Remote Sensing

con il patrocinio di

14° Workshop tematico di Telerilevamento

TELERILEVAMENTO APPLICATO ALLA GESTIONE DELLE RISORSE IDRICHE

6-7 Giugno 2024

Bologna

Oratorio San Filippo Neri - Via Manzoni 5

A cura di
Elena Candigliota e Francesco Immordino

ENEA

Divisione Modelli e Tecnologie per la Riduzione degli Impatti Antropici e dei Rischi Naturali.

Dipartimento Sostenibilità dei Sistemi Produttivi e Territoriali.

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SOMMARIO

THE ITALY FLOODS IN 2023, THE COSMO-SKYMED SATELLITE SUPPORT DURING THE EMERGENCY

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Keywords: Flood, COSMO-SkyMed, Emergency, Map Italy

Abstract
The COSMO-SkyMed (COnstellation of small Satellites for Mediterranean basin Observation) Mission is the largest Italian investment in Space Systems for Earth Observation, commissioned and funded by the Italian Space Agency (ASI) and the Italian Ministry of Defence (MoD). The constellation initially consisted of four identical satellites, each equipped with SAR in X-band, positioned in a synchronous orbit at ~ 620 km above the Earth's surface. Following the four COSMO-SkyMed First Generation satellites (CSK), the mission is continuing with the COSMO-SkyMed Second Generation (CSG) satellites which is based on another group of four identical satellites, again each equipped with an X-band SAR payload and positioned on the same orbital plane of the CSK satellites. CSG aims at providing service continuity to the first generation, while improving performances, functionalities and system services for the users' community. CSG has introduced or improved features like response time, last minute planning, near real time data delivery and on-demand area coverage (M.Virelli et al., 2023).

The constellation was originally designed for provision of institutional support to disaster and emergency management. Although over the years the constellation proved to serve many more applications (e.g. structural stability of buildings ad infrastructure, maritime surveillance, glacier monitoring, conservation of cultural heritage), support during emergencies remains a key feature for COSMO-SkyMed and that the constellation is sought for also by other countries and for international efforts of disaster mapping. Ra-pidity of acquisition under any weather conditions is for sure the essential property required during emer-gencies, alongside the availability of pre-event images to use for change detection and impact assessment. In this respect, very pioneering was the decision of creating a regularly updated interferometric archive over Italy, according to the specific needs of the Civil Protection Department (DPC). To this purpose, in 2009 the ASI activated the Map Italy project, a full interferometric mapping service of the whole National territory based on every-16 days Stripmap Himage acquisitions, both in Ascending and Descending orbit directions, using the COSMO-SkyMed system (Figure 1).

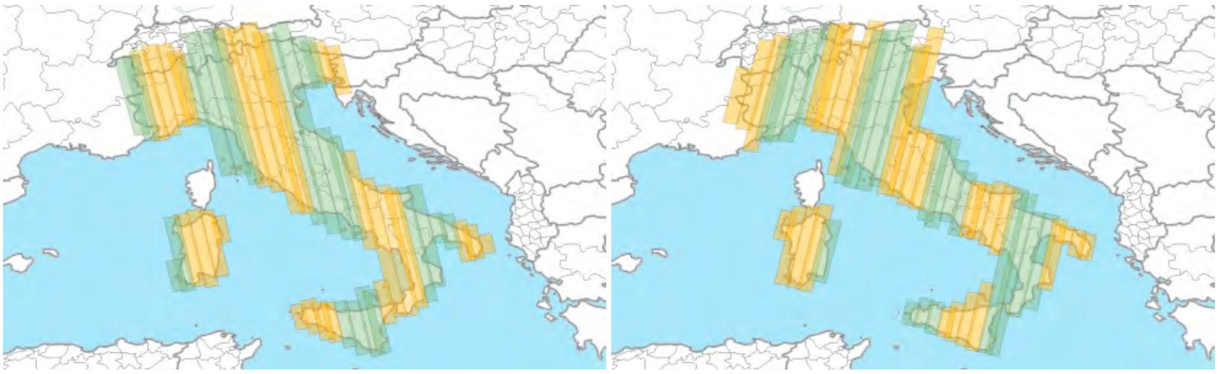

Figure 1 - Map Italy coverage along (left) Ascending and (right) Descending Geometry

The objective is to populate a national geographic reference archive with a specific interferometric historical archive regularly and intensively. In particular, thanks to this project, historical series of images are acquired on the Italian territory in order to use them for interferometric analysis of instability phenomenon and endogenous risk of the same territory (seismic and volcanic phenomena, landslides, subsidence, etc.) and to routinely and intensively populate a specific interferometric historic archive as a National geographic reference.

Considering its strategic importance, this interferometric mission was given a high priority level, so it is now a "foreground mission".
Currently Map Italy project is based on the acquisitions planned to be performed by CSK1, CSK2, CSG1 and CSG2 satellites. These four satellites cover the Italian Peninsula with a total of one hundred and two stripes, fifty Ascending and fifty-two Descending (G. Bausilio et al., 2024). All the SAR observations are performed in the standard StripMap Himage mode that is characterized by a swath extension of 40 km and a spatial resolution of 3 m single look. Although CSG data were provided in dual polarization (HH+HV), only HH data were used for flood mapping, because CSK data were acquired in single polarization.
The Map Italy data archive has proved invaluable for tracking ground deformation and surface change.
The same availability of long time series acquired regularly on the same site, up to hundreds of images over a decade of observation, is a fundamental requisite for being able to set up ordinary high frequency monitoring activities. In this way, it is possible to verify the state of conservation and, on the contrary, identify events of damage, accidental or intentional, natural or anthropic, which could intervene over time, in certain cases even without any warning or possibility of intervening, except that after the event.
The climate crisis that is occurring on a large scale across the planet is the trigger for extreme events that also affect our country.
In 2023 alone, 2 major emergencies due to heavy rainfalls occurred in Italy: in May exceptional and long-lasting floods affected Emilia Romagna and, later, in November, northern Tuscany from the province of Florence to coastal sites in the provinces of Pisa and Livorno.
Between 16 and 18 May 2023, about 350 million cubic meters of water fell within 36 hours across Emilia-Romagna. This caused the overflow of more than 20 rivers across the region. The flood had catastrophic consequences, killing 15 people and leaving thousands inhabitants homeless. The flood was preceded by another one that occurred on 2-3 May, which hit Emilia-Romagna after a drought that dried out the land, reducing its capacity to absorb water.
The monitoring of the Emilia-Romagna flood was requested by DCP on 16 May 2023 and lasted until 3 June. Throughout this time period, 27 images (both CSK and CSG) were specifically tasked and collected by ASI. The SAR acquisitions were programmed with an anticipation of only 24 h, in full emergency mode.In addition to the 27 acquisitions scheduled for the event, between 16 May and 3 June 2023 five Map Italy data were available for Emilia- Romagna. (L.Pulvirenti et all.). An example of the flood maps produced for civil protection purposes is presented in Figure 2.

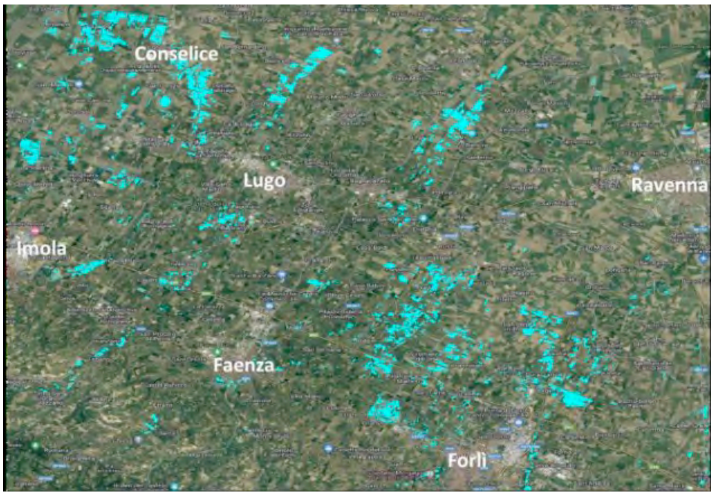

Figure 2 - Flood map over the province of Ravenna and Forlì-Cesena, Emilia-Romagna, derived from the COSMO-SkyMed images acquired by ASI on 17 May 2023 and processed by Fondazione CIMA.

The last days of October 2023 saw northern Italy affected by an intense meteorological event which brought intense rainfall to Liguria, Emilia Romagna, Lombardy, the Province of Bolzano, the Province of Trento, Veneto and Friuli Venezia Giulia in large areas of the territory .
In the following days, starting from the late morning of November 2nd, further rainfall was forecast, with very high cumulative amounts.

On November 3rd there was a worsening of precipitation events in the area of Tuscany south-west of Florence, and the Civil Protection Department requested availability for the acquisition of COSMO-SkyMed radar data. The monitoring of the Tuscany flood was requested by DCP on 3 November 2023 and lasted until 7 November. A total of 20 images, among archive and new acquisitions (both CSK and CSG), were gathered. Again, the SAR acquisitions were programmed with an anticipation of only 24 h. Figure 3 shows an example of the flood maps produced for civil protection purposes. Cyan polygons highlight flooded areas as opposed to permanent water bodies displayed in dark blue.

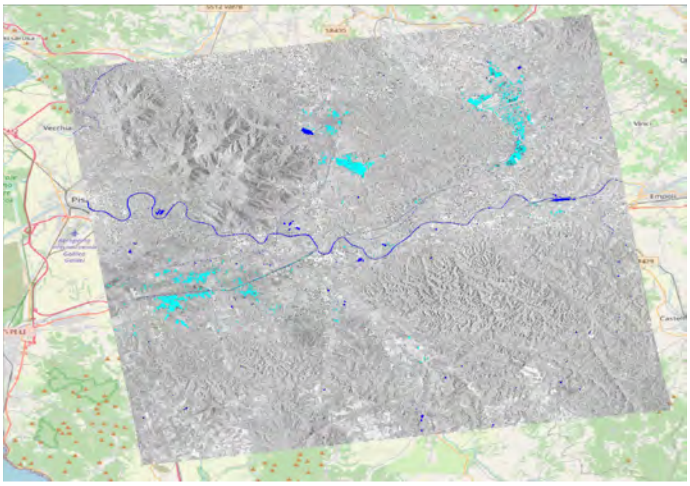

Figure 3 - Flood maps derived from the images acquired on 4 November 2023 and processed by Fondazione CIMA.

During both the flood events, at the beginning of the emergency, a set of pre-flood data archive was delivered by the ASI in order to carry out subsequent processing. By taking advantage of the acquisitions of the COSMO-SkyMed satellites (both first and second generation) it was possible to provide on a daily basis an updated image of the areas affected by flooding and thus input into the change detection chain to produce updated flood maps.

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ADVANCED FLOOD RISK MAPPING FOR ITALIAN COASTS USING HIGH-RESOLUTION OCEANOGRAPHIC MODELS AND REMOTE SENSING DATA

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Keywords: climate, sea level, Mediterranean, ocean model

Abstract

We present an advanced service designed to map Italian coastal areas at risk of flooding, employing the MED16 model (Sannino et al 2022). This model represents a significant evolution in oceanographic simulation, being a tide-including implementation of the MITgcm model optimized for the Mediterranean—Black Sea system with an exceptional resolution of 1/16°. This high-resolution, three-dimensional model facilitates detailed projections of Mediterranean Sea circulation and has been further refined at strategic points like the Gibraltar and Turkish Straits, where the model's ability to simulate complex, hydraulically driven dynamics and near-shore sea level variations has been rigorously validated against observations and numerical reanalyses.

Using the MED16 model, our service integrates cutting-edge satellite-derived ground motion data provided by the European Ground Motion Service of Copernicus. We employ a GIS-based approach to overlay future sea level projections and vertical ground motion estimates onto the best available digital terrain model of the Italian coasts. This integrated method is developed specifically for this project to offer a comprehensive understanding of coastal evolution under changing climatic conditions.

The selected test cases for applying our new mapping approach include the coastal plains of Piombino-Follonica and Marina di Campo in the Tuscany Region, Alghero-Fertilia in Sardinia, and Rome and Latina-Sabaudia in the Lazio Region. These areas are critically important both for their ecosystems and the economic activities they support. They are also considered geologically stable, making them ideal for accurate flood risk projections.

Under the RCP8.5 future scenario analyzed by the MED16 model, projections indicate an overall temperature increase across the Mediterranean, while surface salinity is expected to decrease in areas influenced by the Atlantic stream, with an increase elsewhere. This results in a partial inhibition of deep-water formation, influencing regional patterns of sea level rise and potentially altering flood risks.

For these selected regions, flood maps have been constructed for the reference periods 2010-2040, 2040-2070, and 2040-2099. These new maps are compared with previous projections to highlight differences that stem primarily from the more refined and resolved sea-level projections and the detailed Copernicus ground motion data. This advanced modeling provides a more nuanced understanding of future coastal risks, guiding mitigation, and adaptation strategies more effectively.

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THE ITALIAN SPACE AGENCY'S PROGRAMS OF SCIENTIFIC DOWNSTREAM APPLICATIONS FOR WATER RESOURCES AND HYDRAULIC HAZARD MANAGEMENT

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Keywords: water quality, soil moisture, drought, flood, oil spill, natural reserves, agriculture, irrigation, Synthetic Aperture Radar, optical, hyperspectral, PRISMA, COSMO-SkyMed, SAOCOM, Copernicus

Abstract

Within the Italian Government's guidelines on space and aerospace matters to achieve the strategic objectives of the national space policy (Presidenza del Consiglio dei Ministri, 2019), the "Telecommunications, Earth Observation and Navigation" (TLC/EO/NAV) sector is the first listed by priority order. TLC/EO/NAV satellite services and applications (the so-called "downstream") will be exploited by citizens and valorized by Institutions under an integrated application perspective. The downstream sector is therefore a key element to maximize the socio-economic impact of the investments in the space sector.

To implement these guidelines, the Italian Space Agency (ASI) is committed to contribute to the downstream development and pays particular attention to satellite-based services and applications of potential impact and benefit for the economy and society, in order to support national policies related, but not limited to: civil protection, safeguard the environment, the national cultural and landscape heritage, continuous monitoring of agricultural, forestry and fishing systems, monitoring of air/water quality, mitigation of weather-climatic events and the effects of global warming, monitoring of infrastructures and critical structures (energy and transport), management of public services and services to citizens, public green spaces and public goods, and scientific research (ASI, 2022).

With regard to Earth Observation (EO), in the last years, ASI has invested in sensor-specific national programs such as the "Multi-mission and multi-frequency SAR" (2021-2023) (Tapete et al., 2022, 2023) and "PRISMA Scienza" (2022-ongoing) (Licciardi & Battagliere, 2023) aiming to support the national scientific and industrial community in consolidating their expertise in algorithms development based on the existing satellite assets operating with Synthetic Aperture Radar (SAR) and hyperspectral optical sensors, respectively. At the same time, projects with consortia industrial companies and research bodies such as "Development of hyperspectral advanced prototype products" (Contract n. 2021-7-I.0) (Sacco et al., 2022) were undertaken to upgrade the portfolio of algorithmic processing chains allowing the generation of prototype products from satellite data flow.

In the above programs, a focus was on water resources under a variety of application domains and different components of the water cycle. For example, R&D activities were specifically undertaken on soil moisture retrieval for agricultural applications, as well as assessment and monitoring of quality of inland and coastal waters.

In the framework of the "Multi-mission and multi-frequency SAR" program, two projects – i.e. SARAGRI (Mattia et al., 2023) and CLEXIDRA (Gentile et al., 2024) – developed new methods for soil moisture retrieval from either SAR and optical data for applications in agriculture. During the ASI – CNR-IREA Funding contract n. 2021-6-U.0 SARAGRI, EO-based retrieval and classification algorithms were developed to transform time series of SAR and multi-spectral satellite data into multi-temporal series of surface soil moisture (SSM) and vegetation water content (VWC) and into maps of irrigated/non-irrigated areas. Among the outcomes, the project demonstrated the interoperability between Sentinel-1 and SAOCOM systems to retrieve consistent fields of SSM. The rationale was that an interleaved C- and L-SSM product would have reduced the gap between subsequent observations and the surface masked due to the presence of vegetation. Quantitative assessment was based on the records measured by the hydrologic network distributed across the Apulian Tavoliere test site, in Apulia region, southern Italy, and

a network of temporary stations deployed over Jolanda di Savoia test site, Emilia-Romagna region, northern Italy. This analysis showed that the combined C- & L- SAR-based SSM product achieved a root mean square error of ~0.06 m^3/m^3 over 120 observations and good consistency of the spatial patterns (Mattia et al., 2023). Furthermore, it was proved that the use of SSM at high resolution (~100m) enables the identification and classification of irrigated fields. The advantage brought by SAR and optical data for the early detection of irrigated areas and the leverage of the extensive information on irrigation management were effectively demonstrated in the irrigation district of Riaza in Spain (Balenzano et al., 2022).

In the same program, the ASI – e-GEOS Funding contract n. 2021-15-E.0 CLEXIDRA developed methods for soil moisture retrieval based on: (i) multi-frequency and polarimetric SAR data in L- (SAOCOM), X- (both COSMO-SkyMed First and Second generations) and C-band (Sentinel-1) integration; (ii) bare and vegetated soil scattering models inversion; (iii) Bayesian minimization and machine learning techniques; (iv) biomass estimation from hyperspectral and multi-spectral electro-optical data; and (v) ground-truth data collected over crop fields located in Jolanda di Savoia and Monte Buey, the latter located in Argentina (Gentile et al., 2024). The algorithms were implemented for precision agricultural applications, thus enabling SAR products of soil moisture in agricultural irrigation management systems, as well as in global weather models for environmental monitoring purposes.

With regard to water quality, one of the eight hyperspectral advanced prototype products developed during the Contract n. 2021-7-I.0 (Sacco et al., 2022) relates to the characterization of inland, coastal, and marine water: Phytoplankton, Total Suspended Matter (TSM) concentration, water turbidity, and substrates type fractional coverage. The processor implements: (i) an adaptive band ratio algorithm for Chlorophyll-a (Chl-a) and Cyano-phycocyanin concentration; (ii) a semi-analytical algorithm for TSM and Turbidity; and (iii) the inversion of bio-optical models for retrieving Chl-a in oligotrophic deep waters and fractional substrate coverage in shallow waters (Tricomi et al., 2023). Tests were performed over five lakes in central-northern Italy, the Po River delta and the lagoon of Venice. Targeted in situ campaigns were carried out during PRISMA satellite overpasses (± 2-3 hours). The performance achieved was very promising for the whole suite of products.

All the above experiences led to a national heritage of scientific validated algorithms, prototype products and ecosystem of competences among the involved research groups. According to the ASI's roadmap for scientific downstream applications (Tapete & Coletta, 2022), in order to capitalize such heritage into a valuable contribution to address real-word applications and support final users' needs, the next step in development is provided by the new program called "Innovation for Downstream Preparation" (I4DP) (Figure 1). I4DP is composed by demonstration projects that involve not only the developers but more importantly the final users. The technological solutions are tested in real-world scenarios to assess how they can input into daily duty workflows of either scientific, commercial or institutional users. The latter are the user categories that I4DP targets through three specific streams of activities.

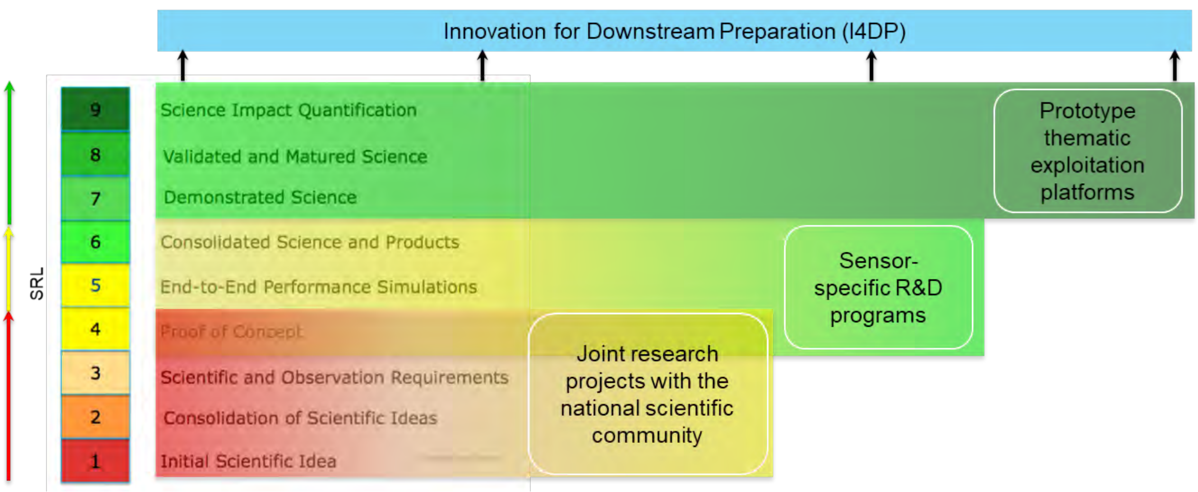

Figure 1. ASI's roadmap for scientific downstream (Tapete & Coletta, 2022). Notation: SRL – Scientific Readiness Level as per the definition in the European Space Agency (ESA) SRL Handbook EOP-SM/2776

Of these three streams, “Innovation for Downstream Preparation for Science” (I4DP_SCIENCE) is the one devoted to the Scientific User Community, i.e. Italian Universities and Public Research Bodies. I4DP_SCIENCE is composed of joint projects with ASI demonstrating the usefulness of novel methods and algorithms to support applications of user’s interest falling within topics of national relevance, e.g. defined by the National Copernicus User Forum, and/or falling within international agendas, e.g. the UN Sustainable Development Goals (SDGs). All the demonstrations are carried out jointly with the reference users who are actively engaged since the initial user requirement consolidation and, throughout the project, via capacity building and training activities towards the user uptake.

Launched in early 2022, so far the I4DP_SCIENCE program has been developed through the issue of two calls for ideas centered on the themes of “Sustainable Cities” and “Agriculture and Sustainable Use of Water Resources”, respectively. How much downstream applications for water resources and hydraulic hazard management are at the core of I4DP_SCIENCE is proved by the fact that five out of the six ongoing projects relate to water quality (EcoNet, SatellOmic), urban floods in a multi-hazard/risk context (GEORES), irrigation regimes in agriculture (TETI) and agricultural and hydrological drought (GRAW). Here below a brief introduction to each project is provided, whereas all the technical details are illustrated in the presentations composing the ASI’s special session at AIT-ENEA workshop 2024.

Started in November 2022, EcoNet (Agreement n. 2022-32-HH.0) is a joint project between ASI and the Institute of Nanostructured Materials of the National Research Council of Italy (CNR-ISMN) with the participation of University of Tor Vergata (UTOV) that aims to develop an integrated sensor-driven system managed by artificial intelligence (AI) for monitoring surface waters near human settlements (La Pegna et al., 2023). By integrating Sentinel-2 and PRISMA-based mapping products related to water quality (Chl-a, TSM, Colored Dissolved Organic Matter, Total Phosphorus and Total Nitrogen), in-situ bio/chemosensoristic devices and AI, EcoNet pursues: i) association and correlation between two or more indices measured continuously by remote sensing and/or ground sensors; ii) complementarity of ground and satellite sensor systems. To validate the designed methodology, the test areas include the following natural reserves of the Natura 2000 network, hosting rare and threatened species for which the prime concern is to ensure long-term subsistence of the habitats: Riserva Naturale Regionale “Selva del Lamone” (Farnese, Viterbo, Italy); Riserva Naturale Regionale “Nazzano Tevere-Farfa” (Nazzano, Roma, Italy); Lago di Piediluco (Piediluco, Terni, Italy). All the test areas share common factors of anthropogenic pressures deriving from punctual and diffuse sources of pollution: peri-urban agro-zootechnical productions and discharges from wastewater treatment plants. Local stakeholders responsible for managing the natural reserves and water resources are involved in the project, providing support for the identification of surface water sampling points and field activities, including the sampling itself.

