. Other criticalities (question 81).

	Description
Belgium	Some groundwater bodies are in a bad quantitative status.
Cyprus	
Italy-1	Very complex governance of water due to the high number of laws and public bodies involved implies difficulties in monitoring and law enforcement.
Italy-2	Concerning water management, many different levels of organization and decision making, fragmentation of competences, different boundaries between water basins and administrative limits at various level (Provinces, Regions,..); too many public bodies involved (permit release and control / management / monitoring ..).
Malta	
Romania	
Slovenia	Information about soil subsidence is not available. Other criticalities: a) Surface water over-abstraction and minimal ecological flow (endangering the survival of riverine ecosystem (problem of dry riverbed): could the EO technologies be used in support of control of extreme over abstraction e.g. dry riverbeds? Have this problem been noticed in your territory? Conditions in water permit? b) Oil or natural gas extraction from underground and influence on groundwater or on soil subsidence: Have this problems been noticed in your territory? Conditions in water permit?
Spain	

8.7 Auxiliary data availability

Table 46. Auxiliary data availability – Part 1 (questions 82 – 87).

	Are agricultural parcels organized in a Geographic Information System ?	*Comments*	*Are meteorological data available from a meteorological monitoring network ?*	*Comments*	*Are water-table level data available from a piezometer network ?*	*Comments*
Belgium	Yes		Yes		Yes	
Cyprus	Yes		Yes		Yes	
Italy-1	Yes	The land GIS is managed mainly for administrative purposes by AGEA, other information systems with different levels of detail are also available (Regione Emilia Romagna, ARPA Emilia Romagna).	Yes	The newtwork is managed by ARPA Emilia Romagna and it includes more than 300 stations and about one thousand sensors (temperature, precipitation, river level, air humidity, solar radiation, wind speed and direction, soil moisture and temperature etc.).	Yes	There are at least three network, one for deep aquifers (ARPA Emilia Romagna) and one for shallow ones (Regione Emilia Romagna/Cer). Surface soil moisture is also monitored by ARPA Emilia Romagna.

	Are agricultural parcels organized in a Geographic Information System ?	***Comments***	***Are meteorological data available from a meteorological monitoring network ?***	***Comments***	***Are water-table level data available from a piezometer network ?***	***Comments***
Italy-2	Yes	Pretty good knowledge of land use parcel and agricultural use, difficulties in matching water abstraction from rivers through irrigation systems and the effective water supplies on the ground (lack of knowledge about efficiency in water distribution, etc…).	Yes	Regional authomatic weather stations network is managed by ARPA Lombardia, for a total of more than 300 stations.	Yes	Quantitative regional groundwater network is managed by ARPA Lombardia, for a total of approximately 150 stations; the main constraints are that data are not available in real time; these stations are part of the wider qualitative regional groundwater network (approx. 300 stations); in general, data measurements are monthly or seasonally.
Malta	Yes		Yes	As from 2008 air temperature, precipitation, humidity, wind velocity and solar radiation are available for the whole country from a dedicated meteorological monitoring network. Data on air temperature and precipitation is also available for most of the island from the 1940s till the present day.	Yes	
Romania	No		No		No	

	Are agricultural parcels organized in a Geographic Information System ?	*Comments*	*Are meteorological data available from a meteorological monitoring network ?*	*Comments*	*Are water-table level data available from a piezometer network ?*	*Comments*
Slovenia	Yes		Yes		Yes	
Spain	Yes		Yes		Yes	

Table 47. Auxiliary data availability – Part 2 (questions 88 - 93).

	Are crop water requirements for the main crops available ?	*Comments*	*Are data on current crop phenological state available ?*	*Comments*	*Are data on soil subsidence available ?*	*Comments*
Belgium	Yes		No	I don't know if this data are available.	Yes	I think these data are available
Cyprus	Yes				No	Due to the geology of Cyprus, there is no way to relate soil subsidence with water overabstraction.
Italy-1	Yes	Please refer to regional "disciplinari di produzione integrata" (integrated crop production guidelines)	Yes	no more surveys, but there is a phenology station in Bologna (University) and a phenological garden at the "Giorgio Fea" weather centre (Arpa)	Yes	Remote sensing and GPS technologies are used.

	Are crop water requirements for the main crops available ?	***Comments***	***Are data on current crop phenological state available ?***	***Comments***	***Are data on soil subsidence available ?***	***Comments***
Italy-2	Yes	General theoretical CWR estimations are available.	Yes	Partially: these kind of information are in general estimated for agrometeorological application and approach, not directly from field surveys.	Yes	Not from GPS network. Some data about subsidence are available partially in time and space. From a regional point of view, information in the past is available for the whole region from SAR interpherometry. Locally, more detailed and updated SAR interferometry analysis are available nearby Underground Gas Storage sites in small part of the lowlands.
Malta	Yes	Crop water requirements for the hydro-climatic conditions of the Maltese islands were modeled through CROPWAT, which a crop water requirement modelling tool developed by the Food and Agricultural Organisation.	No		No	
Romania	No		No		No	
Slovenia	Yes		Yes		No	Information not available.

	Are crop water requirements for the main crops available ?	***Comments***	***Are data on current crop phenological state available ?***	***Comments***	***Are data on soil subsidence available ?***	***Comments***
Spain	Yes		Yes		No	

8.8 Earth Observation experiences

Table 48. Earth Observation experiences (questions 94 – 95).

	Mapping reservoirs	*Mapping crop types*	*Mapping irrigated areas*	*Mapping crop water requirements*	*Monitoring irrigation requirements*	*Monitoring soil subsidence*	*Other*	***Comments***
Belgium								The Environmental Inspection Division has no Earth Observations experiences.
Cyprus	√	√	√					Difficulties because of: • the small parcel size; • mixed crops in one parcel; • many sources of water in one parcel.
Italy-1	√	√				√		ARPA Emilia Romagna is now involved in the H2020 Moses project (2015-18) aiming at the monitoring of irrigated areas and irrigation requirements using weather forecasts and remote sensing technologies.
Italy-2	√	√	√	√		√		Earth Observation applications are currently operational in different environmental monitoring activities. EO for legal and illegal water over-abstraction detection and assessment in Lombardy is a new “challenging” task.
Malta								Currently Earth Observation is not being used as a tool to monitor or identify legal and illegal groundwater abstraction.
Romania								No Earth Observation experiences.
Slovenia								no Earth Observation experiences
Spain	√		√					