Issues due to pollution of inland and coastal waters are also tackled by SatellOmic (Agreement n. 2023-36-HH.0), a project between ASI and the Istituto Superiore di Sanità (ISS) that started in July 2023 and involves the Scuola di Ingegneria Aerospaziale (SIA) of Sapienza University of Rome as a partner. SatellOmic is pioneer in combining EO-based water quality products with metagenomics analyses, building upon very recently developed methods (D’Ugo et al., 2024) and spectral indices (e.g. the VIS-NIR reflectance ratio Index – VNRI; Laneve et al., 2022). The project aims to demonstrate not only that Sentinel-2 and PRISMA-based products can support timely monitoring of water bodies threatened by oil spills, but also that the combination with metagenomics can allow for the design of recovery strategies based on the use of valuable hydrocarbonoclastic microorganisms. It is indeed known that environmental microbial metagenomics can unveil complex information about microbial communities in aquatic ecosystems, including changes in microbial communities during pollution events on the type of pollutant present and on microbial proxies for oil pollution. While the microbial response to petroleum hydrocarbon contamination in freshwater environments is not well-documented due to the rare occurrence of oil spills, if the combined method showed the presence of microorganisms, some of these microorganisms may be important for the protection of water basins (D’Ugo et al., 2024). The SatellOmic method is currently being tested in a selection of Siti di Interesse Nazionale (Sites of National Interest) spread across Italy.

While EcoNet and SatellOmic concentrate on reserves and basins that represent water reservoirs, other projects investigate how EO data can help in improving water usage, e.g. in agriculture. This is the case of TETI (Agreement n. 2023-52-HH.0), the project between ASI and the Institute for Electromagnetic Sensing of the Environment (IREA) of CNR that started in November 2023 and focuses on the demonstration of EO capabilities for the early forecast of irrigation needs. In particular, building upon the suite of algorithms developed during the SARAGRI project (see above) and state-of-the-art soil water balance hydrological and crop models, TETI aims to implement and assess the performance of a Spatial Decision Support System (SDSS) in three use cases: early stage (at the end of the winter season); beginning of the season (right after the sowing); and during the season, every week (Satalino et al., in press). The semi-arid Mediterranean environment where the TETI SDSS is being tested is the "Fortore" irrigation district in the Apulian Tavoliere, managed by the Consorzio di Bonifica della Capitanata (CBC), i.e. the pilot user of the project. There, a set of ground data in terms of daily weather data, crop surveys and irrigation data collected from hydrants, are available and will be exploited to validate the EO-based estimates.

Prediction is also the ultimate goal of GRAW (Agreement n. 2023-52-HH.0), the project between ASI and Sapienza University of Rome aiming to exploit EO data and pilot applicatives for monitoring and forecast of hazards due to hydrological and agricultural drought. While hydrological drought indicates a scarcity of both surface and groundwater resources, which results in reduced water levels of rivers, lakes, and aquifers, agricultural drought is related to crop yields and is caused by inadequate water supply to crops. With regard to hydrological drought, GRAW is monitoring the extent, levels and volume variation of surface water reserves by combining optical multispectral and SAR imagery (e.g. from COSMO-SkyMed) and laser/radar-altimeter measurements. With regard to agricultural drought, the project is testing a monitoring approach integrating several EO-based indices. In particular, a data-driven approach could support the development of a model able to assess drought damage at a large scale, by integrating satellite data with ground meteo-climatic variables. Two data-driven approaches are tested: polynomial (cubic) regression and multinomial logistic regression model. The first one aims to infer the percentage of drought damage and shows an average R^2 of 0.76. The second one aims to classify each field into a drought risk category (high-risk damage, medium-risk damage, low-risk damage) and shows more promising results, achieving an average F1 score equal to 0.93 (Bocchino et al., in press).

Finally, I4DP_SCIENCE focuses not only on water resource management, but also fosters innovation in support to hydraulic hazard management and understanding of the mutual relationships between the natural environment and urbanization. With regard to applications for natural hazard assessment and mitigation, I4DP_SCIENCE is funding the GEORES project (Agreement n. 2023-42-HH.0) with University of Bari and the partner CNR-IREA. GEORES is developing a geospatial application meant to improve environmental sustainability and resilience to climate changes in urban areas, through a multi-risk platform composed of four main modules: (1) Sediment Connectivity; (2) Land Displacement; (3) Urban Floods; (4) Urban Wildfires. For each module, EO data (including the Sentinels, COSMO-SkyMed, SAOCOM and PRISMA), calculation models and algorithms (e.g. including interferometric Synthetic Aperture Radar techniques) are integrated to identify "hot-spots" of urban and peri-urban territory at high risk from the point of view of land degradation caused by phenomena of hydrogeological instability, sediment flow or vegetation fires. The extracted information is expressed with specific indicators ("geo-analytics") calculated dynamically and automatically (Lafortezza et al., in press). The demonstration is undertaken in the Metropolitan City of Bari and the urban settlements in Gargano Promontory, Apulia Region, southern Italy. In particular, the Urban Floods module will provide high spatial and temporal resolution maps of the flooded areas by exploiting: Sentinel-1, COSMO-SkyMed and SAOCOM data; ancillary information; statistical modeling of SAR time series through the use of parametric and/or non-parametric models; Bayesian inference of the posterior probability of observing water over a given area at a certain date.

One of the key commonalities of the above five projects is the user-driven perspective that guides the demonstration of the technological novelty of the specific algorithms and functionalities of the platforms and plugins that are being developed. Final users and stakeholders (starting from those that are the managers of the demonstration sites) are actively engaged in the demonstration process. This approach ensures that the demonstration happens in real-world conditions and make the experimentations relevant to the users, beyond the scientific research scope.

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ADVANCED SURFACE WATER MONITORING BY AI-MEDIATED INTEGRATION OF SATELLITE AND GROUND SENSOR DATA: THE ECONET PROJECT

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Keywords: Hyperspectral remote sensing, Bio/chemosensoristic devices, Artificial Intelligence, PRISMA, Sentinel-2, Freshwater ecosystems, Natural reserves

Abstract
The EcoNet project aims to design and develop an integrated system for the monitoring of changes in surface waters based on different sensoristic techniques. The proposed integration approach combines ground measurements and hyperspectral satellite images. The promising dialogue that occurs between these two multi-sensoristic technologies requires the implementation of Artificial Intelligence (AI), as a tool particularly suitable for handle and analyse very subtle relationships among data. This technique's integration can open enormous potential for overcoming the limits of traditional environmental monitoring and diagnostic [1]. Earth Observation (EO) multi/hyperspectral optical imaging technologies have proved their effectiveness as affordable and practical support for traditional ground-based methodologies. Advantages include: provision of an independent characterization based on electromagnetic principles and wide range of spatial/temporal resolution, making the integration a valuable way for monitoring aquatic status and allowing early identifications of hazards and alert procedures [2, 3]. Ground (bio)sensoristic devices as on site and cost effective analytical systems can provide real time information about the presence of bioactive compounds in environmental matrices like surface waters [4].
Test areas chosen include natural reserves of the Natura 2000 network, hosting rare and threatened species: Riserva Naturale Regionale "Selva del Lamone" (Farnese, Viterbo, Italy); Riserva Naturale Regionale "Nazzano Tevere-Farfa" (Nazzano, Roma, Italy); Lago di Piediluco (Piediluco, Terni, Italy). All test areas share common factors of anthropogenic pressures deriving from punctual and diffuse sources of pollution: peri-urban agro-zootechnical productions and discharges from wastewater treatment plants.
Whitin project activities, field measurements are carried out by the CNR-ISMN research group through the implementation of "Snoop" prototype, a European patent coupled with other sensoristic probes. 'Snoop' prototype measurements were carried out for the assessment of general or integral toxicity levels, linked to the presence of contaminating bioactive substances (e.g., pesticide residues and heavy metals) in surface water samples. Surface water samples were weekly/monthly collected by each test area in surface water sampling points located in the waterways.
Relevant aquatic parameters retrieved from satellite data are carried out starting from the most significant remote sensing techniques available in literature: Chlorophyll-a (Chl-a), Total Suspended Matter (TSM), Colored Dissolved Organic Matter (CDOM), Total Phosphorus (TP) and Total Nitrogen (TN) are considered in this work [5].
ASI's PRISMA (PRecursore IperSpettrale della Missione Applicativa) hyperspectral images are used, while target values are obtained via physical models derived with visible bands from Landsat 8/9 and Sentinel-2 images [6,7], which are both characterized by a higher temporal frequency of data acquisition, but lack in spectral resolution [8]. The retrieval algorithm relies on the reflectance in the visible spectrum (range 438-754 nm) given the strong sensitivity to the chosen water parameters. The integration of data acquired in-situ by the CNR-ISMN group is complemented by including these concentration values as additional example data to be inserted into the AI models to increase the density and accuracy of the proposed examples.

Multi-Layer Perceptron (MLP) models were chosen, being Artificial Neural Network generally used for retrieval prediction analysis [9]. The input layer, consisting of reflectance values at sensitive channels, the amount of neurons in the hidden layer and the training epochs are determined depending on water parameter and density of the input dataset. Outputs of the models represent the estimated concentration values of every water parameter. The trained model is then extended to the entire surface of the water body to observe spatial distribution of significant indices.
The preliminary results currently derived from the AI models development proved to be interesting. In particular, for each test sites, R^2 values of above 0.67 up to 0.95 were obtained. Figure 1 shows the results achieved at the confluence of the Tiber and Farfa rivers in the Nazzano reserve for TSM.

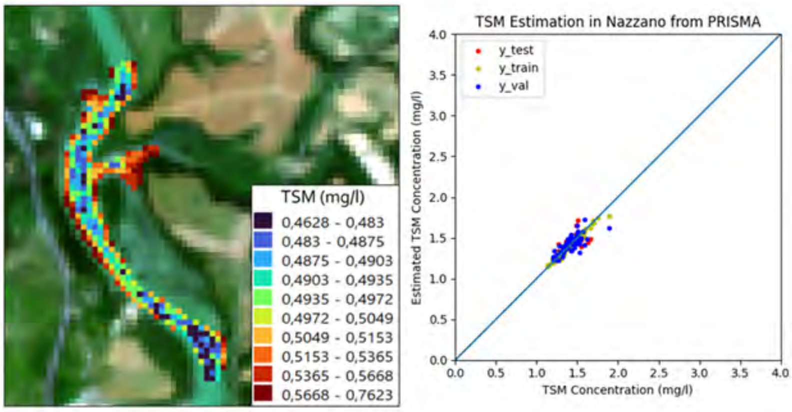

Figure 1 - Left side: Estimated concentration of TSM at the confluence of Tevere and Farfa rivers (Nazzano reserve) derived from PRISMA image of 27/06/2023. Right side: Scatterplot of TSM concentration derived from Landsat 8 physical model vs. TSM estimated with AI model in Nazzano reserve.

As an example, Figure 2 shows the results collected from Selva del Lamone from "Snoop" measurements of ammonium ion (NH_4^+) concentration in water samples, which can be present in water, often resulting from the breakdown of organic matter or the discharge of nitrogen-containing compounds.

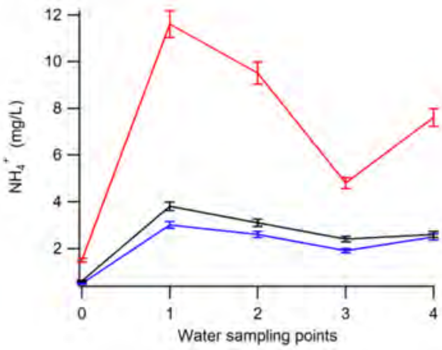

Figure 2 - Ammonium ion (NH4+) concentration (mg/L) measured on water samples collected from Selva del Lamone reserve. Blue line, black line and red line refer to 14 July 2023, 31 July 2023 and 28 August 2023 water sampling campaigns, respectively. Surface water sampling points on X-axis: 0 (Mezzano lake), 1 (Valle Latera), 2 (S. Maria di Sala bridge), 3 (Salabrone waterfalls), 4 (Farnese water treatment plant). %RSD ≤ 5%.

The processing of the sensoristic data obtained so far offers interesting prospects. The integration of ground measurements with satellite data can enable reliability of monitoring alterations in the natural state of freshwater bodies since multi-sensor data approach can overcome the limitations of single acquisitions techniques, providing also the chance to gain higher spatial and temporal resolutions. EcoNet therefore contributes to the ongoing efforts to optimize the early identification and assessment of possible hazards in freshwater.
To this scope, EcoNet also fosters user uptake of the developed method, as well as public awareness of the challenges involved in the protection of surface waters in natural reserves. In April 2024 the project entered the final phase which encompasses dissemination and events with final users and stakeholders at

Nazzano-Tevere Farfa and Selva del Lamone natural reserves. Announcements of these events and further details about the project are published on a regular basis on the project website: https://www.econet.cnr.it/.

Acknowledgment
The EcoNet project is funded by the Italian Space Agency (ASI), agreement n. 2022-32-HH.0, as part of the program "Innovation for Downstream Preparation for Science" (I4DP_SCIENCE) [10].

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SATELLITE AND METAGENOMICS SURVEILLANCE FOR THE MONITORING AND PROTECTION OF WATER BASINS

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Keywords: satellite, water bodies, pollution, metagenomic

Abstract

Freshwater contamination is a global concern. The enormous impact of the natural and anthropogenic organic substances that are constantly released into the environment requires better knowledge of the chemical status of Earth's surface waters (Sousa et al., 2018). The identification of chemical contaminants over large areas can provide indications regarding the type of danger and the need for timely interventions for the conservation of water supplies and its services. Emerging satellite technologies could allow the monitoring of sensitive water basins whose quality is important for human and animal health. Aqueduct management companies that draw drinking water from large water basins such as lakes, threatened by industrial plants, could make use of a multispectral satellite surveillance system which, through validated algorithms, identifies the presence of pollutants. With the aim of demonstrating the usefulness of such novel method and associated algorithms to support user-driven applications of water quality monitoring and management, since July 2023 the Italian Space Agency (ASI) and the Istituto Superiore di Sanità (ISS) have initiated the collaborative project SatellOmic ("Integrazione di sistemi satellitari e metagenomici per il monitoraggio e la tutela di bacini idrici"), with the participation of the Scuola di Ingegneria Aerospaziale (SIA) of Sapienza Università di Roma as partner.

SatellOmic exploits the hyperspectral images collected by the sensor on board of the PRISMA satellite. The PRISMA (PRecursore IperSpettrale della Missione Applicativa) imager is ASI's hyperspectral technology demonstrator mission. The satellite is in orbit since March the 22nd 2019 and is currently in the operational phase, with a repeat cycle of approximately 29 days. The tilting capability of the sensor allows to image a specific area with, at best, a frequency of 7 days. Identification of pollutants and oil spills and generation of water quality products are achieved by combining image processing algorithms and metagenomic analysis. This combination offers useful tools for the timely monitoring of water bodies, as well as for the design of recovery strategies based on the use of valuable microorganisms. In this regard, among the scope of SatellOmic activities, a mobile phone application is being built to disseminate the prototype products developed during the project. The idea behind this application is to test the usefulness of such a digital mean to update the scientifically-based information about the ecosystem status of water basins taking into account the parameters derived from satellite images and data obtained from chemical and biological analyzes of environmental matrices.

Environmental changes have been analysed with the combination of satellite monitoring and metagenomic in other studies. Red snow phenomenon, in Franz Josef Land's Arctic observed by satellite, is the result of a microbial succession dominated by Chlamydomonas nivalis, a unicellular, red-colored photosynthetic green algae. Similarly, satellite monitoring and metagenomic monitoring were used to assess the impact on coral reefs of a huge quantity of mud spill from iron ore mining on the Abrolhos Bank reef in Brazil.

In order to study the suitability of PRISMA (and Sentinel-2) images to characterise water bodies status, a series of field campaign has been planned over a selection of SIN (Siti di Interesse Nazionale) sites in Italy (Figure 1). The first mission was carried out at the SIN sites of Gela and Augusta-Priolo from 6 to

10 November 2023 by ISS and SIA, while ASI collected co-located PRISMA images. These sites are the most exposed to oil spills of petroleum origin in Italian territory. Detecting oil spill, using satellite images and, consistently and reliably, confirm its presence through metagenomic analysis is one of the primary objectives of the project (Laneve et al. 2022, D'Ugo et al. 2024). Therefore, these sites represent a potential target for the identification of hydrocarbons and microbial communities that sense their presence. The Saline di Priolo site represents instead a negative control compared to the other two sites mentioned above, where, from the point of view of the indicators used, better water quality may be found. The SIN of Pisticci Scalo Tecnoparco represents a territorial collector of industrial waste in the valley characterized by the Basento river. Although not observable from satellites due to the small number of satellite pixels that can be examined, it could represent an *in situ* control of algorithms developed for satellites. The site was in fact flown over by SIA's Mica-Sense multispectral drone and could be used for the validation of a Sentinel-2 algorithm for the detection of oily substances developed in a previous SIA-ISS collaboration (Laneve et al. 2022).

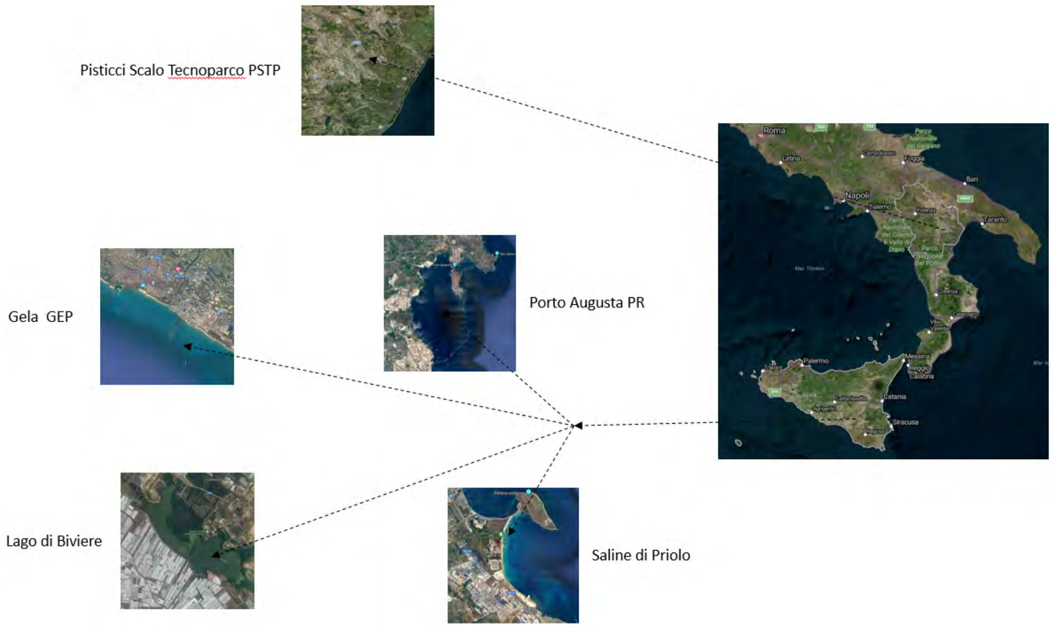

Figure 1. *Map of the sites visited during the field campaign carried out in 6-10 November 2023 in Sicily and Basilicata.*

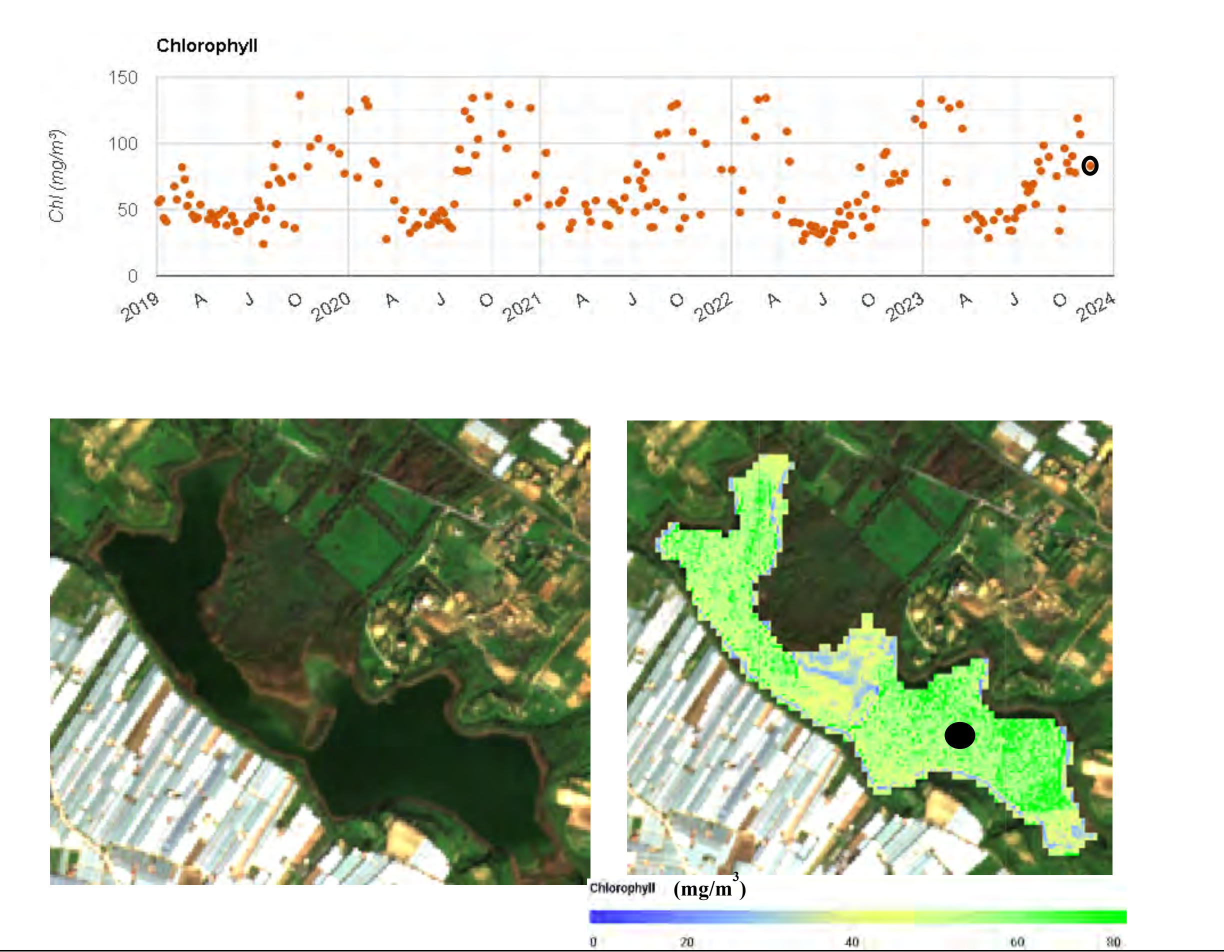

Figure 2. *Top panel:* example of chlorophyll concentration temporal behavior in the Biviere di Gela lake, as revealed by Sentinel-2, between January 2019 and December 2023. The black void circle refers to the simultaneous in-situ measurement carried out during the field campaign. *Bottom panels*: satellite image of the Biviere di Gela lake (left), and correlated chlorophyll concentration acquired by Sentinel-2 during the field campaign. The black point represents the area which the above chl-a time distribution refers to.

The waters of the Biviere Lake Nature Reserve (Figure 2) have in the past been the subject of indiscriminate spills due to industrial waste that reaches the lake through two supply aquifers. Currently, the anthropic weight is reduced, but the states of disturbance of the lake are still evident, characterized by frequent algal blooms and cyanotoxins. Also in this case, ground samples and multispectral images were collected.

The preliminary analysis of the samples obtained in Lake Biviere di Gela showed high levels of Chlorophyll A as well as impressive blooms of green algae (*Coelastrum reticulatum*, Dictyosphaerium, Crucigenia) diatoms (Stephanodiscus) and the presence of cyanophyceae: Cylindrospermum, *Planktolyngbya limnetica*, *Oscillatoria putrida*, Merismopedia). The chemical state highlights the presence of metals and heavy hydrocarbons C>12. The PICRUSt2 bioinformatic analyses of the lake community show the presence of microorganisms with a catabolic apparatus suitable for the degradation of aliphatic and aromatic hydrocarbons compared to the controls used in the metagenomic analyzes of the lake communities. Abound enzymes for the degradation of aliphatic hydrocarbons such as alkane monooxygenase, haloalkane monooxygenase, nitronate monooxygenase, alkanesulfonate monooxygenase and enzymes for the degradation of aromatic hydrocarbons such as Protocatechuate 3,4-dioxygenase, Homogentisate 1,2-dioxygenase, Catechol 1,2-dioxygenase, Catechol 2,3-dioxygenase, 4-hydroxybenzoate 3-monooxygenase, and others.

These data suggest that, although oil activities have been interrupted near this SIN, sources of contamination persistently affect the water quality of this important reservoir. Preliminary data from SatellOmic suggest that the combination of observational data such as satellite data and *in situ* chemical-biological data can give useful indications on the health status of aquifer ecosystems subject to environmental accidents.

Acknowledgments

This research is carried out within the SatellOmic project, funded by the Italian Space Agency (Agreement n. 2023-36-HH.0) under the ASI's program "Innovation for Downstream Preparation for Science" (I4DP_SCIENCE).

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THE USE OF EARTH OBSERVATION FOR THE EARLY FORECAST OF IRRIGATION NEEDS

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Keywords: Earth Observation, SAR and Optical data, Soil Moisture, Irrigation Needs, Hydrologic Model, Crop Model, Artificial Intelligence

Abstract
This paper illustrates the ongoing activities for a Spatial Decision Support System (SDSS) implementation whose task is the early, medium and short-term forecast of irrigation needs in a semi-arid Mediterranean environment. The activities are carried out in the context of the "EarTH Observation for the Early forecasT of Irrigation needS (THETIS)" project, supported by the Italian Space Agency (ASI).

The peculiarity of THETIS is the integration of a soil water balance (SWB) hydrological model and a crop model (CM), both fed by meteo-climatic data, and the exploitation of an innovative approach that leverages advanced Earth Observation (EO)-derived products from both SAR and optical data. Moreover, THETIS include Artificial Intelligence (AI) methods, which are applied to observed and forecast Copernicus meteo-climatic data, and a WEBGIS interface platform, designed for a graphical access to the generated data.
THETIS started in November 2023 and has the objective of providing forecasts of basin-scale irrigation needs for summer crops. On the basis of the user requirements expressed by the Pilot User of this project (i.e., the Bonifica Capitanata Consortium (CBC) partner), three use cases for the application of THETIS have been established. They are characterized by different delivery times of the prediction of irrigation needs, i.e., I - early stage (at the end of the winter season); II - beginning of the season (right after the sowing); and III - during the season, every week. The early forecast allows for an estimate of the seasonal demand that may improve water management in the medium term. On the other hand, periodic forecasts during the season can support a more efficient supply and distribution of water to farmers and/or irrigation districts.
The study area is the "Fortore" irrigation district in the Apulian Tavoliere (AT), Foggia (Italy), which is managed by CBC, and where a set of ground data in terms of daily weather data, crop surveys and irrigation data collected from hydrants, are available.
The principal modules of the THETIS architecture are: EO data and EO-derived products; AI for the spatialization of meteo-climate data; SWB model; CM; and WEBGIS. In the following, a brief description of the modules is given.

EO data and EO-derived maps: SAR data include Sentinel-1, COSMO-SkyMed, and SAOCOM. Multispectral data encompass Sentinel-2, integrated with PRISMA hyperspectral data. EO data are used to derive thematic information such as Surface Soil Moisture (SSM) [Balenzano et al., 2021], irrigated areas [Balenzano et al., 2022], tilled (ploughed or rolled soils) [Satalino et al., 2018], and vegetation indexes (e.g., Normalized Difference Vegetation Index (NDVI), Leaf Area Index (LAI), etc.). These parameters are retrieved by exploiting algorithms that were developed, tested and consolidated during the

ASI-funded project SARAGRI [Mattia et al., 2023]. The final products are used in input into and/or assimilated into SWB and CM models.

AI module: This module is dedicated to downscaling the seasonal forecasts of meteorological and climate data, distributed by the Copernicus Climate Change Service (C3S) system, through advanced AI algorithms. Parameters such as solar radiation index, temperature and precipitation are considered. The downscale modelling is driven by a historical data set of meteorological data collected since 1990 over AT.

SWB Model: The SWB model has the task of estimating the soil water content to input into the CM. A suite of hydrologic water balance models structured in a hierarchical way in order to ensure progressively increasing accuracy is implemented. The selected models are the BIGBANG (hydrologic Balance GIS Based at National scale on regular Grid) [Braca et al., 2021], DREAM (daily basin-scale hydrological model) [Manfreda et al., 2005] and SMAR (Soil Moisture Analytical Relationship) [Manfreda et al., 2012]. BIGBANG supports the identification of the initial conditions of the DREAM model to be run at the scale of the river basin. The DREAM model is used to perform simulations on a daily (or sub-daily) scale based on meteorological and climatic observations and/or forecasts. It allows a reliable simulation of hydrological soil dynamics in gauged and ungauged basins. The SMAR model transforms SSM into the soil moisture content of the deeper layers by using a physically based formulation. Specifically, the SMAR model allows to relate the soil moisture maps from SAR data (i.e., S-1 or other sensors) and the output of the DREAM model. This comparison could also serve as a local forcing for the DREAM model, which operates over the whole hydrographic basin exploiting spatialized climatic data and transfers soil moisture information for the initialization of the crop model.

Crop Model. The CM is based on the AquaCrop architecture [Steduto et al., 2009]. It uses inputs from EO, AI and SWB modules to forecast the evapotranspiration and irrigation needs over the study area at an early stage and in the medium-short term during the growing season. The model estimates water stress as a function of the water available in the soil and the ability of the crop to adopt water stress resistance mechanisms. The outcomes of CM is closely dependent on the initial soil water content at the beginning of the growing period, which is provided by the SWB model.
The CM uses historical data of irrigation needs and tillage change maps from EO data to make an early estimate of the annual irrigation needs. In fact, the area tilled for summer crops can provide, before the emergence of the plants, an early forecast of the area intended for irrigation. This first estimate is refined at the beginning of the season with the quantification of the sown areas effectively irrigated.
Historical vegetation indices are also used to delineate crop rotation cycles and identify the different sowing and transplanting periods. At the beginning and during the season, these estimates are updated with the use of irrigation maps and current vegetation indices.

Figure 1 shows the functional scheme of the THETIS architecture and illustrates the main relationships between the SWB and CM models, highlighting the EO-derived information used as input. Information such as LAI and irrigated surfaces, whose variability depending on the season and irrigation practices may influence the predictive capabilities of the water balance model, can be directly or indirectly assimilated into the SWB module.

Acknowledgment: The project "EarTH Observation for the Early forecasT of Irrigation needS" (THETIS) is funded by ASI under the Agreement N. 2023-52-HH.0 in the framework of ASI's program "Innovation for Downstream Preparation for Science" (I4DP_SCIENCE).

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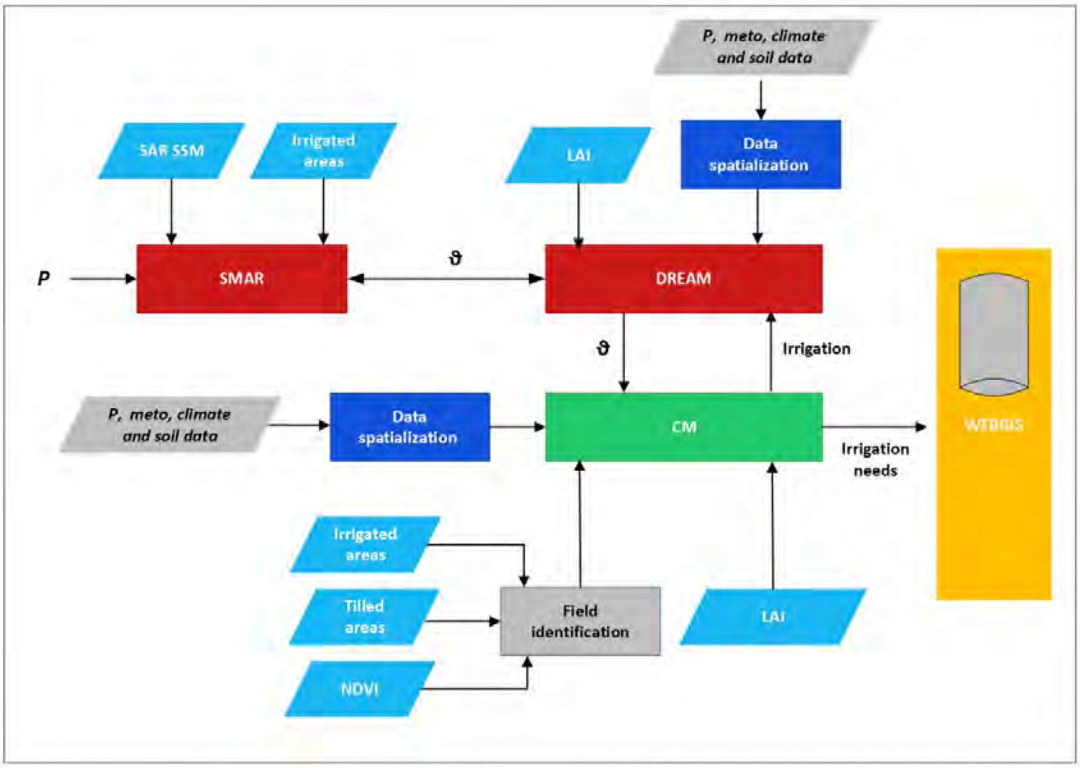

Figure 1: Functional diagram on the integration of data and models in THETIS. P: input parameters; ϑ: soil water content.

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EXPLORING WATER RESERVOIR DYNAMICS IN CENTRAL ITALY: A PRELIMINARY WORKFLOW FOR COSMO-SKYMED IMAGERY-BASED WATER SEGMENTATION

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Keywords: Hydrological drought, COSMO-SkyMed, Water monitoring, Inland water extent, Water segmentation

Abstract

Hydrological drought is one of the most critical effects of climatic change, affecting inland water body extent and level, and threatening the surrounding ecosystem and industries. Traditionally, ground instruments have been used as the primary method for monitoring reservoir water level changes. However, these measurements are generally conducted with pre-installed gauge stations, which do not provide estimates of the extent of changes and raise challenges in their set-up and maintenance, especially in remote areas. Conversely, Earth Observation technologies can remarkably reduce monitoring costs and provide frequent and regular data that can facilitate the continuous monitoring of water bodies.

This work is developed within the *Geomatics for Resilience Against Water scarcity* (GRAW) collaborative project (Agreement n. 2023-1-HB.0) between the Geodesy and Geomatics Division (DICEA) of the Sapienza University of Rome and the Italian Space Agency (ASI), in the framework of the ASI *Innovation for Downstream Preparation for Science* (I4DP_SCIENCE) program. It aims to develop a methodology for the routine monitoring of water resources from the analysis of satellite imagery both in terms of inland water reservoir extent and level. Here, a preliminary workflow for automatic water segmentation (Figure 1) using Synthetic Aperture Radar (SAR) COSMO-SkyMed imagery is presented.

Methodology

Among the products available within the ASI COSMO-SkyMed catalogue and accessed from the institutional new MapItaly portal (ASI, 2023), orthorectified StripMap HIMAGE images with a spatial resolution of 2.5 m and HH polarization were selected. The analyses presented here refer to the area of Albano Lake (central Italy). The proposed workflow is based on a radiometric approach which takes advantage of the differences in the back-scattered SAR signal to distinguish the water pixels from the land ones. In particular, the workflow consists of two main steps: image pre-processing (normalization and filtering) and thresholding.

At first, the input data were normalized to 8-bit images to stretch the intensity values. Subsequently, standard filters were used to improve the contrast of the images for finer water body detection (histogram equalization) and to remove the noise (bilateral filtering and morphological transformation). A final normalization step was applied forcing the gray-scale values to be included in the range from 0 to 1. At this primary evaluation stage, this range was chosen by trial and error to ensure that distinct intensity values represent the water basin and the land. Then, the images were segmented using a binary thresholding approach, identifying Binary Large OBjects (BLOBs); the largest BLOB corresponds to the lake and it was saved as its final mask. This procedure was replicated using different images to generate water masks for each epoch of interest.

First results

Three images capturing Albano Lake were processed with the developed workflow. The images were selected with the same acquisition geometry (descending orbit) and during the same period in different years (July 2017, July 2020, and July 2023). The resulting masks were compared to analyze the lake extent variation during the 3 years under investigation (Figure 1). The following preliminary results are based on only three analysis periods since the purpose of this study is to test and demonstrate the potentialities of the proposed workflow. The corresponding areas during the three periods were calculated as shown in Table 1. It was found that from 2017 to 2020, considering the period of July, Albano Lake remained almost identical in its extent, while from 2020 to 2023 it decreased by 0.3% of its total area.

Years	2017	2020	2023
Area (km^2)	5.530	5.531	5.515

Table 1: Water area extent of Albano Lake during July 2017-2023.

The results also showed that the areas most affected by variation correspond to the shoreline areas, where erosion processes and changes in water levels are likely to be most present and thus constitute an element of variation in lake contours. Figure 2 shows the consistent changes in the northern shoreline of the lake, where the retreat reaches the highest value between 2020 and 2023 (around 20 m).

Nevertheless, it is important to highlight that some issues might have affected the definition of the contours of the water basin along the steepest or vegetated areas around the lake, due to the known limitations of SAR technology in these areas. For this reason, the masks obtained from the workflow should be considered preliminary and need to be validated with an accurate reference (e.g., in situ measurements provided by basin authorities).

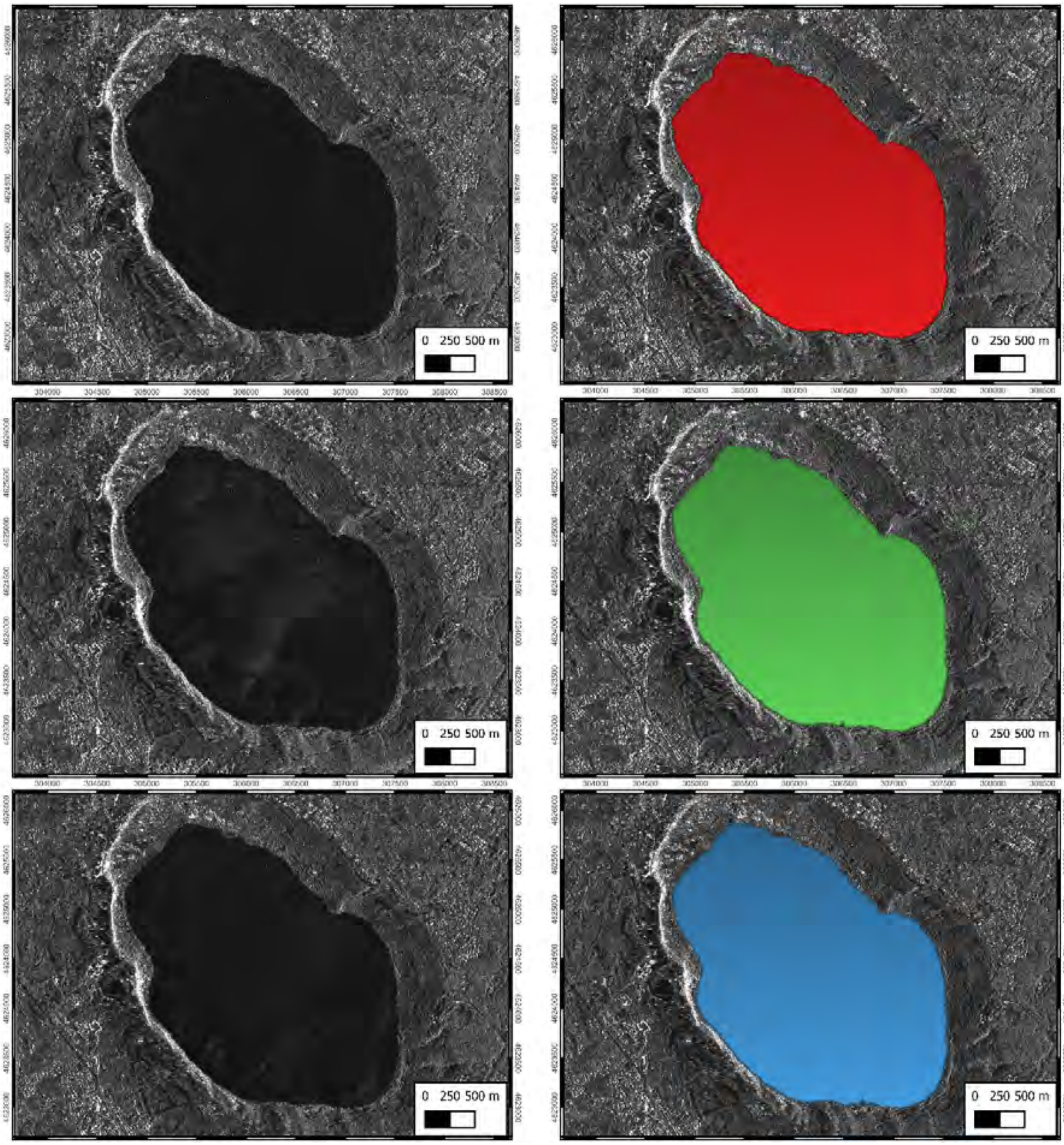

Figure 1: (Left) COSMO-SkyMed-1 image. (Right) COSMO-SkyMed image with lake mask overlay (July 2017 (red) - 2020 (green) - 2023 (blue) – EPSG 32633).

Figure 2: Comparison between the masks of 2017 (red), 2020 (green), and 2023 (blue) of Albano Lake in the northern shoreline (EPSG 32633).

Outlook for the future

This work proposes a preliminary workflow for monitoring water reservoir dynamics using high-resolution SAR imagery. The first results demonstrate the feasibility of this approach for water segmentation and water area change computation. Nevertheless, implementing an adaptive thresholding technique (e.g., Otsu), applicable to different regions and not affected by vegetation or man-made structures, could improve the segmentation results and the procedure efficacy.

Future developments will therefore include further evaluation of the investigated workflow performances using a larger dataset, focusing also on the effects of different acquisition geometries. Furthermore, a validation procedure will be implemented to estimate the accuracy of the proposed methodology.

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DEVELOPMENTS AND APPLICATION OF A BAYESIAN STATISTICAL APPROACH TO MAP FLOOD EVENTS FROM SAR DATA TIME SERIES

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Keywords: Urban floods, Flood monitoring, SAR time series modelling, Bayesian estimation

EXTENDED ABSTRACT

Recent methods of mapping floods benefit from remote sensing. A statistical analysis of historical time series of remotely sensed data can be used to determine the likelihood associated with the presence of water in an area of interest. Lidar, optical, GNSS, and Synthetic Aperture Radar (SAR) data can be used to this end. SAR data, which can be collected independently from illumination and cloud cover conditions, are particularly useful to monitor floods with high resolution in both space and time. Probabilistic algorithmic techniques, like the Bayesian model, are appropriate for the analysis of time series of the variables under consideration.

In the hypothesis of wanting to define the concept of flood risk in a given area, the proposed method defines the flood confidence level connected to the presence/absence of water on the surface which can be assessed through the intensity and interferometric coherence quantities associated with the SAR images, in different polarizations when available, according to a Bayesian approach [1]. In this context, floods are considered as temporally impulsive events lasting a single, or a few consecutive acquisitions within a series of hundreds of SAR images. Specifically, ongoing research work concerns the design of a method capable of estimating the historical series of flooding confidence maps, over an area of interest. Hydrogeomorphological ancillary data, including maps of slope, height above the nearest drainage (HAND) and radar layover/shadow, are useful aids for characterizing the probability calculations within the Bayesian model. According to Bayes' equation [2], we can express the posterior probability $p(F|\epsilon_1, \epsilon_2, .., \epsilon_n)$ for the presence of floodwater (F) for a certain pixel at a certain time *t*, conditioned by the observables $\epsilon_1, \epsilon_2, .., \epsilon_n$, as a function of the flood likelihoods $p(\epsilon_1|F)$, $p(\epsilon_2|F), \dots$, $p(\epsilon_n|F)$, the non-flood likelihoods $p(\epsilon_1|\bar{F})$, $p(\epsilon_2|\bar{F}), \dots, p(\epsilon_n|\bar{F})$, and the a priori probabilities $p(F)$ and $p(\bar{F})$:

$$p(F|\epsilon_1, \epsilon_2, .., \epsilon_n) = \frac{p(\epsilon_1|F) \cdot p(\epsilon_2|F) \cdot \dots \cdot p(\epsilon_n|F) \cdot p(F)}{\prod_i p(\epsilon_i|F) \cdot p(F) + \prod_i p(\epsilon_i|\bar{F}) \cdot p(\bar{F})}$$

The observable variables that can be examined include the intensity, σ^0 (normalized backscatter), and the interferometric coherence, γ, intended here as the coherent correlation between consecutive SAR images. These can be used in different polarization combinations such as vertical- or horizontal-transmit / receive (VV, VH, etc.), and combined in the Bayes' Theorem. The flood likelihoods can be estimated from Gaussian distributions of data fitted over permanent water areas, whereas, to estimate the likelihood of no-flood conditions, we consider the residuals of the time series with respect to a temporal model trend, assumed to be a smooth function, relying on the above-mentioned assumption that flood events appear as anomalies in a temporal SAR intensity or coherence trend. Generally, the smooth variables variations in time over land areas can be modelled as parametric functions, such as low-degree polynomials or sums of harmonic terms. In our

work we use Gaussian processes (GP)-based regression to fit the temporal intensity and coherence time series. The prediction is probabilistic (Gaussian), so that one can compute empirical confidence intervals (online fitting, adaptive fitting) for the prediction in some region of interest. Different autocovariance functions, or kernels, can be specified. Common kernels are provided, but it is also possible to specify custom kernels. GPs are valid alternatives to parametric models, in which data trends are modeled by "learning" their stochastic behavior by optimizing some "hyperparameters" of a given kernel [3].
We present results over three case studies. The first one concerns the Metaponto coastal plain, in the Basilicata Region (southern Italy), facing the Ionian Sea. The area is crossed by five main rivers, i.e. Bradano, Basento, Cavone, Agri and Sinni, which reach the Gulf of Taranto with directions perpendicular to the coastline. In the last two decades the area has been affected by a recurrence of flood events from these rivers, which have caused extensive economic damage to infrastructures, agricultural, geotourism activities and archaeological heritage, although with an intensity that is not exceptional on an absolute scale. In this case, attention was paid to the flood events of 11-18 March 2016, 27-28 March 2018, 18-23 October 2018 and 26-27 March 2020. For the study of this area images from the Sentinel-1 C-band satellite constellation were used, in VV and VH polarizations, acquired from an ascending orbit from 2015 to 2021, and made openly available by the European Space Agency (ESA) [4]. The second case study concerns an inland area of Northern Italy located in the Piedmont region, crossed by the Sesia river and its tributaries, which involves various municipalities, including Vercelli, and in which there are several rice fields. In October 2020, after incessant rains that hit upper Piedmont, the floods of the Sesia devastated the valley floor causing the collapse of the bridge connecting the municipalities of Gattinara and Romagnano Sesia. In this context, a flood event that occurred on 4-6 October 2020 was examined. To study this area, another Sentinel-1 C-band time series in VV and VH polarizations in ascending orbit from 2015 to 2023 was used. The third study area concerns the Gargano promontory, north of the Puglia region, in the eastern part of the Foggia province, semi-surrounded by the Adriatic Sea. Here the surface hydrographic network is deeply incised into the Gargano mountains. Exceptions are small areas in the north, where a few seasonal waterways of limited length and flow are concentrated, which flow into the Adriatic in the municipal areas of Vico del Gargano and Rodi Garganico, or which flow into the coastal lakes of Lesina and Varano. In this area, attention was paid to flood events occurred on 15-16 July 2016, 18-19 July 2021 and 28 August 2021. For the study of this area, a series of COSMO-SkyMed images in X-band was used, acquired in HH polarization, in ascending orbit from 2011 to 2022. These data were made available by the Italian Space Agency (ASI) in the framework of the GEORES collaborative project (Geospatial application to support the improvement of environmental sustainability and resilience to climate change in urban areas - Agreement n. 2023-42-HH.0) between the University of Bari (UNIBA), the Institute for Electromagnetic Sensing of the Environment of the Italian National Research Council (CNR-IREA), and ASI.
With regard to the first case study, the time series of confidence maps of the presence of surface water was obtained, and validated through comparison with rainfall data acquired from three rain gauge stations located in areas where flooding was detected on the dates indicated. By observing the condition of some pixels within the study area, a more effective classification capacity was found through confidence maps of the presence of water created through Gaussian Processes fits compared to those created through harmonic fits. A problematic aspect of some particularly intense atmospheric disturbances was highlighted, which may alter the C-band SAR signal in the Sentinel-1 images, causing classification errors in terms of confidence in the presence of surface water.
In the second case study, the time series of the confidence maps of the presence of surface water were obtained through different combinations of the variables σ^0_{VV}, σ^0_{VH}, γ_{VV}, γ_{VH} within the extended formula of Bayes' Theorem. A validation of each type of output map was attempted through the computation of ROC curves based on the comparison with the Copernicus Emergency Management Service (ECMS) map referring to the flood event of 4 October 2020 (activation ECMS EMSR468; https://emergency.copernicus.eu/mapping/list-of-components/EMSR468). Subsequently, a study was conducted for each type of land cover, according to the Corine Land Cover 2021 map distributed by the Higher Institute for Environmental Protection and Research

(ISPRA). Within this area of study, evaluations are underway regarding the possibility of defining more specific kernel functions capable of making Gaussian Process regression more effective, and whose hyperparameters can be used also for classification purposes.

In the third case study, the time series of the confidence maps of the presence of surface water were obtained by applying Bayes' Theorem with respect to the variables σ^0_{HH} and γ_{HH}. In this case, the sequence of water confidence maps highlights a significant involvement of the coastal strip and some small internal areas of the Gargano promontory. Also in this case, classification errors were detected due to atmospheric disturbances that altered the X-band SAR signal in the COSMO-SkyMed images. This last research work has recently found application within the GEORES project. GEORES is based on the synergistic use of the most advanced Earth Observation technologies and methods based on artificial intelligence (AI, XAI) for the identification of portions of urban and peri-urban territory at high risk from the point of view of land degradation caused by hydrogeological instability phenomena, sediment flow and/or vegetation fires [5]. The project involves the integration of data, calculation models and algorithms developed by the University of Bari (Agronomy, Physics and Geology Departments) in collaboration with CNR-IREA and, jointly with ASI, the component related to flood risk will be developed using the confidence maps of the presence of water deduced from the Bayesian statistical approach.

Acknowledgments
This research is carried out within the GEORES project, funded by the Italian Space Agency (Agreement n. 2023-42-HH.0) under the ASI's program "Innovation for Downstream Preparation for Science" (I4DP_SCIENCE).

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SAR REMOTE SENSING AND MODELLING TECHNIQUES APPLIED TO THE STUDY OF WATER RESOURCES AND RELATED EFFECTS ON SETTLEMENTS AND INFRASTRUCTURES

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Keywords: Remote Sensing, SAR, Water resources, MT-InSAR, Climate changes

Abstract

Climate change is one of the 21st century's most significant social, economic and ecological challenges. Its impact on the environment is heavy and, among others, concerns the management of available water resources. For this reason, continuous monitoring of the water resources, such as river basins, lakes, groundwater table levels, glaciers or dams, can be fundamental to both understanding the evolution of the issue and assisting the planning and development of regional and/or national strategies for the management of water resources. Analysing time series of satellite-based measurements can provide cost-effective and reliable information on the water bodies that decision-makers can use. Within this context, remote sensing plays an important role. In particular the Synthetic Aperture Radar (SAR) and related processing techniques, thanks to its fine spatial resolution imaging and the almost all-weather and day and night acquisition capability, can be a very useful tool to monitor water resources. State-of-the-art approaches, aimed at exploiting the SAR imagery to monitor the water extent of inland water basins, are mainly based on the use of SAR imagery collected at different times, i.e., a time series analysis [1,2,3]. Water content variations can also impact the land surrounding a water body producing ground subsidence/uplift which can be effectively monitored with millimetric accuracy by Multi-Temporal SAR Interferometry (MT-InSAR) techniques [4,5]. The aim of this work is to describe some case studies dealing with the exploitation of the water resources, the monitoring of artificial basins, the effects of water level changes on the dam and the glacier dynamics. In the context of glacier studies, SAR data can be exploited to estimate the rate of melting due to the global temperature increase. To this aim, a processing technique working on the amplitude of the SAR signal, called Pixel Offset Tracking (POT), can be applied, since it is not affected by phase ambiguity problems due to the strong ice flow velocity in the order of metres/day. Here the Viedma glacier located in Patagonia (Argentina) was studied using a pair of Sentinel-1 images acquired on 15th May and 8th June 2021. Viedma is the second largest glacier in the Southern Hemisphere with a length of approximately 70 km. In the time interval between the acquisitions, POT analysis of the Viedma glacier shows a cumulative displacement of about 50m especially considering its terminal part towards lake Viedma (Figure 1). Such results highlight how the glacier is subjected to flow velocity of around 1-2 m/day.

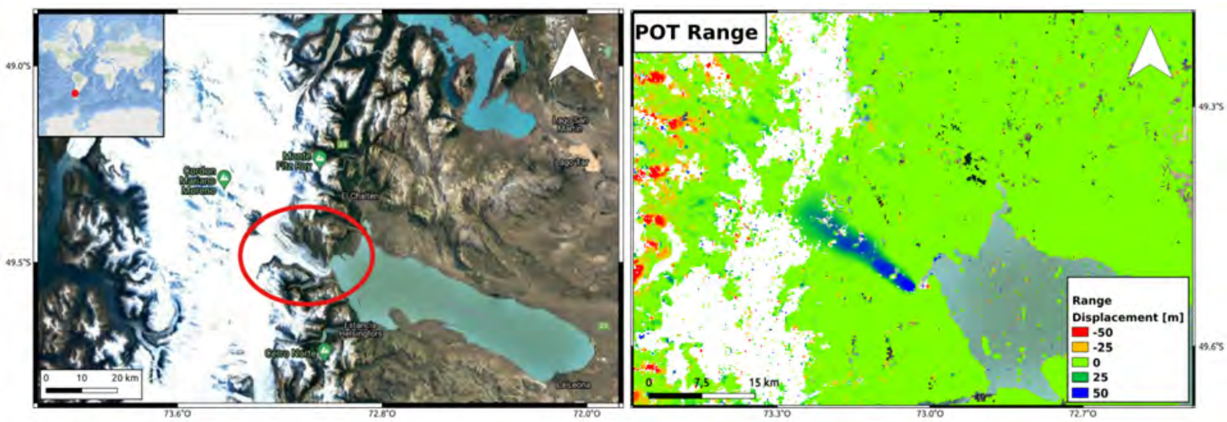


Fig. 1. Viedma glacier (left) and POT range displacement (right) from Sentinel-1 data.

A second case study combines remote sensing and hydrology focusing on a portion of the Po Valley, specifically the North-Western area of the Emilia Romagna region. Here we used Cosmo-SkyMed and Sentinel-1 data, in order to estimate the cumulated vertical ground displacement from June 2012 to January 2022. To the proposed aim, we applied an MT-InSAR technique called Small Baseline Subset. Such method allowed us to retrieve some areas affected by noticeable subsidence phenomena: (i) the southern part of Reggio Emilia municipality, (ii) several industrial areas around Modena, Parma and Reggio Emilia, (iii) a sector of the high-velocity railway connecting the cities of Milan and Bologna. The piezometric level analysis suggests that subsidence occurs when groundwater withdrawal exceeds aquifer recharge (since mid-2015 at the southern part of Reggio Emilia – Fig. 2a). Moreover, the fast lowering of the water table heavily increases the deformation trend at the railway embankment (Fig 2b) where primary consolidation processes of the soils affect the transport infrastructure.

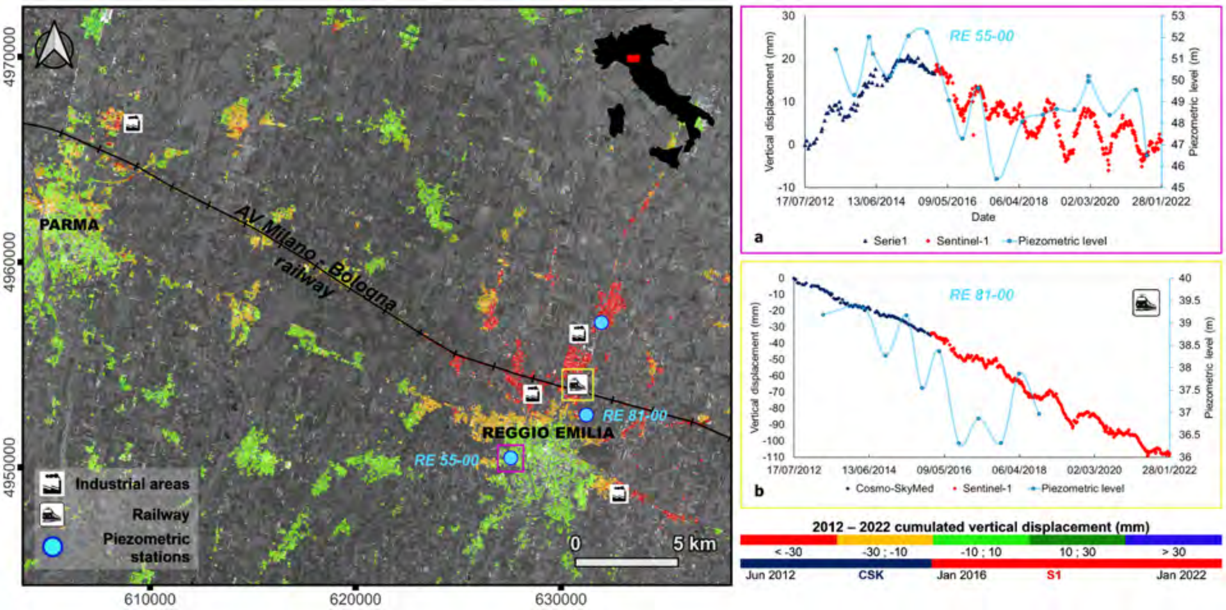
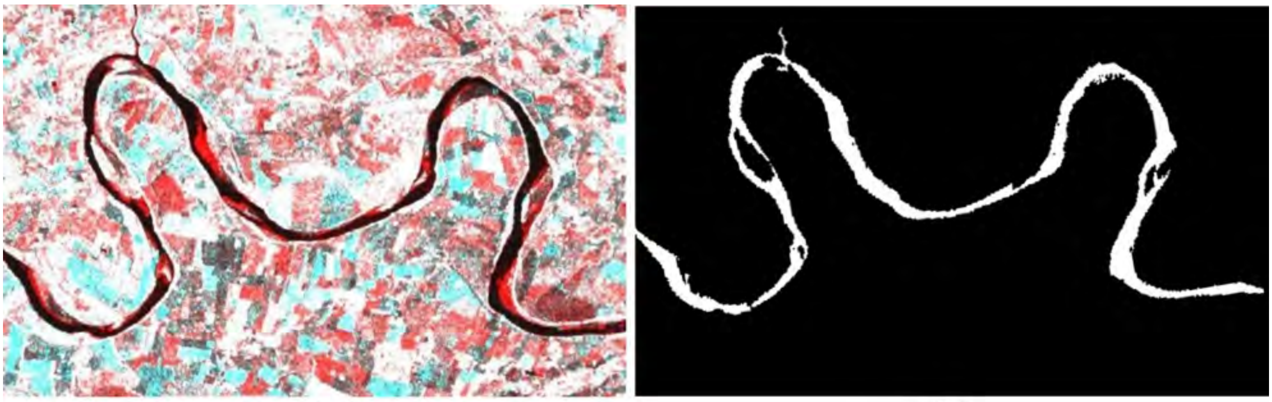


Fig. 2. Cosmo-SkyMed and Sentinel-1 cumulated vertical displacement map and displacement time series plotted (a) at the southern part of Reggio Emilia municipality (pink polygon) and (b) at the Milano-Bologna railway sector (yellow polygon). The light blue line reflects the piezometric variations recorded at the measuring station closest to each studied area.

A further case study concerns the effects of the drought impacting the Po River basin in 2022, declared the most severe water crisis of the last 70 years by the Po River District Basin Authority. The main goals of this study were: 1- estimating the water-covered area and tracking it over time; 2- complementing the previous estimates with vertical ground deformation from InSAR processing. These two approaches are applied to a 7-year series of 217 Sentinel-1 SAR data collected over the Po River section close to Piacenza, Emilia Romagna, from June 2015 to September 2022. The selected test site was strongly affected by drought in the summer of 2022, hence, monitoring the area is fundamental to understanding its emplacement evolution and climate change effects. An excerpt of the RGB false-colour composite image is shown in Figure 3 (a), where red = green and blue are associated with the VV intensity channel collected in June 2022 and June 2015, respectively. With this setting, the areas affected by drought are well visible in red colour. The proposed methodology consists first in obtaining binary images where land and river are clearly distinguished by using the methodology introduced in [3] along the whole time series of Sentinel-1 SAR imagery, second in estimating the extent of the water coverage by using the pixels labelled as “water” in the binary image, see Figure 3b. According to [3], the water-body area is estimated from the binary imagery considering the 5x20m^2 pixel size of IW Sentinel-1 data. The results obtained processing the whole time series are shown (as a blue line) in Figure 4a, where the hydrometric water level, provided by the District Basin Authority, is also shown (red line) as a benchmark. This result shows seasonal and interannual trends with a particularly marked decrease in the water-covered area in 2022. The second part of this study relies on the estimation of the ground deformation phenomena affecting the banks of the river using the MT-InSAR approach [6]. The InSAR-based deformation results show an uplift during the drought period and subsidence when the surface load due to river water level and rainfall increases, thus suggesting a prevalent elastic behaviour of the riverbanks (Figure 4).



(a) (b)

Fig. 3. (a) False colour composite image of a section of the Po River close to the town of Piacenza, where R = G = June 2022 and B = June 2015. The areas affected by the drought are visible in red; (b) binary image related to June 2015 obtained using the global threshold CFAR method.

A further case study deals with the analysis of ground subsidence in Mexico. Several cities in Mexico experience strong ground subsidence due to the overexploitation of water resources for agricultural purposes. Our analysis deals with the use of long InSAR time series based on ENVISAT, Sentinel-1, and COSMO-SkyMed image stacks over the city of Guzman. The mean velocity map reveals a high deformation gradient in the city up to 60 mm/yr (see Figure 5). The intense water exploitation has caused ground fissuring within the city. The deformation trends have been also modelled through numerical methods, and we found that ground deformations and fissuring are due to variable sediment thickness and differential compaction, driven by the exploitation of the aquifers and controlled by buried faults.

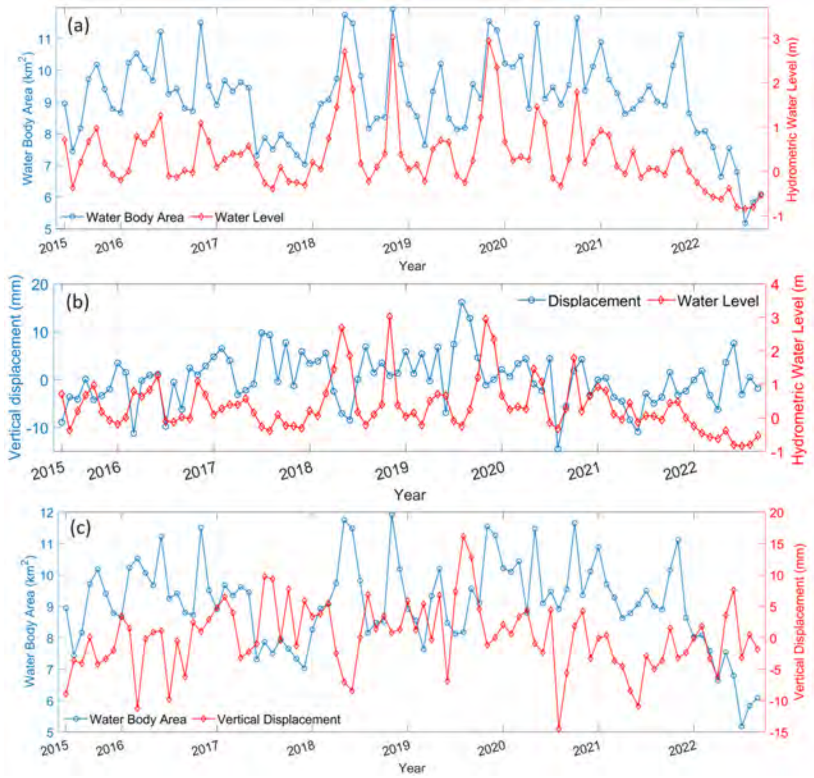


Fig. 4. Comparison between (a) water body area and water level; (b) InSAR-based vertical displacement and hydrometric water level; (c) water body area and InSAR vertical displacement.

Strong ground subsidence has also affected Mexico City for several decades. It has been assessed that ground subsidence affects soil's spatial and temporal seismic response [7]. In particular, in approximately nine years, Mexico City's ground surface has subsided by approximately 0.5-3.5 m, and the soil resonant period has decreased by approximately 0.1-0.4 s. The estimated change in the resonant period significantly impacts the response spectra used for design purposes. It is then necessary to update the map of the soil resonant period to account for the change of dynamic properties of soils caused by subsidence.

In summary, the results proposed in this study demonstrate that SAR and related processing techniques are effective tools for studying the effects of the exploitation of water resources, performing the monitoring of artificial basins, measuring the effects of water level changes on dams, and to carry on the monitoring of glaciers. In addition, InSAR provides useful hints to the decision-makers regarding climate change's short-, medium, and long-term impact on water resources and infrastructures.

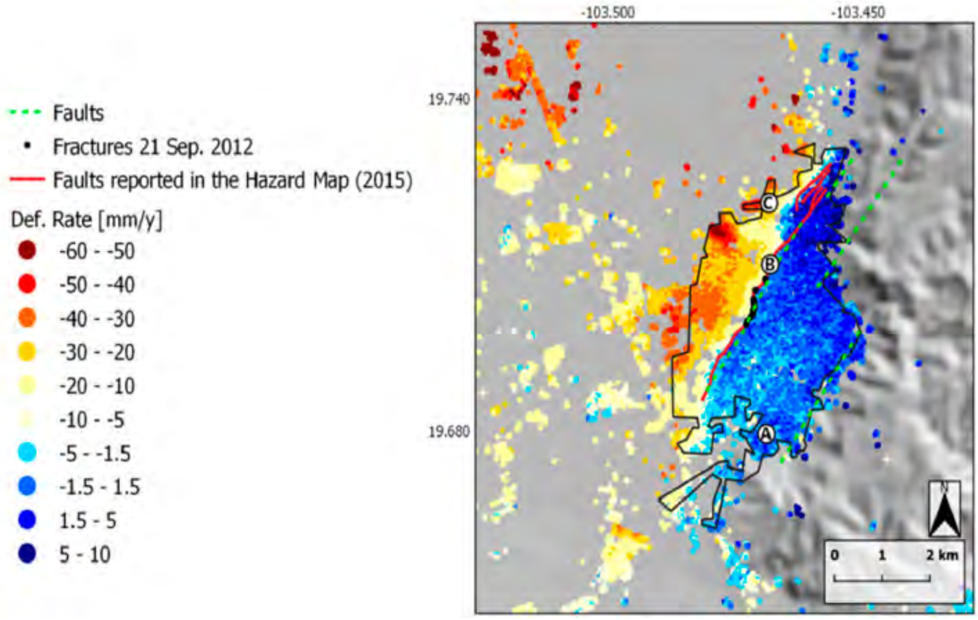


Fig. 5. Sentinel-1 velocity map on ascending orbit, faults (dashed green and red lines), and observed fractures (black points).

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L'INTELLIGENCE SATELLITARE PER LA MANUTENZIONE PREVENTIVA DELLE RETI IDRICHE E DEGLI IMPIANTI

G. Forenza

Planetek Italia

Keywords: Planetek Italia, Rheticus, Rheticus Network Alert ; Copernicus Sentinel-1; Earth Observation; Geo-analytics, MTInSAR Monitoring; Synthetic Aperture Radar;

Abstract

Il monitoraggio satellitare è un'importante risorsa nel campo della gestione delle risorse idriche. Globalmente, le soluzioni offerte da Planetek Italia nel settore delle Water Utility e degli Enti di tutela e gestione delle risorse idriche integrano tecnologie avanzate di remote sensing con l'esperienza nel settore geospaziale, fornendo strumenti e informazioni cruciali per affrontare le sfide legate alla gestione delle risorse idriche in modo efficace e sostenibile.

L'esperienza maturata in oltre 30 anni di attività continuativa ha permesso di definire l'offerta di servizi denominata: LO SPAZIO PER LE WATER UTILITIES.

Utilizzando tecnologie satellitari avanzate è possibile ottenere informazioni cruciali sulla distribuzione, sulla qualità e sulla quantità delle risorse idriche in diverse regioni del mondo.
I principali ambiti applicativi delle soluzioni di monitoraggio satellitare sviluppate da Planetek Italia a supporto della gestione delle risorse idriche includono:

1. **Monitoraggio dei movimenti**: monitoraggio continuo dei fenomeni di instabilità che interessano le reti di condotte (idriche e fognarie) nelle aree urbane ed extraurbane, e causati dagli spostamenti del terreno.
2. **Monitoraggio dell'umidità dei suoli**: Pre-localizzazione perdite idriche per fornire un supporto alle attività del gestore del SII riducendo le aree su cui focalizzare le risorse di indagine in-situ.
3. **Mappatura dei cambiamenti del territorio**: analisi delle trasformazioni antropiche in prossimità di condotte idriche e fognarie, per monitorare le *aree di tutela assoluta* ed individuare i cambiamenti del territorio ai fini della gestione patrimoniale.
4. **Monitoraggio della qualità dell'acqua**: I satelliti possono rilevare la qualità dell'acqua attraverso varie tecniche, come la misurazione della torbidità, delle concentrazioni di nutrienti o di inquinanti. Queste informazioni sono cruciali per valutare la sicurezza e l'idoneità dell'acqua per scopi come il consumo umano e l'irrigazione.
5. **Monitoraggio della vegetazione**: Il monitoraggio satellitare può aiutare a valutare lo stato della vegetazione e le anomalie stagionali che possono ricondursi a difetti infrastrutturali e/o possono indicare cambiamenti nei modelli di pioggia o nella disponibilità di acqua nel terreno.
6. **Analisi degli eventi estremi**: Aiuta i gestori delle risorse idriche e le autorità di protezione civile a prepararsi e rispondere tempestivamente agli eventi metereologici estremi

Nell'intervento presso 14° Workshop Tematico AIT-ENEA analizzeremo 3 casi applicativi:

1. CAMBIAMENTI CLIMATICI – FRANCIA. Siccità estreme in terreni argillosi causa di danni alle infrastrutture interrate
2. MONITORAGGIO DIGHE - ITALIA. Qualità dell'acqua negli invasi e stabilità dei versanti
3. RIUSO DELLE ACQUE REFLUE IN AGRICOLTURA - ITALIA

1 - CAMBIAMENTI CLIMATICI – FRANCIA

Ottobre 2023 è stato il più caldo della storia (dati Copernicus ECMWF).
Stagionalità anomale e fenomeni di siccità straordinari hanno causato danni tangibili con impatti notevoli sulla gestione delle acque e le infrastrutture.
In particolare, le case costruite su terreni argillosi risultano visibilmente colpite.
Nei periodi di siccità il terreno si restringe e, al contrario, si gonfia durante i periodi piovosi.
Ciò provoca movimenti del terreno e di conseguenza ciò provoca danni visibili con fessure e crepe nei muri
In Francia, secondo il Ministero della Transizione Ecologica, quasi la metà dei suoli è esposta a questo fenomeno.
Quanto più gli episodi meteorologici sono gravi e frequenti, tanto maggiori sono i danni. La siccità record dell’estate 2022 a cui è seguito un altro record nel 2023 ha quindi conseguenze senza precedenti.
Il risarcimento dei danni del solo 2022 dovrebbe avere un costo record quest'anno, tra 1,9 e 2,8 miliardi di euro, secondo quanto dichiarato da Florence Lustman, presidente della Federazione francese delle assicurazioni.
In Francia l'emergenza nazionale ha inoltre portato alla realizzazione di una *Mappa Nazionale di Rischio legato ai suoli Argillosi* che viene diffusa a tutti i livelli affinchè si conoscano le portate del fenomeno e si mettano in campo misure di mitigazione dei rischi.


ici PAR FRANCE BLEU ET FRANCE 3 | Le média de la vie locale

Maisons fissurées : un coût record à cause de la sécheresse de 2022

Les conséquences de la sécheresse record de cet été se ressentent encore. Des fissures apparaissent sur des maisons dans toute la France. L'indemnisation des dégâts devrait donc avoir un coût record cette année, compris entre 1,9 et 2,8 milliards d'euros, selon les informations de France Inter.

De Léa Dubost

Lundi 21 novembre 2022 à 7:04

Par France Bleu

La sécheresse peut provoquer de graves fissures sur les maisons, notamment sur des sols argileux. © Maxppp - JOURNAL SAONE ET LOIRE

FIGURA 1-La siccità può causare gravi crepe nelle case, soprattutto su terreni argillosi.
© Maxppp - RIVISTA SAONE ET LOIRE

I servizi Rheticus® di supporto ai nostri clienti in Francia e nel mondo, oggi si sono arricchiti di nuove funzioni specifiche di monitoraggio di questi fenomeni legati ai cambiamenti climatici.

I suoli con queste particolari argille sono diffusissimi anche in Italia, ad esempio nella Pianura Padana, e nel resto dell'Europa.

Rheticus® Network Alert

Identificare potenziali problemi sulle condotte interrate prima che diventino critici è un’attività sfidante.Le aziende multi-utility investono grandi risorse finanziarie per mantenere le reti ed individuare perdite e problemi strutturali.
Ad oggi le politiche di manutenzione delle aziende sono strettamente orientate alla riduzione delle dispersioni in caso di interruzioni di servizio causate da problemi rilevanti.
Un gran numero di aziende mette in campo attività di sostituzione delle tubazioni solo in quelle aree in cui intensi fenomeni di subsidenza hanno rilevato perdite nelle condotte.

In questo panorama, identificare i movimenti del terreno prima che diventino critici è un’attività sfidante.

Grazie ai satelliti radar e le tecniche interferometriche, oggi è possibile monitorare il territorio e le infrastrutture in modo continuo e su aree vaste o remote, individuando per tempo le infrastrutture a rischio.

Rheticus® Network Alert è un servizio web verticale chiavi in mano per il monitoraggio continuo dei fenomeni di instabilità che interessano le reti di condotte (idriche e fognarie) nelle aree urbane, e causati dagli spostamenti del terreno.
Rheticus® Network Alert indica le condotte da ispezionare e/o sorvegliare e consente agli operatori di agire in base alle indicazioni fornite dal servizio, di semplificare le attività di manutenzione e di organizzare le ispezioni in base a differenti livelli di priorità.
Pertanto, il servizio consente un approccio "a priori", contribuendo a evidenziare i possibili problemi prima che diventino critici.
Di conseguenza, le aziende gestiscono meglio le proprie risorse finanziarie, riducendo interruzioni di servizio e/o rischi per persone e beni.

FIGURA 2 – Rheticus® Network Alert – Classificazione delle reti - Inspection Priority Score®

L'analisi della stagionalità
Il funzionamento della rete idrica è caratterizzato da particolari peculiarità, rendendo strettamente connesso il sistema di riparazione dei guasti con la manutenzione dell'affidabilità operativa.
Le Water Utilities mantengono un registro dettagliato dei guasti, tuttavia esso contiene soltanto dati conclusivi che non individuano le cause primarie.
Sebbene sia possibile identificare il tipo di guasto, come corrosione o fessurazioni, individuarne l'origine risulta molto più complesso.
Studi accademici([1]) dimostrano che il tasso di guasti delle condutture idriche è influenzato da diversi fattori, tra cui l'instabilità del terreno, l'età della conduttura, la sua funzione e i materiali utilizzati. L'impatto stagionale, insieme alle variazioni di temperatura, ha un'influenza significativa sul tasso di guasti.
Molte situazioni presentano irregolarità e fluttuazioni nel tempo, inclusi fenomeni stagionali che contribuiscono ad aumentare l'incidenza dei guasti, soprattutto in determinati periodi dell'anno.
In Francia, i 2 principali operatori del ciclo idrico integrato che utilizzano Rheticus® Network Alert riportavano una maggiore concentrazione di danni alle condotte interrate proprio in corrispondenza delle aree più critiche individuate dalla Mappa Nazionale di rischio legato ai suoli Argillosi.

FIGURA 3 – Integrazione della Mappa Nazionale dei rischi per i territori argillosi di tutta la Francia

La classificazione delle condotte offerta da Rheticus® Network Alert è basata sull'analisi dei movimenti della supperficie terrestre grazie alla tecnicha di interferometria SAR multitemporale (MTInSAR) che consentono di rilevare e monitorare spostamenti millimetrici che si verificano su bersagli puntuali selezionati che mostrano proprietà di retrodiffusione radar coerenti nel tempo.
Le misure prodotte sono rese disponibili attraverso il geo-portale Rheticus® Network Alert.
Attualmente sono operative diverse missioni spaziali con radar ad apertura sintetica (SAR), ad esempio la costellazione italiana COSMO-SkyMed (CSK) e la missione Copernicus Sentinel-1 (S1) che garantiscono archivi di dati per la produzione dei trend storici e continue acquisizioni con cui aggiornare le misure nel tempo.
Applicazioni di successo a diversi fenomeni geofisici sono già state dimostrate in letteratura(2;3;4;5).

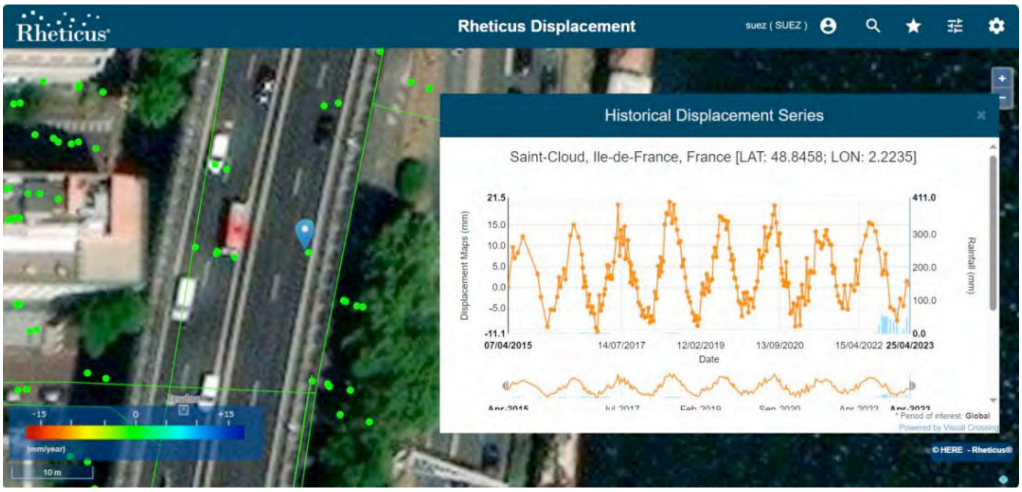

FIGURA 4 - Andamento stagionale dei movimenti analizzati nel portale Rheticus® Displacement

L'esperienza con gli utenti in Francia ha portato allo sviluppo di nuove features del servizio Rheticus® Network Alert che si basano su:

- La capacità di analisi dei trend di spostamento che impattano le condotte
- La capacità di tematizzare le infrastrutture indicando livelli di priorità grazie all'algoritmo brevettato Inspection Priority Score®
- Analisi dell'andamento stagionale dei movimenti che interessano l'area a causa dell'espansione dell'argilla.

L'analisi stagionale dei movimenti consente all'utente un' immediata individuazione dei tratti maggiormente impattati dal fenomeno grazie ad un indicatore geo-analitico dedicato denominato Seasonality Score.

FIGURA 5 – La dashboard dinamica di Seasonality Score con coefficiente da 0 a 1 permette una selezione dei tratti da analizzare rispetto al livello di stagionalità dei trend di spostamento

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FORECASTING SERVICES PLATFORM FOR ALGAE BLOOMS IN SARDINIAN RESERVOIRS (MULARGIA, FLUMENDOSA & TIRSO)

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Keywords: water quality, Landsat-8 -9 and Sentinel-2A -2B, early warning and previsional model platform

Abstract

Within the H2020 project PrimeWater, the partnership generated operational satellite-based water quality datasets for four different case studies in Europe, Australia and the USA. The applied physics-based retrieval algorithm Modular Inversion and Processing system (MIP) accounts and corrects for a variety of environmental impacts, such as atmospheric conditions, adjacent land cover, water surface and composition of water constituents as well as considering varying observation geometries and sensor properties. It delivers main water quality parameters like turbidity, chlorophyll-a concentrations, Secchi disk depth, water temperature and a harmful algae bloom indicator which is sensitive to cyanobacteria. The automated delivery mechanisms, the datasets are ingested directly into the online accessible PrimeWater platform and are further used for assimilation with modelled data. Based on Copernicus missions of Sentinel-2A/B combined with additional data from Landsat 8, spatial resolutions down to 10m pixel size allow monitoring of larger reservoirs, such as Lake Mulargia and Flumendosa in Italy. For these use cases, time series from 2015 are used both from satellite and in situ analysis.

Scope of the work

The present abstract refers to the provision of operational water quality forecasting platform services for the multipurpose interconnected reservoirs of Mulargia, Flumendosa and Tirso (under implementation) in the central Sardinia. The reservoirs are also used for recreational activities, hydropower and/or flood management with impacts to the lives of many inhabitants nearby.

Lake Tirso

Lake Mulargia

Lake Flumendosa

Fig.1 Case study reservoirs

The operational tools and services for the 3 reservoirs provide the following functionalities:

1) Monitoring of reservoirs with EO-based products obtained from Landsat and Sentinel satellites.
2) Hydrological forecasting services for river discharges and nutrient loads in the upstream catchments of the 3 reservoirs.
3) Water quality forecasting in the 3 reservoirs through 3-dimensional coupled hydrodynamic and water quality models.
4) Scenario-based tool for blending optimization between the interconnected reservoirs.

The forecasting services start from the existing setups from previous modeling attempts (e.g., PrimeWater project) for Flumendosa and Mulargia reservoirs. The scenario-based tool for Blending Optimization developed in PrimeWater Project (Horizon 2020), that were limited to Flumendosa and Mulargia reservoir will be extended and modified to account for water originating from Tirso reservoir, and the scenarios to be examined will be finalized.

The following tables (Table 1-3) summarize the core characteristics of the monitoring and forecasting components.

Table 1. Core service characteristics for EO monitoring

Spatial resolution	From 10x10m^2 (Sentinel) to 30x30m^2 (Landsat)
Water Quality variables	Chlorophyll-a, Surface Water Temperature, Turbidity, Total Suspended Matter, Secchi Depth, Total Absorption, Harmful Algae Bloom Indicator, True color Image
Update interval	up to multiple images per week depending on weather conditions (cloudiness, sun glint, etc.)
Monitoring Product delivery	EO-based water quality images will be provided on web-based platform.

Table 2. Core service characteristics for Hydrological Forecasting

Models	E-HYPE Hydrological model
Spatial resolution	Catchment based modelling. Average hydrological catchment size 200 km^2
Temporal resolution	Results available in daily time step
Forecasting horizon	Short to medium term forecasting (Up to 10 days lead time)
Forecasted hydrodological variables	River discharges, water temperature, nutrient loads (nitrogen & phosphorus), suspended sediment
Forecast update interval	Every 24 hours
Forecast delivery	Maps and time series of forecasted variables are delivered through web-based platform

Table 3. Core service characteristics for Water Quality Forecasting

Models	Coupled hydrodynamic and ecological modelling with Delft3D FLOW and Delft3D WAQ
Data Assimilation	Real time assimilation of EO-based water quality products (e.g., chlorophyll-a, water temperature), upon data availability
Spatial resolution	Regular grid with cell size depending on reservoirs surface area (typical 100x100 m^2). Vertical discretization in layers depending on reservoirs depth (typical 5-20).
Temporal resolution	Results available in 6 hours' time step
Forecasting horizon	Short to medium term forecasting (Up to 7 days lead time)

Forecasted hydrodynamic variables	Water velocities, water temperature
Forecasted WQ variables	Chlorophyll-a, Nitrogen (NO3, NH4), Phosphorus (PO4), Dissolved Oxygen
Forecast update interval	Every 24 hours
Forecast delivery	Maps and time series of forecasted variables are delivered on web-based platform

<u>Satellite imagery dataset and product delivered</u>

The calculated high-resolution satellite-based time series in the pilot use cases can help to identify spatial and seasonal trends for a set of important water quality related parameters.

For the described use case, a set of water quality products are generated using the MIP processing chain in a fully operational way, including the most important parameters of Chlorophyll-a (CHL) in µg/l, Harmful Algae Bloom Indicator (HAB) sensitive to the appearance of Phycocyanin and Phycoerythrin, Secchi Disc Depth (SDD), Surface Water Temperature (SWT).

In total, over 3,000 single satellite scenes from Sentinel-2A/B and Landsat 8 have been processed from 2015 to spring 2021.

For each satellite record, the satellite-based water quality parameters have been calculated and delivered in 10m (Sentinel-2A/B) and 30m (Landsat 8) spatial resolution, giving insights to the actual water quality status and distribution patterns.

Sentinel-2 A/B and Landsat 8 data have been processed using EOMAPs proven physics-based Modular Inversion and Processing System (MIP), which is orchestrated by the EOMAP Workflow System (EWS). While the EWS manages the workflow itself, the MIP architecture systematically handles the independent properties of sensor parameters and specific optical properties as well as the radiative transfer relationships. Radiative transfer modelling in the coupled atmosphere-water systems is based on the reference model Finite Element-Method (FEM) with 30 years of development history (Heege and Fisher, 2004; Heege et al., 2019; Bresciani et al., 2019).

<u>Results and further implementations</u>

The early warning capability developed in the platform allows periodic monitoring within the 9 days preceding the event, whether it be an algal bloom or a state of distress in the water. The indicators strategically positioned near the dam and at the tributaries which are known to represent the main vehicles of solid transport and therefore of nutrients, when interrogated, provide information on the quality of the water in the surrounding area as is also highlighted by the coloring of the pixels on a scale of reservoir invaded.

The knowledge of the status in the reservoirs can be used in management by directing fresh water from the northern Flumendosa to the southern Mulargia in case of occurring algae blooms or increased turbidity to improve the water quality.

Seasonal occurrence of algae blooms and its interannual changes can be identified through the calculated chlorophyll-a concentrations from the multispectral satellite sensors. By this method, annual comparisons can also be drawn.

See below the different application on platform (Fig.2, 3, 4):

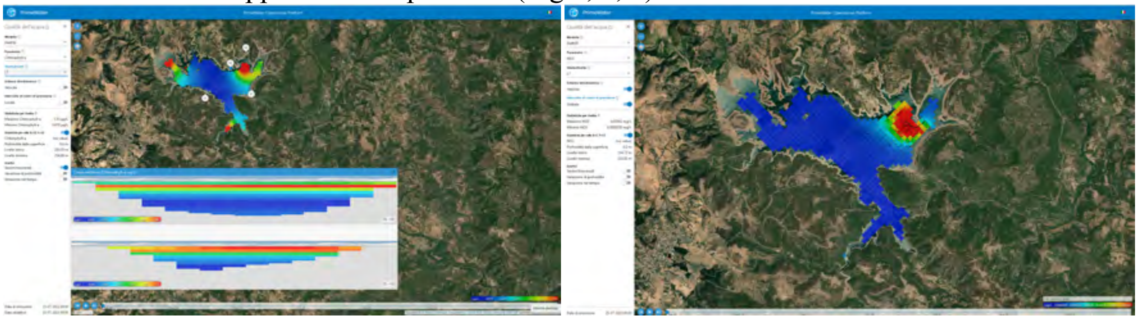

Fig.2 Water quality monitoring and hydrodynamic scheme of Mulargia reservoir

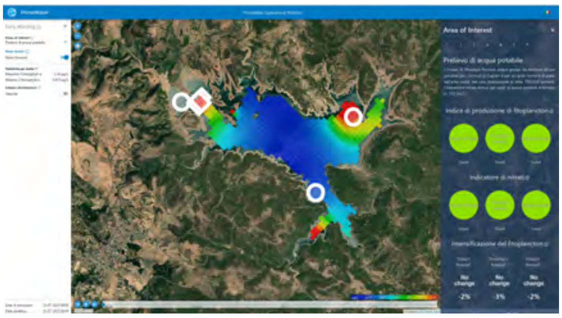

Fig. 3 Indicators of algal bloom presence in the Mulargia reservoir

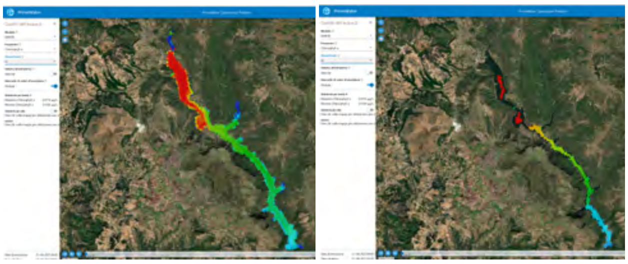

Fig. 4 State of water quality (Chlorophyll parameter) at different deep (3m, 8 m) in the Flumendosa reservoir

Others opportunities to study the water quality can be offer to hyperspectral data just experimented from airborne and in situ campaign control, that showed their potentiality to retrieve water quality parameters of Lake Mulargia. In the future the integration of this dataset with different optical satellite data such as PRISMA, DESIS, and Sentinel-3 will help to understand the spatial, spectral and temporal resolution necessary to provide useful information for water management.

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PRESENTING AN EARTH OBSERVATION SERVICE FOR MONITORING WATER RESOURCES: FIRST RESULTS

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Keywords: Earth observation (EO), Sentinel 2, Water Resources, Water Bodies, Monitoring, Drought, Early Warning

Abstract
Monitoring the availability of water resources stored in reservoirs is of paramount importance for their correct management linked to human-related applications, such as drinking, irrigation and hydroelectric power generation. This topic is particularly relevant in these last years, characterized by an increasing occurrence of drought events as a consequence of climate change. For this reason, it is important to develop reliable monitoring systems to support decision-makers accountable for water management and civil protection applications. In this framework, satellite data provides a valuable tool for implementing operational services to monitor - in a synoptic and cost-effective way - water resources availability, also in data-scarce environments (e.g., ungauged water reservoirs) and/or during crisis periods (e.g., drought events). These characteristics are likely to be present in developing countries, that are also the most vulnerable to climate change effects (e.g., exacerbation of weather-related risks). Therefore, these systems should be capable of detecting early signs of critical periods (e.g., extreme conditions potentially leading to drought events) to allow managing authorities to undertake actions useful to mitigate the negative effects associated with these hazards.

Within this context, this work was carried out to design and validate a prototype of an Earth Observation (EO) service for mapping and monitoring the water resources by means of Sentinel 2 (S2) data. The service provides the following outputs:

1. Daily Water Bodies (WB) Map: A map of the WB Extent, representing the surface area of the reservoir covered by water on the day of the S2 acquisition. This map is produced with a pixel size of 10 m, by merging the information obtained from different spectral indexes: i.e., the Normalized Difference Water Index (NDWI), the Modified NDWI (MNDWI) and the Automated Water Extraction Index (two versions: AWEIsh and AWEInsh). It is important to highlight that pixels located within the reservoirs and classified as clouds or shadows by the S2 Scene Classification maps are masked out from the analysis. If more than 40% of the reservoir's pixels is masked out, the S2 image is discarded.
2. Daily % WB Extent Time Series: A time series representing the reservoir "degree of filling", in terms of WB Extent percentage. This information is obtained by comparing the Daily S2 WB Map extent against the maximum WB Extent derived from the Global Surface Water (GSW) dataset (obtained by using Landsat data acquired from 1984 to 2021).
3. Monthly % WB Extent Time Series: A monthly time series of % WB Extent data, computed by averaging the Daily % WB Extent data collected every month.
4. Monthly % WB Extent Anomalies Time Series: a monthly time series of % WB Extent Anomalies computed as $X_t - X_\mu$, where: X_t is the Monthly % WB Extent value of a given month and X_μ is the temporal long-term Monthly % WB Extent average (for that specific month) obtained by using the GSW dataset and the available S2 data. Indeed, anomalies are a valuable and widely used tool to identify periods characterized by anomalous conditions (e.g., drought events).

The validation of the service was carried out in the San Giuliano Reservoir (Basilicata, Southern Italy) for the time period July 2019 - June 2023. This study area was selected because of the availability of daily

reference data related to the volume of water stored in the reservoir. These data were used to compute, initially, the Daily % WB Volume Time Series (i.e., a time series representing the reservoir "degree of filling", in terms of water volume percentage) for the same days for which the S2 images were available. Then, the Monthly % WB Volume Time Series and the Monthly % WB Volume Anomalies Time Series were computed (as in the Extent case). It is worth noting that, during the validation of the service, both Extent and Volume Monthly Anomalies were calculated by using historical data collected in the long-term period ranging from July 1998 to June 2023. Finally, the Daily & Monthly WB Extent and Volume Time Series were compared by computing the following statistical metrics:

i. The Pearson correlation coefficient (ρ), which was used to evaluate the agreement between the time series trends.
ii. The average difference (μ_{Diff}: % Extent - % Volume), which was exploited to evaluate the presence of systematic errors (i.e., bias).
iii. The standard deviation of the average difference (σ_{Diff}), that provided information about the presence of random errors (i.e., noise).
iv. The Root Mean Squared Error (RMSE), which gave overall information about the errors affecting the analysis, since it encompasses for both systematic and random errors.

Results showed that both Daily & Monthly WB % Extent data have a strong linear correlation with the corresponding Daily & Monthly WB % Volume data ($\rho \approx 0.9$). The correlation is slightly higher for Monthly data, because averaging daily data on a monthly time scale slightly reduces the contribution of the random noise ($\sigma_{Diff} \approx 10$ %). The source of this error is mostly due to the presence of the pixels masked out during the data processing (i.e., clouds and shadows), whose contribution is attenuated by the averaging operation. The RMSE associated with both Daily & Monthly WB % Extent data is ca. 22%. The source of this error is mostly due to the presence of a strong bias between the Daily & Monthly S2 % Extent data and Daily & Monthly Volume data ($\mu_{Diff} \approx 20$ %). This systematic error is linked to the effect of the bathymetry of the reservoir and cannot be removed from the analysis. Indeed, EO data can be used for mapping WB Extents and not WB Volumes, unless accurate bathymetric information is available. The analysis also showed that visualizing data in terms of Monthly Anomalies is a viable solution to overcome the abovementioned "bias issue" and to identify critical periods, like those potentially connected to drought events. Indeed, although the correlation coefficient associated with the Monthly % WB Extent Anomalies is ca. 0.7, the corresponding RMSE is ca. 7 %.

These findings suggest that, on the one hand, Daily & Monthly WB % Extent information derived from S2 data can be used to accurately monitor the temporal trend of the reservoir's "degree of filling". On the other hand, the corresponding Monthly % WB Extent Anomalies based on both GSW and S2 climatological data can be exploited to detect signs of critical periods and to implement early warning systems (e.g., for managing hydrological drought). Further validation analyses will be carried out in the future to test the service performance in other reservoirs characterized by different environmental conditions.

ASSESSMENT OF THE POTENTIAL OF INSAR TIME SERIES TO SUPPORT SUSTAINABLE GROUNDWATER MANAGEMENT IN THE EMILIA-ROMAGNA REGION

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Keywords: groundwater; InSAR; land subsidence; Sentinel-1

Abstract

The sustainability of groundwater resources is influenced by various factors, such as the decrease in groundwater storage. A significant challenge in achieving groundwater sustainability lies in fully comprehending the implications of different alternative management strategies [1]. Previous studies based on satellite measurements have exploited the potential of Interferometric Synthetic Aperture Radar (InSAR) time series to monitor aquifer-related deformation [2,3], detect aquifer storage changes [4], estimate aquifer hydraulic properties [5,6], model hydraulic head at well locations [7] and calibrate three-dimensional (3D) finite element groundwater flow and geomechanical models [8].

The alluvial plain of the Emilia Romagna region (Italy) is a sedimentary basin affected by subsidence induced by natural and anthropic factors for decades. Since the 1950s, various agencies have established different monitoring networks for subsidence, employing geodetic leveling techniques and for groundwater monitoring in areas where the phenomenon has become relevant [9,10]. Both coastal and internal areas experienced land subsidence due to groundwater extraction [11–13]. In this region, the subsidence has reached alarming levels, forcing regional and local authorities to take legislative measures aimed at controlling the process [14].

In this study, we aim to evaluate the benefits and limits of the use of free available Copernicus Sentinel-1 European Ground Motion Service (EGMS) data [15] to support sustainable groundwater management. The proposed approach focuses on assessing the relationship between InSAR-based ground deformation and piezometric level changes in the Emilia Romagna region during the period 2018-2022. Specifically, the analysis will utilize the groundwater monitoring database provided by the Regional agency for environmental protection, and the technical institute for the Region of Emilia-Romagna (ARPA Emilia-Romagna) (Figure 1).

Various statistical analyses [17,18] will be performed to distinguish the different components of the movements and to verify the correlation between these variables at the well locations (Figure 2).

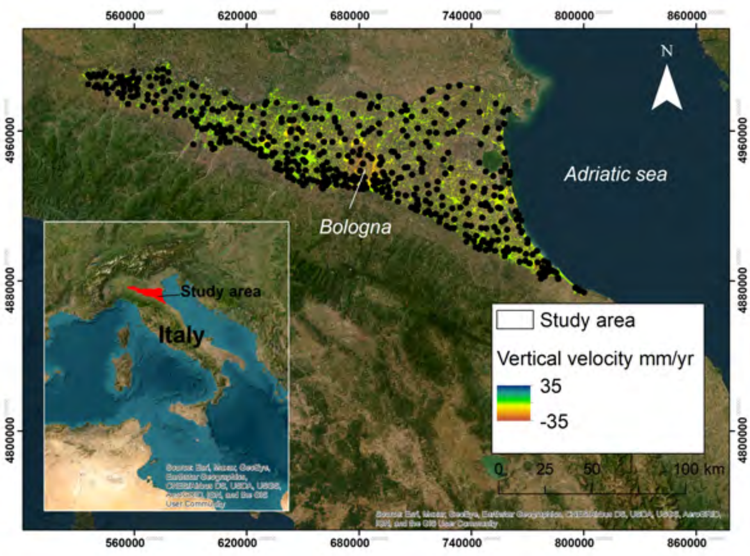

Figure 1. Location of the Emilia Romagna region.
EGMS Sentinel-1 average vertical velocity for the period 2018-2022 [15] and distribution of the groundwater monitoring wells (black points) of the ARPA-ER [16] in the study area.

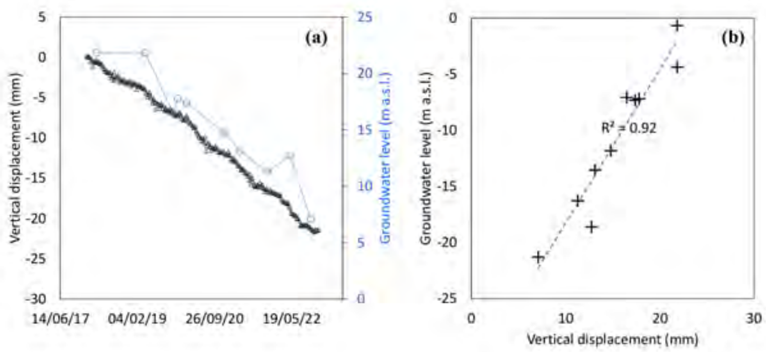

Figure 2. Example of cross-correlation between InSAR-based vertical displacement and groundwater level changes for one piezometer located in Bologna (see the city location in figure 1). (a) Time series comparison and (b) correlation scatter plot. The coefficient of determination, denoted as R^2 is also reported.

These activities are carried out within the framework of the project SubRISK+ [19] which is funded by the European Union – Next Generation EU, under the umbrella of the Research Projects of Significant National Interest (PRIN) 2022 National Recovery and Resilience Plan (PNRR) Call.

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ANALYSIS OF PO RIVER SHRINKING DURING THE RECORD-BREAKING SUMMER 2022 USING SATELLITE EARTH OBSERVATION DATA

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Keywords: river shrinking, Sentinel-2 MSI, Po river, hydromorphology

Abstract

Earth observation capability to monitor inland waters plays a fundamental role in supporting sustainable water resources management, especially under climate change scenarios. Such capacity improved over the past years, with the availability of dense satellite Earth Observation time series at high and very-high spatial resolution. In particular, a significant contribution is offered by Copernicus Sentinel-1 and Sentinel-2 satellites constellations, whose high revisit frequency, observation scenario and guaranteed continuity encourages the development of operational services, like hydromorphological assessment and monitoring, supporting sustainable water resources management. Another major contribution is constellations of commercial cubesats satellites, which can provide an unprecedented ability to monitor the Earth surface with daily revisit time, although it requires costs for data collection. Satellite sensor interoperability allows to achieve higher temporal revisit frequency from multiple sensors imagery, rigorously spatially co-registered, which produces denser time series to strengthen monitoring capability, as compared with reduced revisit frequency.

Summer 2022 was the hottest ever recorded in Europe and was characterized by prolonged drought conditions due to absence of precipitation for more than 100 days in the Italian peninsula. Consequently, river discharge was subjected to a massive reduction, resulting in the lowering of the water level and significant shrinking.

River shrinking analysis using optical multispectral dense time series at high spatial resolution is here presented. The study case is focused on the Po river during summer 2022. Sentinel-2 MSI satellite data acquired during the period 2016-2023 have been used for the analysis. Information about horizontal linear local shifts at pixel level was used to significantly improve Sentinel-2 MSI imagery spatial coherence and time series consistency. Fractional water content in each pixel was calculated from normalized water spectral index. Additionally, monthly frequencies of water fractional content were calculated for each pixel, and anomalies in monthly water frequencies were estimated by comparing each month with the climatology of the same month up to the previous year, and against the previous month water frequencies.

An evaluation of the use of PlanetScope satellite data was also conducted, which highlighted the need for proper data pre-processing including normalization and temporal co-registration of images, for effective use of the data for analysis.

Results demonstrate the capability of medium-term satellite time series, by assessing the increase in natural fluctuations in seasonal water availability in large rivers, to monitor climate change threatens related to the availability of freshwater resources and conservation status of river ecosystems. Capability to generate near-real time monitoring maps and indicators for hydromorphological assessment allows the establishment of a thematic monitoring service, informing domain specific decision making for sustainable water resources management and ecosystem conservation and management. Evidences from satellite derived thematic products should foster the establishment of water resources management considering drought as a chronic phenomenon rather than an acute episode.

LAND SUBSIDENCE INDUCED BY GROUNDWATER EXPLOITATION: USING SATELLITE INSAR TO ESTIMATE CURRENT AND FUTURE RISK FOR URBAN LANDSCAPES IN ITALY

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Keywords: groundwater, land subsidence, InSAR, risk mapping, future scenarios

Abstract
Italy is among the 15 world countries with the largest estimated groundwater extractions, with a total of 10.4 km³/year (Margat & van der Gun 2013). When groundwater withdrawal and natural discharge exceed recharge rates, aquifer systems are over-exploited (Gleeson *et al.* 2012), resulting in resource depletion, storage loss and compaction of confining clay beds (Galloway & Burbey 2011). The induced land subsidence may cause direct/indirect impacts on urban landscapes (ground depressions, earth fissures, structure damages, increased flood risk, loss of land to water bodies) and economic loss. High to very high subsidence susceptibility and hazard levels characterize many Italian regions (Herrera-García *et al.* 2021), and a number of subsidence hotspots have been observed using satellite Interferometric Synthetic Aperture Radar (InSAR) methods (Rosen *et al.* 2000), such as the Po River and Florence-Prato-Pistoia plains.

The project SubRISK+ (https://www.subrisk.eu) innovates in this field by providing new Earth observation (EO)-derived products and tools aiming to enhance the understanding of subsidence risk in major urban areas of Italy, towards sustainable use of groundwater resources and urban development (Cigna *et al.* 2024; Bonì *et al.* 2024). Started at the end of 2023, the project is funded by the European Union – Next Generation EU, in the framework of the Research Projects of Significant National Interest (PRIN) 2022 National Recovery and Resilience Plan (PNRR) Call.

The project is assessing current and future subsidence risk in Italy using a multi-scale methodology, with implementation spanning from the national to the local scale. Risk is estimated with matrix-based risk assessment approaches (Fig.1) (Cigna & Tapete 2021), embedding InSAR-derived ground deformation observations (e.g. Copernicus' European Ground Motion Service, EGMS; Fig.2), hydrogeological, topographic and land use data. Hazard levels are estimated via computation of angular distortion (Skempton & McDonalds 1956) and horizontal strain (Tandanand & Powell 1991) induced on urban infrastructure, as derived from InSAR datasets. Exposure and vulnerability are assessed based on type and height of urban infrastructure, and geospatially combined with hazard information via a risk matrix to derive risk levels, from very low to very high (e.g. R1 to R5; Fig.1). Statistics on the population living within the various risk categories are finally extracted. At regional scale, accurate detection of hotspots and drivers is enabled by implementing advanced geostatistics and exploiting time series analysis tools (Bonì *et al.* 2016, Abdollahi *et al.* 2019), including Independent Principal Component Analysis (IPCA) and Optimized HotSpot Analysis (OHSA).

An advanced numerical model coupling 3D transient groundwater flow and geomechanics of heterogeneous aquifer systems (Teatini *et al.* 2016; Bonì *et al.* 2020) will also be developed to quantify the effects of groundwater usage to land deformation, and estimate uncertainties at local-scale in a highly vulnerable city. The output from the groundwater flow model will serve as input in the deformation model, utilizing the same computational grid and distribution of mechanical parameters to create a consistent flow-deformation model. A calibration procedure will be implemented where uncertainties associated to available piezometric records and InSAR measurements and from modelling approach are integrated to estimate the parameters of both the groundwater flow and deformation models.

The calibrated (and validated) models will be subsequently employed to forecast the consequences of future hydrological regime and pumping scenarios associated to climate change. The potential increase in uncertainty over longer prediction time spans will be properly quantified through the proposed approach.

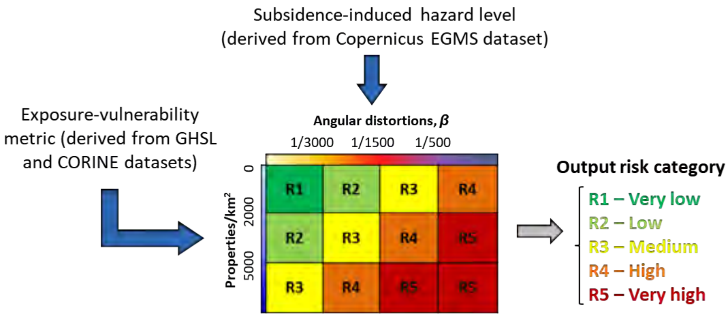

Fig.1: Matrix-based subsidence risk assessment approach adopted by the SubRISK+ project, following the methodology developed by Cigna & Tapete (2021).

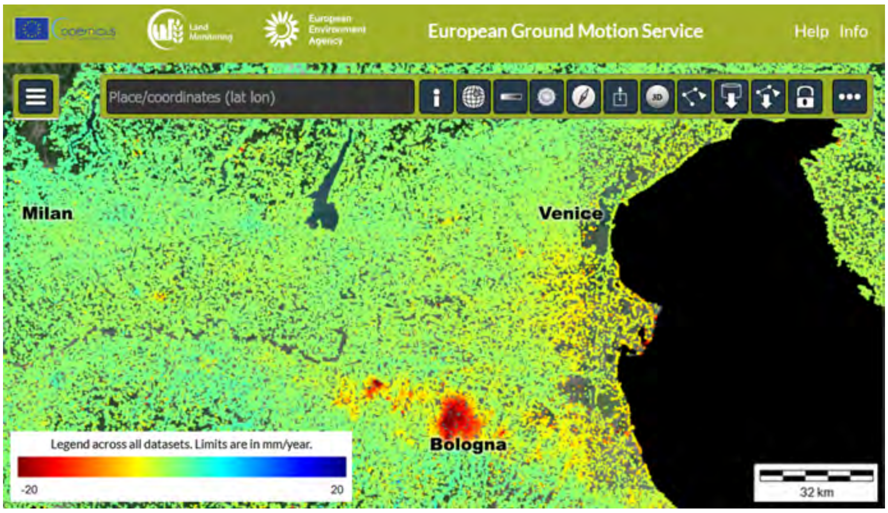

Fig.2: Zoom onto the Copernicus' European Ground Motion Service (EGMS) dataset (Crosetto et al. 2020) showing vertical land deformation in 2018-2022 over northern Italy. Contains modified Copernicus Sentinel-1 data 2021.

A tailored socio-economic impact analysis will be developed to quantify market and non-market direct/indirect losses at national, regional and local scale (Hallegatte 2014), based on affected areas' exposure, vulnerability and resilience. Future subsidence risk by 2050 and 2100 under climate change (RCP4.5/8.5, medium/high emissions), demographic and urban development, will be assessed for the metropolitan cities and, locally, by adapting the numerical model to support long-term risk predictions under different scenarios. Predictions of future land use changes using socioeconomic and environmental parameters will contribute to an integrated, indicator-based approach at city scale (Jiang *et al.* 2022, Meroni *et al.* 2017) that will enable assessment of urbanization patterns and identification of potential areas prone to future subsidence (Birkmann *et al.* 2021, Paranunzio *et al.* 2022).

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A QUANTITATIVE ANALYSIS OF THE DROUGHT EFFECTS ON THE PO RIVER: THE EVOLUTION OF SURFACE WATERS IN 2020-2021-2022

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Keywords: Land, climate-change, drought, waterbodies, remote sensing, machine learning

Abstract
In recent years, the global effects of climate change are also affecting Europe, leading to a greater frequency of extreme events, in terms of heat waves, droughts and high-intensity precipitations. In 2022, the Veneto Region -as well as most of Italy- was affected by a severe and prolonged drought, caused by low cumulative rainfall and extraordinarily high temperatures. As a consequence, a significant decrease in the flow of the main hydrographic networks was recorded during the summer period. These effects were particularly evident for the Italian main river, the Po River, where numerous sandy islands emerged due to the low flow. This work aimed to define an operational methodology to perform a quantitative analysis of the areas occupied by water surfaces and sandy islands in an area of the Po River basin, using satellite data through a supervised classification algorithm (Random Forest) (Figure 1). The supervised classification was therefore performed on Sentinel-2 images acquired for three consecutive years 2020-2021-2022 in the month of July, in order to monitor the evolution of the river surface in dry conditions (Figure 2). The results of the supervised classification showed a high accuracy (90%), suggesting this methodology can offer trustful results in drought monitoring, with a relatively simple procedure.

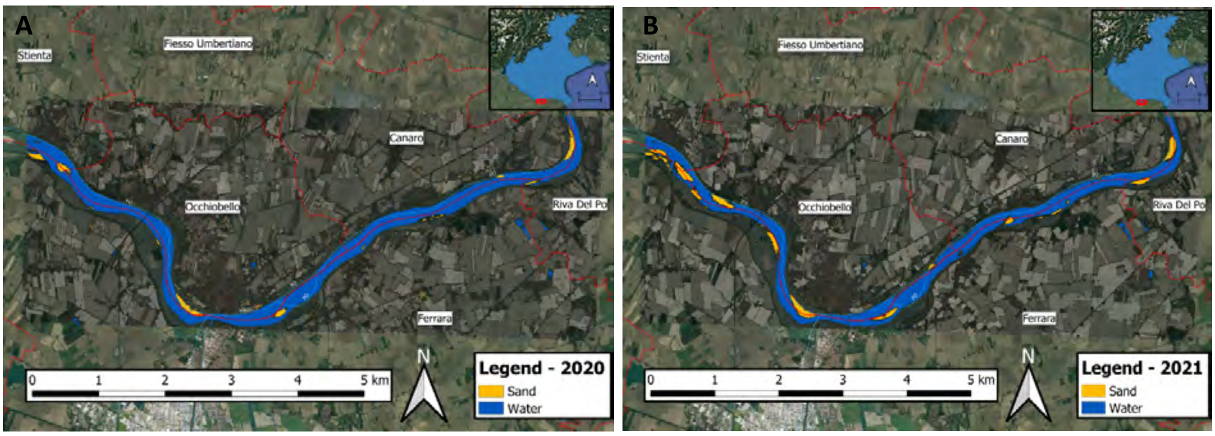

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Figure 1. Supervised classification (Rando m Forest model) of the study area through the years 2020-2021-2022 (A, B, C respectively). Reference frame: Sentinel L2A in true colour visualization.

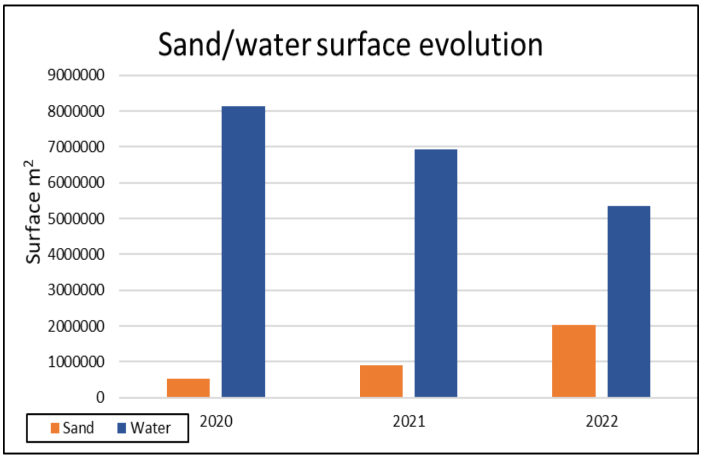

Figure 2. The evolution of sand and water surfaces in the study area during the three years observed.

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EXPLOITING SENTINEL-2 DATASET TO ASSESS HYDROLOGICAL CONDITIONS IN TEMPORARY RIVERS

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Keywords: Temporary rivers, Remote Sensing, Sentinel-2, Random Forest, Hydrological model

Abstract

Temporary rivers (TRs) are characterized by periods with zero flow and are the predominant river type globally. Due to water abstractions and climate change, river conversion from perennial to temporary is accelerating. Therefore, developing appropriate instruments for easily identifying TRs and classifying the flow intermittency is crucial for biodiversity and aquatic habitat preservation. Within the RIVERTEMP project [Erasmus+ 2022-1-IT02-KA220-HED-000086223], Sentinel-2 multispectral images are used to classify TR hydrological conditions (namely flowing - F, ponding – P, and dry - D) conditions. This work presents the results of the RIVERTEMP project in two case study in Italy and Greece and integrates satellite images with machine learning techniques and hydrological models to identify and classify TRs. The combination of Sentinel-2 images and Random Forest (RF) models were used in the Sangone river (Northern Italy), whereas the combination of Sentinel-2 images and hydrological models were used in the Keritis river (Isle of Crete, Greece). In the first case study, a RF model was used to fill the gaps between satellite images. For the second case study, the comparison between modeled flowrate and classified satellite images allows to define flowrate threshold values to distinguish between flowing and non-flowing conditions. On one hand, the RF models achieved high prediction accuracy (0.89-0.99), revealing significant annual variability in non-flowing conditions. On the other hand, satellite images allowed to better calibrate the hydrological model in the Keritis river and better classify the TR hydrological conditions. The obtained results represent a practical and efficient toolbox to map TRs and flow intermittency across Europe and, thus, to quantify surface water availability in the context of climate change.

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SNOW COVER CHANGES ANALYSIS USING MODIS DATA AND GOOGLE EARTH ENGINE

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Keywords: Snow Cover, Remote Sensing, Multitemporal, NW Alps

Abstract
Studying environmental components and their spatial/temporal dynamics is crucial in the climate emergency context. Monitoring water supply has pivotal role for agriculture in crops and food optimization, but also for alpine reservoir design and water management. Especially in Italy over 2022 and 2023, drought events have significantly affected agricultural sector (Arpa, 2023). In this framework, snow and ice cover is an important water stock. In fact, hydrogeological dynamics coupled to local irrigation infrastructures that ordinarily affects water availability for agricultural purposes.

Stimulating by these dynamics, this study allows the foundation to be laid for future developments in terms of water resource management and understanding, supported by the Mount Resilience project - HORIZON-MISS-2022-CLIMA-01-06. It aims at improving yield in agriculture, alpine reservoir design, and climate studies in climate emergency.

The study area (AOI) is located in North-west Italy and considers the Piemonte and Aosta Valley regions.

The main research question is to map and understand snow persistence changes at the regional level and quantify trends at regional scale longing for a strategic planning and management of water use.

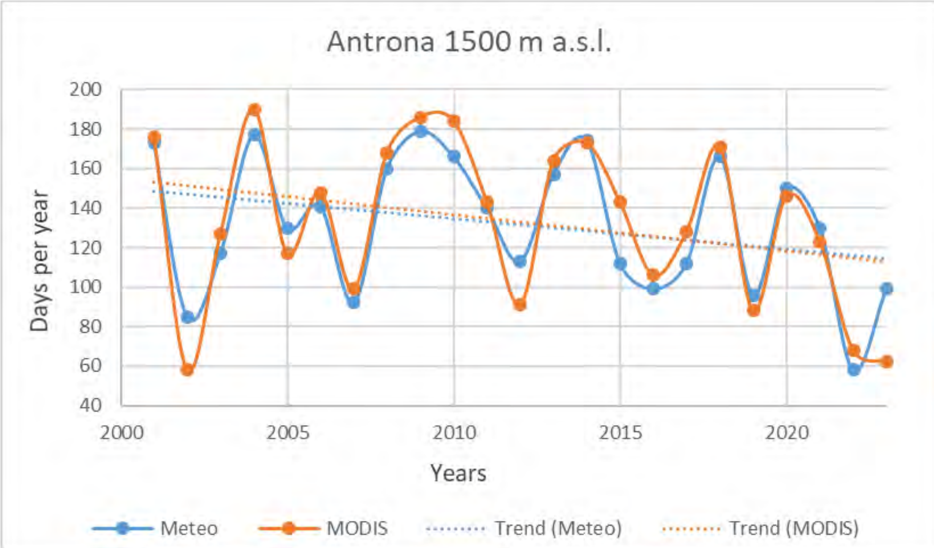
In particular, historical data from the Italian Glaciological Committee on snow since the 1960s (CGI, 1960), Moderate-Resolution Imaging Spectroradiometer (MODIS) images and local meteorological stations data were collected to analyse snow changes in AOI adopting a time-series analyses approach.

Data pre-processing was performed directly in Google Earth Engine (GEE) platform, which made it possible to process a large amount of multitemporal data. Considering a sensing period between 1st October 2000 and 30th September 2023 more than 8000 daily snow cover maps images (MOD10A1.061 product) were analysed. This allowed 23 years of data to be obtained on a daily basis.

Moreover, Copernicus Digital Elevation Model (resampled to MODIS scale) was used in order to obtain real pixels areas, since our study area is topographically very varied, from flat sectors up to mountainous sectors. Then the information content of the single pixel was transformed from a percentage of snow cover to hectares covered by snow in each pixel generating new layers hereafter called snow cover area (SCA). Furthermore, a binary classification (snow presence/absence - SP) was performed by set a threshold of snow cover >0.

Finally, considering the hydrological year (from 1st October to 30th September) the yearly sum of SCA and SP layers were performed creating 2 new multitemporal stacks having 23 bands per stack.

To validate the proposed approach a comparison to ground snow persistence derived from local meteorological stations (snowmeter) *vs* yearly cumulated SPs layers (Fig. 1). Results show good a mean absolute error equal to 10 days yr^{-1} denoting high accuracy in SP mapping. Similar research topic was already investigated by other authors (Fugazza et al., 2021) but a validation was not provided.



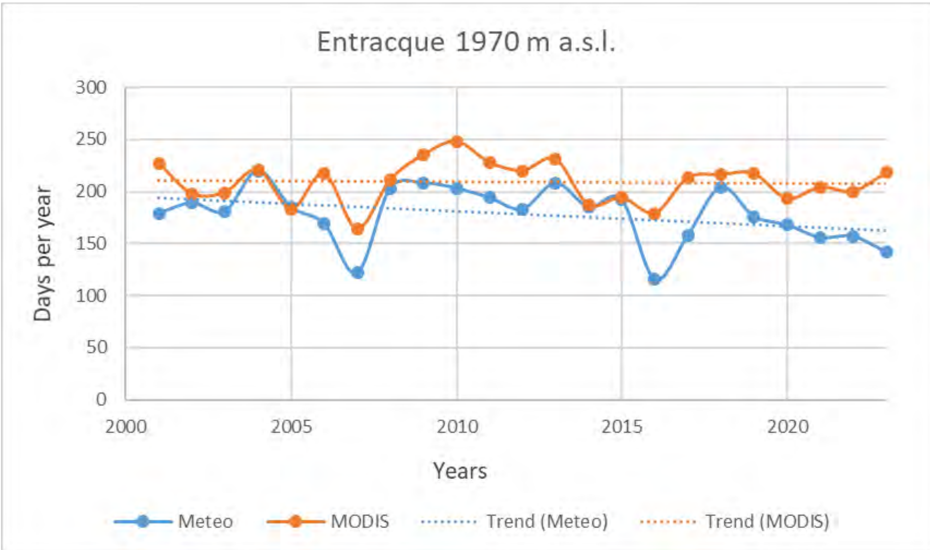


Figure 1: The two figures show the comparison between the snow persistence calculated by the Modis analysis, in orange, and meteo stations analysis, in blue.

Finally, SCA stack (iSCA) was modelled at the pixel level by first order polynomial in R environment was estimated and mapped representing the 23 years trend. The slope of local linear regression was estimated and mapped (Fig. 2a) representing the 23 years trend of snow areas (and consequently water stocks). Dividing the local slope by offset of local linear regression a normalization procedure allows to synthesised the trend allowing a comparison between different zones starting from different environmental context (e.g., mountains and lowlands) (Fig. 2b).

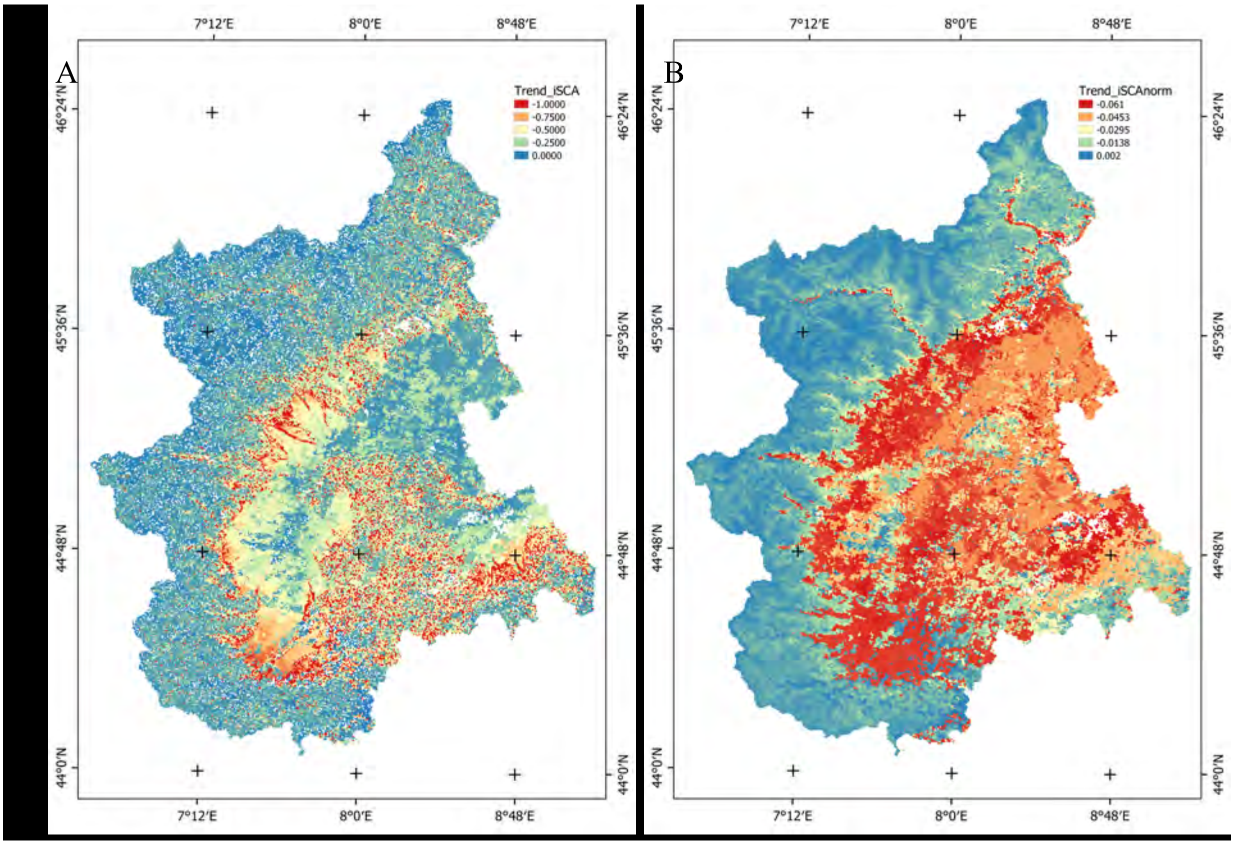


Figure 2: The two figures show the trend of 23 years of evolution of snow cover areas. A shows the trend of snow cover changes in terms of ectars loss through the years. In B the trend was normalized with the hectars of snow cover to better understand the impact of the trends in the different sectors.

Proposed multitemporal snow cover analysis allows to understanding and locally mapping the 23 years snow dynamics and related water stock issues over NW-Italy supporting local institutions by focusing on lowlands and valleys areas where negative trends highlight anomalies.

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IDENTIFICATION OF PLASTICS IN THE SEA FROM SATELLITE IMAGERY

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Keywords: Sentinel-2; plastic indices; SAM

Abstract

The accumulation of plastics in the sea is a growing and very complex phenomenon, often overlooked. Although small rivers have been identified as the main vector through which plastics reach the sea, at present their monitoring is very limited. Remote sensing techniques can support the analysis for this problem, as they provide large-scale observations with frequent temporal coverage. This study aims to test the current techniques for detecting plastics in the sea on a sample of Sentinel-2 images, to verify their potentials and limitations. The dataset consists of 10 sites where plastics presence has been determined, to be used as training, and 15 analysis and testing sites around the world. Among these, some cover Italy, in particular the waters off the Po mouth and Calabria region. The performance of some spectral indices for the identification of plastics, specifically the FDI and PI indices, was investigated. For them, new ranges have been defined starting from the analysis of multispectral images of plastic targets placed in the sea. In addition, by exploiting spectral signatures extracted from the known cases, the effectiveness of the SAM classifier was evaluated. The results obtained show how the outputs obtained through indices and by the SAM proved to be complementary in terms of performance.

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LE RICERCHE GEOARCHEOLOGICHE DE L'ORIENTALE DI NAPOLI NELLA PENISOLA ARABICA. CONTESTI GEOMORFOLOGICI, STRATEGIE DI INSEDIAMENTO E ANALISI TELERILEVATE IN AMBIENTI ARIDI

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Keywords: geomorfologia, archeologia, geoarcheologia, Penisola Arabica, metodologia della ricerca archeologica

1. Introduzione

È apparso sempre più evidente nel corso degli studi degli ultimi decenni che le varie emergenze archeologiche, con particolare riguardo ai siti insediativi, per essere comprese nella loro formazione, successivo sviluppo e finale decadenza ed abbandono, devono essere collocate spazialmente in rapporto alle forme del paesaggio e alle risorse naturali coeve, ovvero alle condizioni fisico ambientali del passato che sovente non corrispondono a quelle del presente.

Tra le risorse, l'acqua è certamente quella alla base dello sviluppo di insediamenti permanenti che basino la loro sussistenza *in primis* sulla pratica agricola, come pure è alla base di ogni forma di commercio sulle lunghe distanze poiché garantisce tappe di approvvigionamento necessarie. I contesti aridi della Penisola arabica forniscono appunto casi studio esemplificativi del ruolo svolto dall'acqua e grazie all'integrazione tra il dato archeologico e l'osservazione da remoto è possibile definire, lungo un ampio arco cronologico, sia le diverse strategie di insediamento e come le comunità si siano adattate a un clima mutevole, ovvero più arido a partire dal medio olocene, sia quelle forme di commercio antico basate sullo sfruttamento di rotte predeterminate stabilite sulla base di caratteri morfologici specifici dell'ambiente.

2. Metodologia

L'idea progettuale, che si basa sull'interazione tra archeologia, geomorfologia, geologia e toponomastica antica, si inserisce nel solco tracciato da 40 anni di attività archeologiche delle missioni de "L'Orientale" nella Penisola arabica, a partire dallo Yemen, e dunque si fonda su una metodologia di telerilevamento oggi testata sia in contesti nordarabici, per le geo-localizzazione dei siti preistorici in aree logisticamente inaccessibili o per il riconoscimento di antiche vie carovaniere; sia in contesti omaniti, in particolare per l'identificazione delle oasi urbane in contesti montuosi del I millennio a.C.; sia in contesti yemeniti, dove ben si apprezzano le strategie di insediamento dell'Età del Bronzo e la disposizione delle coeve evidenze funerarie lungo rotte di passaggio scandite da specifici caratteri geomorfologici. Si tratta dunque di mettere in campo un modello predittivo basato sul riconoscimento geomorfologico di elementi salienti del paleo-ambiente, ovvero la risorsa idrica, che, in passato, possano aver attratto o orientato l'uomo e a cui sono associati i siti archeologici. Fondamentale è l'acquisizione di riprese satellitari ad alta risoluzione e l'interazione tra un *expertise* geomorfologico in grado di descrivere le forme del paesaggio antico e un *expertise* archeologico in grado di riconoscere e interpretare le evidenze antropiche, che operino contestualmente attraverso il telerilevamento. I lavori delle missioni de "L'Orientale" in Arabia, nonché la letteratura specialistica di riferimento, dimostrano quanto tale approccio da remoto sia efficace e come tutti i dati raccolti, gestiti in un sistema applicativo integrato (Quantum GIS), possano generare carte tematiche archeologiche *open source*.

Da un punto di vista archeologico, al fine di riconoscere in un paesaggio arido la disponibilità della risorsa idrica, risultano utili le riprese Landsat a falsi colori, unitamente all'esperienza acquisita sul campo in oltre 40 anni di ricerche. Si aggiunge, a questa, la più sofisticata adozione di immagini Cosmo Sky Med (progetto congiunto UNIOR-ENEA "wadi Sirhan").

3. Casi studio

Due casi studio saranno presentati al fine di valorizzare le diverse varianti regionali di adattamento a una esigenza comune, il processo di desertificazione che mette fine alla fase umida olocenica arabica. Sia sulla base di dati telerilevati sia sulla base di prospezioni verità terreno si presenteranno le strategie di insediamento e sfruttamento di aree oggi desertiche ma che, all'alba di questo radicale cambiamento climatico, hanno nonostante tutto visto l'emergere e successivo sviluppo di società complesse.
In ordine cronologico, il primo caso è quello della regione nordarabica del Jawf saudita e del neolitico (VI millennio a.C.) delle Harrat al-Harra e del wadi as-Sirhan. L'identificazione di paleo risorse idriche ha permesso di ricostruire un capillare panorama neolitico caratterizzato da architetture semi stanziali e da gruppi umani mobili grazie all'identificazione di paleo laghi e paleo corsi d'acqua.
Un secondo caso studio, databile all'avvento del processo di desertificazione (IV-II millennio a.C.), è quello dell'Età del Bronzo yemenita. Il contesto, dall'Arabia meridionale, mostrerà come le sempre più ridotte risorse idriche furono sapientemente impiegate in determinati contesti morfologici assieme allo sviluppo di complessi sistemi idraulici. Tale caso studio rappresenta un caso eccezionale in quanto mostra, a livello archeologico, quali possano essere le risposte delle comunità stanziali ai processi di desertificazione e come nonostante la crescente aridità prendano vita le prime rotte del commercio internazionale sulle lunghe distanze.
Infine, saranno presi in esame i contesti funerari dell'Arabia orientale, con particolare riguardo alla regione del Wadi bani Khalid e del Wadi Wadd, dove nel I millennio a.C. prendono forma le cosiddette forme di urbanizzazione dell'Età el Ferro.

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ON THE ROBUST AND EFFICIENT MAPPING OF HORTICULTURE GREENHOUSE WITH SPACEBORN SENSORS

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Keywords: Protected agriculture, OPAC, Sentinel2, AVIRIS, PRISMA

Abstract
The presence of agricultural catchments used for protected agriculture is growing worldwide. Protected agriculture encompasses greenhouse horticulture production, which allows for an increase in food security with less irrigation water. However, monitoring studies document the depletion of surface- and ground-water resources as well as high levels of plant production products. Sentinel-2 satellite-based land cover classification models have been developed for the purpose of mapping protected agriculture (la Cecilia et al., 2023 and references therein), even at the continental (pan-European) scale with the exploitation of cloud computing facilities (la Cecilia et al., 2024). However, the current models suffer from an overestimation of the area mapped as greenhouses due to the limited spectral range and resolution of multispectral satellites in orbit. Recently, we have discovered that plastic greenhouses have a very peculiar reflectance around 1700 nm as compared to any natural and artificial land cover (Parmeggiani et al., 2024). This result was achieved thank to the analysis of images from the AVIRIS airborne sensor over the protected agriculture area of Salerno in southern Italy. AVIRIS is a sensor with over 400 bands covering the visible (VIS) to the shortwave infrared (SWIR) region, with a spatial resolution down to 1 m. Focusing on the identified characteristic narrow region we were able to remove false positives mostly arising from very reflective clayey soils and urban areas. At the workshop, we will also present the initial activities related to the current studies on PRISMA hyperspectral data at 30 m pixel resolution, aimed at understanding whether greenhouses can be classified by this sensor on a global scale.

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MAPPING WATER BALANCE TRENDS OVER CROPS AND NATURAL AREAS USING MODIS AND ERA5 MULTI-YEARS IMAGES

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Keywords: water balance, crops, satellite, evapotranspiration, climatic data

Abstract

Water scarcity is a critical challenge facing agriculture, food security, livestock, and forestry globally. Long term earth observation missions like the MODIS one, allows to monitor vegetation evapotranspiration rate providing a spatial overview of water use over crops or natural vegetation with a high temporal resolution. Despite evapotranspiration data availability, literature currently lacks in exploring water balance over crops jointly adopting remotely sensed thermal images and climatic data. For this reason, this work has explored how to combine evapotranspiration images form MODIS and ERA5 data to estimate and map water balance over vegetated areas between Piemonte and Valle d'Aosta regions (North-west Italy). MOD16A2 images were collected from Google earth engine (GEE) platform considering a sensing period between the 1st October 2001 and 1st October 2022 over study area and considering only pixels classified as vegetated from MODIS Global land cover. MOD16A2 data provide 8-days aggregate evapotranspiration maps with a 500 m geometric resolution. Otherwise, ERA5-Land Daily Aggregated is climatic imagery having 10 km geometric resolution that was resampled at the same resolution of MOD16A2. Total precipitations, snow melt, snowfall layers were selected and analysed. All these layers were processed directly on GEE in order to compute the yearly sums of each variable. A total of 22 images per 4 variables were stacked along 4 different multitemporal stacks and locally downloaded. Subsequently, these variables were combined to compute yearly water balance expressed as mm pixel^{-1} year^{-1} and its trend estimated along the 22 available years as the slope of linear regression of multitemporal profiles. A final map of local trends was computed, and anomalies identified. Summary statistics were also retrieved at basin level in order to provide useful map to regional stakeholders like water consortia, regional administrations, farmer associations. These players can adopt derived deductions to focus their efforts in most critical zones showing water scarcity trends by planning a mitigation and adaptation strategies.

ASSESSING THE ACCURACY OF MOD16A2 FOR AGRICULTURAL WATER MANAGEMENT IN PIEMONTE (NW ITALY)

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Keywords: Potential Evapotranspiration, Remote Sensing, MODIS, ET0, Model Calibration.

Abstract

In 2022, Europe's agriculture, especially in Italy, faced significant challenges due to severe droughts and heatwaves. The frequency of such extreme events is expected to intensify in the future due to climate change. These conditions have highlighted the necessity for precise and efficient water resource management to support sustainable agriculture. This study evaluates the MOD16A2 remote sensing product's potential evapotranspiration (PET) estimates to improve agricultural water management across the flat agricultural areas of Piemonte region (NW Italy).

The Moderate Resolution Imaging Spectroradiometer (MODIS) is an optical instrument on two NASA satellites (Terra and Aqua) which provides essential global data that supports agricultural management by estimating PET. However, the MOD16A2 product's coarse geometric resolution raises concerns about its local accuracy, making it crucial to assess its consistency with ground-based measurements. This comparison is particularly significant in agriculture where precision is necessary to optimize water use and mitigate potential yield losses due to water stress. Considering the availability of local information from the regional meteorological service (Rete Agrometeorologica Piemonte - RAM), the aim of this work is to analyze the consistency using both temporal and spatial approaches between MOD16A2 Potential Evapotranspiration and the 8-days cumulated one derived from meteorological stations in the Piedmont region (NW Italy) during 2022.

This study analysed the relationship between MOD16A2 and meteorological data from January to September 2022. Daily groud-based potential evapotranspiration (ET0) was retrieved using the Penman-Monteith equation for each meteorological station. Conversely, MOD16A2 PET estimates (8-day temporal and 500 m spatial resolution), were retrieved from Google Earth Engine platform, ensuring that only cloud-free observations were used. To perform direct comparison, the ET0 measurements were then 8-day cumulated to match the MOD16A2 PET estimates' temporal resolution.

The analysis involved both spatial and time-domain approaches to assess the MOD16A2's performance. Both approaches were conducted using linear models to explore the relationship between the PET estimates from MOD16A2 and the ground-based ET0 data. The results generally indicated weak spatial correlations, suggesting that MOD16A2 might not effectively reflect local ET0 variations due to its spatial resolution limitations. Conversely, the time domain analysis showed strong relationships between MOD16A2 PET estimates and ET0 temporal profiles, suggesting MOD16A2 capability to catch the seasonal trends of evapotranspiration across the region.

Despite its ability to follow seasonal patterns, MOD16A2 consistently overestimated ET0, with an average overestimation around 7-8 mm every 8 days. This discrepancy highlighted the need for calibration to align MOD16A2 data with ground measurements. MOD16A2 calibration was performed on the previously conducted time-domain bias analysis.

This approach significantly improved the model's accuracy, as highlighted by increased R^2 values (Figure 1) and reduced mean absolute error (MAE) (Figure 2) of adjusted $\widehat{PET}$, showing that the potential evapotranspiration error decreased to less than 0.4 mm per day.

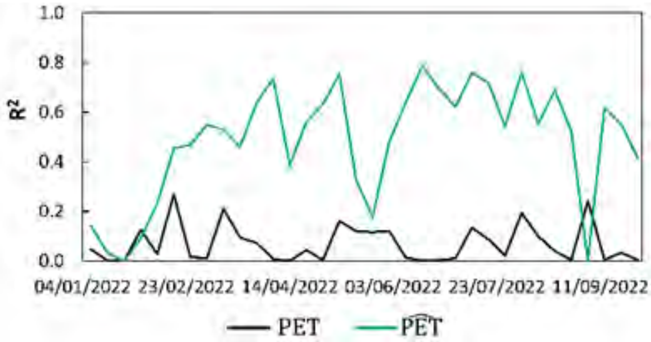

Figure 1. Evolution of R^2 from PET (black line) and adjusted $\widehat{PET}$ (green line) over the period of interest.

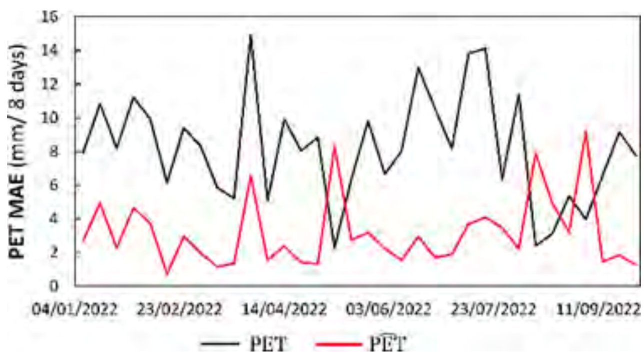

Figure 2. Evolution of MAE from PET (black line) and adjusted $\widehat{PET}$ (red line) over the period of interest.

The study's findings show the critical role of ground calibration in enhancing the applicability of global remote sensing products like MOD16A2 for local agricultural management. While MOD16A2 can provide valuable insights into global evapotranspiration patterns, its application at a regional or local scale requires careful calibration to account for specific geographic and climatic conditions. Following this approach, MOD16A2 can become a more reliable tool for managing agricultural water resources.

The implications of this research extend beyond agricultural applications, suggesting that similar calibration approaches might be necessary for other remote sensing products used in environmental monitoring and management. Future studies should continue to explore the integration of actual evapotranspiration data and other environmental variables to further refine the models used for predicting agricultural water needs, enhancing the precision and sustainability of water resource management.

Acknowledgements

This research was supported by the Research Project of Relevant National Interest from the Italian Ministry for University and Research (PRIN 2022) P2022MTRNX - Earth Observation For Drought Effects Monitoring On Crops (EO4DEMOC).

ABOUT THE STABILITY OF CROP MAPS AND ITS EFFECTS ON FLOOD AND DROUGHT SCENARIOS

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Keywords: GIS, Crop Damage, Spatial Analysis, Crop Stability and Crop Frequency Probability.

Abstract
Understanding the importance of crop rotation and studying it thoroughly is essential for optimizing agricultural management and ensuring the long-term sustainability of agricultural practices. Crop rotation involves the succession of different crops over time with the aim of achieving a series of significant benefits [1]. This practice (i) enhances soil fertility by balancing nutrients and organic matter provided by different crop types; (ii) reduce soil erosion and (iii) support the control of infestations by pests and weeds and of crop diseases, thus reducing the release of chemical treatments [2]. This practice is the main player of crop landscape changes, making the reliability of crop maps limited in time. This is particularly important when pre-existing crop maps are used to derive scenarios useful for quantifying damages to crops during a flood or providing estimates of expected water requirements from agriculture. Crop rotation patterns and their evolution along time is therefore desirable and can certainly be achieved at a large scale level with the aim of analysing changes in soil management, water usage, and farms organization.

This approach is particularly essential for gaining a more complete awareness of the exposure of agricultural areas to the risk of river flooding and, oppositely, of drought.
In this work, focusing on the main stream of the Po River, a detailed insight of local agricultural dynamics was obtained for the period 2018-2023. Crop mapping relies on GSAA (Geo Spatial Aid Applications) Maps provided by farmers when applying for Common Agricultural Policy (CAP) grants with the aim of evaluating crop rotation within the same plots over time and identify trends or significant changes in cropping systems. This detailed analysis not only provides valuable information on temporal variability, but can also guide the development of targeted agricultural policies and soil management strategies that promote environmental sustainability, resilience of agricultural ecosystems, and long-term productivity of the regional agricultural sector. Furthermore, it can provide farmers and other stakeholders useful information to adapt their practices to the continually evolving environmental, economic, and social needs.
In particular, crop rotation characterization within areas prone to river flooding can be used to assess the effectiveness of current practices in mitigating flood risks and identify possible improvements needed to enhance the resilience of the agricultural system in the face of such extreme events.
The analysis here described, is part of a wider research project named MOVIDA (Model for Integrated Flood Damage Assessment) [3], coordinated by the Politecnico di Milano, in collaboration with seven other Italian universities (including the University of Torino – DISAFA [4]), the National Research Council (CNR) and the Po River District Basin Authority.
The project is intended to provide an operational tool to map the expected damage related to flood event along the Po River District, initiating a trial of cost-benefit analysis of intervention alternatives.
A key tool in this analysis has been the Hazard Maps (HM) from the MOVIDA project [2]. DM provides a detailed representation of risk scenarios, categorized into risk levels P1 (low probability), P2 (medium probability), and P3 (high probability). Additionally, to better understand the potential impact of flooding, the ‘Floodable Areas Map’ (FAM) has been used, as well. It was developed within the Flood Risk Management Plan dated October 2022 [6]. FAM offers an overview of potentially flooding areas depending on varying intensities of the event, each determining a different level of exposure to the flood

risk. By integrating this information, it has been possible to identify potentially vulnerable areas and develop effective strategies for hydrogeological risk management in the region.

With these premises, the proposed methodology for mapping crops variability along time over a super-regional area, required data from different sources that were preventively harmonized. The reliability and quality of data were evaluated, as well, to ensure consistency and comparability of deductions over the entire study area.

This effort of data harmonization was crucial to create a coherent and reliable framework of temporal crop variability, necessary for drawing meaningful and informed conclusions about agricultural dynamics over time. The methodology entirely relied on procedures making use of free software: QGIS (version 3.28.6), SAGAGIS (version 9.2.0) and Python (version 3.10).

Two key steps were at the basis of this processing phase: i) designing and association of a unique common code for crops independently from native regional formats and labels; ii) selection of a limited number of crops useful to operate like predictors of a more general behaviour of the entire agricultural landscape. Selection was done at province level.

During data preparation, marginal crop categories (defined as "other" or "fallow") were removed. Then, crops were ranked at province level, in descending order based on their total area. Only more extended crops providing a yearly cumulative frequency up to 97% of the total provincially cultivated area were retained. A further selection was done taking care about polygon geometry for remaining crops. Area (A) and Shape Index (SI) were considered for each patch, and only polygons satisfying the following criteria were considered: (i) $A < 10000$ m² and $SI > 3$; ii) $A < 2000$ m² and $SI > 2.5$; iii) $A < 1000$ m².

The availability of multi-temporal (2015-2023) crop maps made possible to map changing scenarios useful for giving a probability estimate of finding a certain crop at a certain position. This crop probabilistic map (CPM, figure 1) was generated for the entire Po River basin (Lombardia excluded) and can be used to provide the probability of finding a certain crops when the information, for the current year, is still missing.

Additionally, CPM can be also exploited to describe temporal and spatial trends of crops and, possibly, to recognize those environmental and socio-economic factors acting like drivers. This information can be valuable for farmers, regulatory bodies, and other stakeholders to take aware decisions about crop planning, resource optimization, and risk management, with the aim of enabling a greater resilience and sustainability in agriculture.

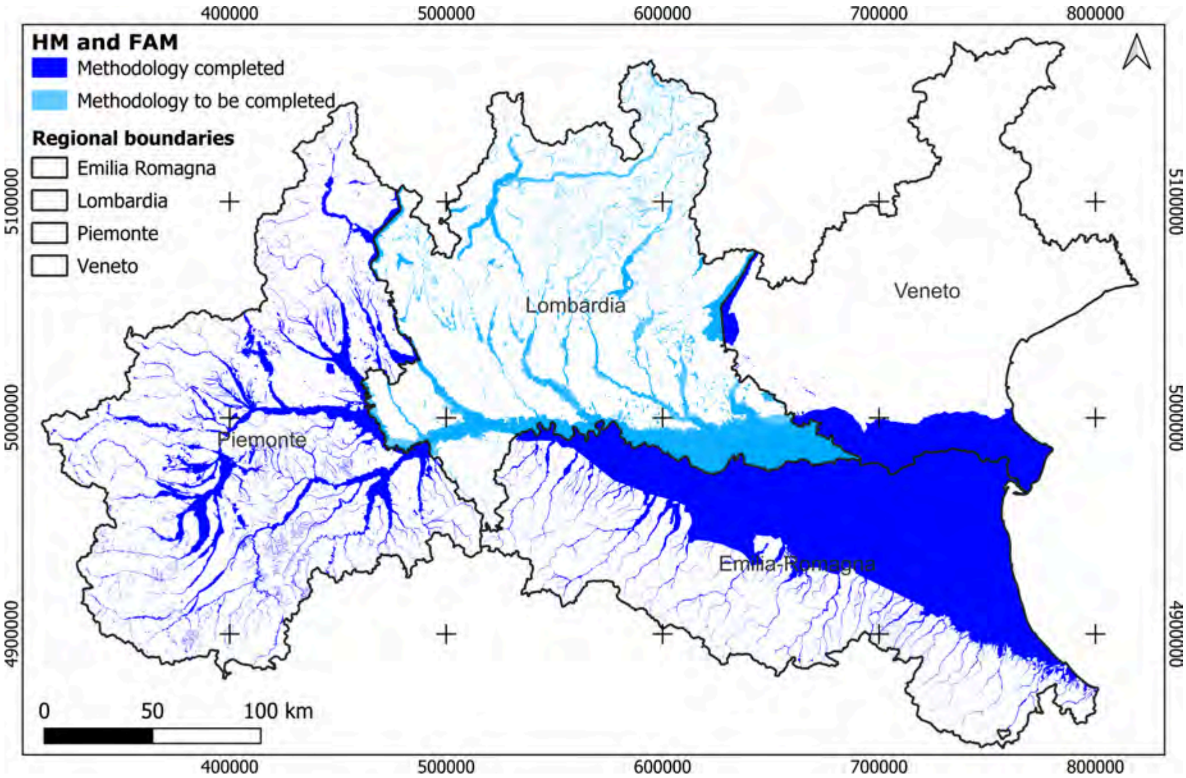

Figure 1 - Study area obtained from MP and AA of all 4 regions: i) in blue, area where the developed methodology has been completed; ii) in light blue, area where the developed methodology has yet to be validated.

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PRELIMINARY RESULTS ABOUT VERIFICATION OF CAP-RELATED GAEC 1 AND GAEC 6 CONDITIONALITIES THROUGH SENTINEL 2 DATA

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Keyword: CAP, GAEC, cover crop, permanent grassland, remote sensing, Sentinel-2, NDVI

Abstract

In the framework of the Common Agricultural Policy (CAP), competent authorities are called to control if farmers' practices on crops are compliant with CAP requirements needed for accessing grants. European Commission has recognized the Copernicus Sentinel-2 satellite mission as one of the main tools for supporting these controls (Sarvia et al., 2021).

In this work, two Good Agricultural and Environmental Conditions (GAEC), namely GAEC 1 and GAEC 6, were accounted for and tested through a satellite-based approach relying on the adoption of time series of Normalized Different Vegetation Index (NDVI) maps (Sarvia, De Petris, Ghilardi, et al., 2022). According to ARPEA, the Piemonte Region Agency for Agricultural Payment, two study areas were selected within the Piemonte Region (North-West Italy, Figure 1).

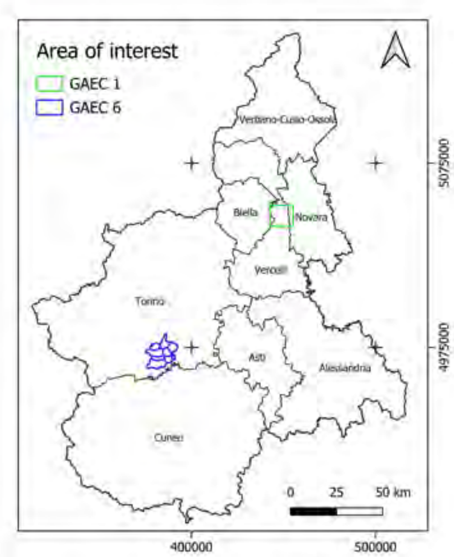

Figure 1. Study areas used t test satisfaction of GAEC 1 and GAEC 6 conditionalities.

Testing GAEC 1 conditionality

GAEC 1 conditionality concerns the detection of permanent grasslands (PG). “Permanent” means that grasslands have to be minimally maintained for 5 consecutive years. An area of interest (AOI) of about 150 km^2 was defined within the Vercelli province (Figure 1).

The yearly NDVI temporal profile of grasslands is quite peculiar, showing small oscillations along an almost constant (or poorly growing) trend. Differently, other crops, develop according to a single wide bell-shaped NDVI profile. Given this premise, the Mean Absolute Error (MAE) computed around the main yearly trend of the local NDVI profile was used to detect grasslands (Sarvia, De Petris, & Borgogno-Mondino, 2022). A binary classification was achieved labelling those pixels showing an NDVI MAE smaller than an appropriate threshold as “grassland” and the others as “no-grassland”. The threshold value was set to 0.11 according to a ROC (Receiver Operating Characteristic) approach. This value ensures that both User’s and Producer’s Accuracy values range between 77% and 99%. This classification approach was yearly iterated since 2018 to 2023. Only parcels labelled as Grasslands in the Geo-Spatial Aid Application (GSAA) from farmers were tested. In the period 2018-2023, in AOI, about 50% of fields matched the GAEC 1 requirements, i.e. were found to satisfy the above mentioned threshold for at least 5 years consecutively. Other intermediate situations, corresponding to a lower number of years satisfying the tested condition, were considered to generate the synthetic graph of Figure 2.

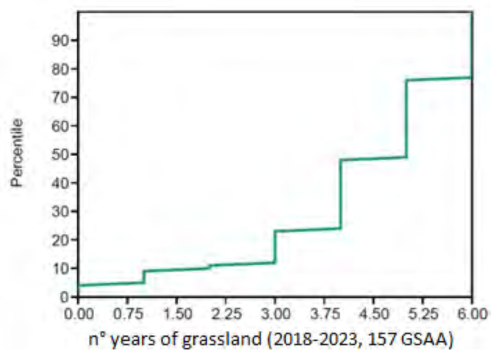

Figure 2. Cumulative frequency of n° of years a field has been recognised consecutively as grassland.

Testing GAEC 6 conditionality

The GAEC 6 conditionality aims at maintaining minimum soil cover to avoid bareness of soils during that part of the year when erosion could act (i.e., 15th September - 15th May). A minimum of 60 consecutive days of vegetation in the reference period are minimally required to achieve GAEC 6 requirements. Soil protection can be achieved using cover crops, a Natural Based Solution (NBS) for mitigation of soil degradation. This type of solution is highly debated in Europe and worldwide and the present analysis well also fits the requirements of the NBSOIL (Nature-Based Solutions for Soil Management) project, some of the authors are involved in. NBSOIL is a 4-year EU-Horizon2020 funded project that aims at supporting soil advisors to implement a holistic vision of soil health through NBS. With these premises, to test if satellite imagery can provide a significant support to recognize cover crops at the ground, an AOI of about 218 km^2 (Figure 1) was selected within the Province of Torino.

Assuming, from literature, that vegetated areas show NDVI values always higher than 0.3, a cautionary threshold of 0.25 was selected to instantaneously separate vegetated areas (NDVI > 0.25) from bare soils or other (NDVI < 0.25). The analysis concerned only GSAA parcels declared by farmers as summer crops. Given the temporal resolution of Sentinel-2 data (nominally, 5 days) the GAEC 6 condition was assumed as satisfied when at least 12 consecutive NDVI observations were found higher than 0.25 within the period 15th September - 15th May. The SCL (Scene Classification Layer) provided with the Level 2A (at the Bottom-of-the-Atmosphere calibrated) Sentinel 2 images (used for NDVI computation) was used to exclude from the

analysis eventual observations when recorded values were not consistent with the analysis (i.e. snowy, cloudy or shadowy conditions).
Results proved that about the 47% of fields were not continuously vegetated between 15th September and 15th May. Only the 24% of fields are compliant with GAEC 6 requiring at least 60 consecutive vegetated days (Figure 3), i.e. 12 consecutive NDVI maps, in the reference period. A summary of parcels behaviour (percentage of consecutive occurrences of tested condition – NDVI > 0.25) is reported in figure 3.

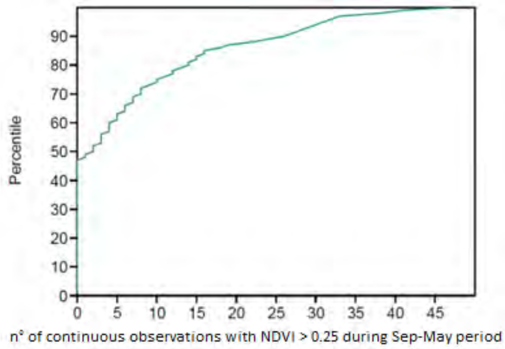

Figure 3. Cumulative frequency of the n° of continuous observations with NDVI higher than 0.25 during Sep-May period.

In this work authors proved that institutional satellite imagery, as Sentinel-2 ones, are a useful tool for monitoring GAEC requirements and supporting administrative CAP controls.

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MONITORING THE IRRIGATED CROPS FROM OPTICAL SATELLITE DATA

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Keywords: Sardinia, Sentinel2, Water Indices

Introduction

The study presents the results obtained from the experimentation aimed at defining a methodology for monitoring irrigation areas, in a multi-temporal key, from satellite images, as part of the "Research project on the creation of the land cover cartography of Sardinia and the system of monitoring the irrigated areas of Sardinia" in collaboration between the Department of Chemical and Geological Sciences of the University of Cagliari and the Directorate General of the Regional Agency of the Hydrographic District of Sardinia. In particular, the territorial districts served by the Sardinian Reclamation Consortia assisted by a managed system of pipelines for the supply of water for agricultural-use on demand are analysed.

Satellite data pre-processing

As is known, data acquired by Sentinel-2 optical satellites can be influenced by atmospheric elements, such as cloud cover. To eliminate this interference, one of the most advanced and, in many cases, decisive techniques is that of multi-temporal composition. The "cloud removal" technique involves the processing of remote sensing data relating to consecutive acquisitions, for the production, through a specific algorithm, of a new summary image which reports, for each pixel, the most statistically representative value of the time series in that same pixel (generally, the median digital number), excluding in the calculation those values interpreted by the algorithm as belonging to cloud bodies or shadows associated with them. This technique, aimed at creating images without cloud cover, produces better results the greater the number of images used to create the synthesis, having a greater probability of having, in the series, for each pixel at least one value not belonging to cloud bodies. In this study, for the period 2022, 2 syntheses per month were created (from day 1 to day 15 and from day 16 to the last day of the month, for each month), for a total of 48 summary images. For each sector, 24 scripts were parameterized, for the synthesis of the images falling in the time window between days 01-15 or 16-01 of each month, finally obtaining 24 images for each dataset. The "cloud removal" technique in the "Google Earth Engine" environment was applied to this data series using the functions developed by Simonetti et al., 2021. As a result, a median numerical value is expected which represents, in each band, the radiometric response of the Earth's surface in the fifteen days considered.

Water Indices

In this study, several algorithms were examined that combine the spectral response in the electromagnetic bands to provide numerical values that can be correlated with the presence of humidity in the soil or in the vegetation cover. Among the indices analysed, the most representative for the purposes of this study are the MNDWI index - Modified Normalized Difference Water Index - (Xu, H.Q., 2006) and the NDWI - Normalized Difference Water Index - (Gao, 1996).

The NDWI index is specifically used as an indicator of vegetation humidity. This index does not remove the reflectance of the signal component coming from the soil and therefore can provide important results even in the total absence of vegetation cover (for example, in plowed or sown land). The NDWI index is defined by the normalized ratio between the near infrared signal and the shortwave infrared signal. To exclude the signal relating to bodies of water, in the specific case of this project the NDWI index is applied in combination with the MNDWI index, with values >= 0. The methodological approach is based on multi-temporal statistical analysis of the soil moisture index, calculated on the basis of satellite data acquired by the Sentinel-2 platform during the calendar year 2022. An example of a bi-weekly multi-temporal synthesis dataset is shown in Figure 1, in which the humidity index in the 24 images relating to the Pesaria Sud district (western Sardinia).

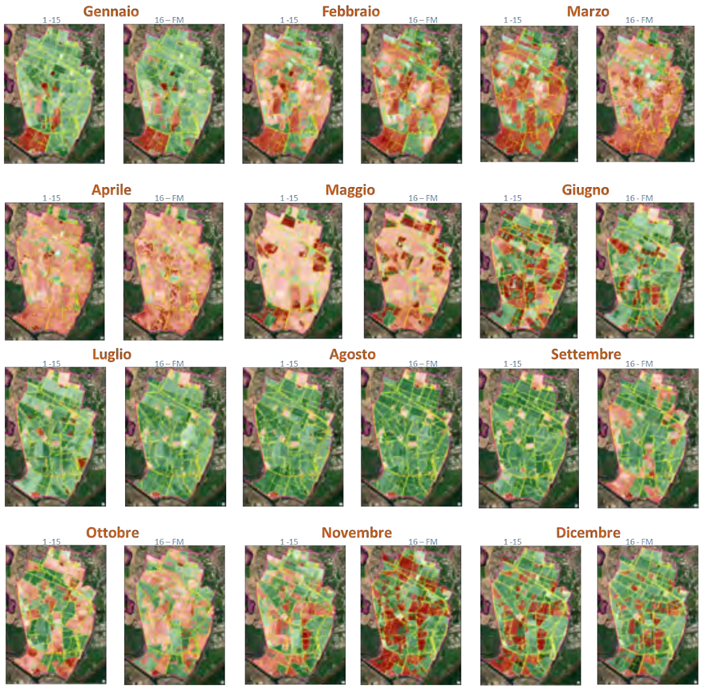
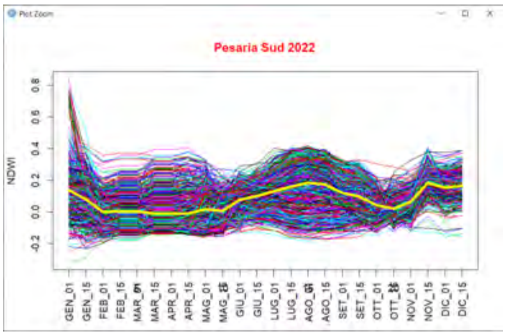


Figura 1: Example of multi-temporal processing of the 24 composite images of the humidity indices in the Pesaria Sud district. The color depth is a function of the humidity, while the distinction of green (vegetation) or brown (bare soil) color is obtained by associating the index NDVI.

In the case of the irrigation districts examined, the statistical analysis is simplified by the substantial cultivation homogeneity applied in the cadastral parcels, which presupposes equally homogeneous irrigation behaviour. Based on this assumption, it is believed that the average curve of all the particle curves of a district can be considered the "standard" reference curve of the irrigation district for the year considered. From a quantitative point of view, to define the intensity of correlation between the particle humidity curves and the standard curves in the 5 irrigation districts of the Oristano area, the Spearman rank correlation method was chosen. This statistical method is used to estimate the "strength" of the relationship between two variables being compared, in particular when populations of data with a high number of cases are compared. The Spearman correlation coefficient can take values between - 1 and +1 (inversely and directly proportional correlation, 0 indicates zero correlation).

Results

The results obtained in the Pesaria irrigation district are reported below (Figure 2). The analysis of the humidity curves in the 24 observations of 2022, as shown on the left, highlights the general adherence of the trend of a large part of the particles compared to the average curve (in yellow, thicker line). On the right is shown the cadastral parcelling, themed on the basis of the coherence of the same parcels with respect to the standard curve (average). The strong spatial dominance of particles that belong to the dark green themed class, those with which a Spearman index is associated with equal to or greater than 80% (0.80-0.98) and greater than 50% is very high and is justifiable, once again, by the presence of almost identical crops, planted at very similar times and managed with almost simultaneous water supply requests.



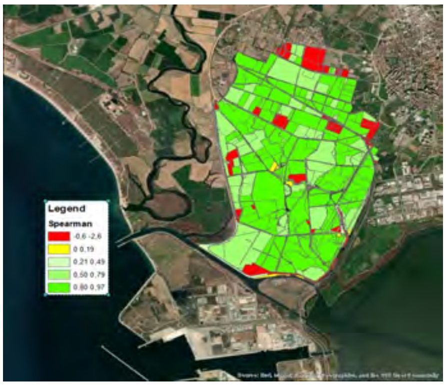


Figura 2: Application of the methodology in the irrigation district of Pesaria Sud. The graph above shows the humidity curves recorded in the 24 biweekly observations in the cadastral parcels. The image below shows a representation of cadastral parcels classified into 5 categories based on the Spearman index.

Acknowledgements

This study has been supported by the Directorate General of the Regional Agency of the Hydrographic District of Sardinia in the framework of the "Activities of realisation of the cartography of the Sardinian soil cover and of the monitoring system of the irrigated areas of Sardinia from remote sensing data".

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PREDICTION OF STEM WATER POTENTIAL IN VINEYARDS USING PLANETSCOPE IMAGERY AND GEOSPATIAL DATA ANALYSIS

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Abstract

Assessing plant water status accurately in both time and space is crucial for maintaining satisfactory crop yield and quality standards, especially in the face of a changing climate. Remote sensing technologies offer a promising alternative to traditional in situ measurements for estimating stem water potential Ψ. In this study, we carried out field measurements of Ψ stem in vineyard orchards located in southern Italy during the 2022 and 2023 growing seasons. Between June and October in both years at midday we jointly acquired water status and reflectance data from 90 sampling points in two different study areas for a total of 750 repetitions. With the aim of estimating the radius of spatial and temporal autocorrelation of the Ψ stem measurements, we performed a preliminary geospatial analysis and used the inferred radius to design a spatial and temporal cross-validation framework that avoids overoptimistic performances due to spatial data leakage. We used multispectral optical imagery as input to different machine learning models to predict field stem water potential. The good accuracy levels we obtained allow generalization for real time Ψ stem monitoring avoiding time-consuming and resource-intensive fieldwork.

IRRIGATION WATER ESTIMATES IN TUNISIA BY THE USE OF AGROMETEOROLOGICAL AND SATELLITE DATA

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Keywords: annual crops, actual transpiration, NDVI, Sentinel-2 MSI.

Abstract

During the last decades, climate changes have strongly affected the Mediterranean region and in particular North Africa, which is included among the climate hotspots by the International Panel on Climate Change (Ali et al., 2022). For Tunisia, a possible reduction of 28% in water resources in the next ten years has been estimated, with heavy consequences on all socio-economic sectors and especially in agriculture (Chebbi et al., 2019). Therefore, the sustainable use of water resources in the latter sector requires an accurate knowledge of the production condition and a constant monitoring of irrigation water (IW).

To this aim, a preliminary study on the application of a recently proposed remote sensing-based methodology for annual crop IW monitoring (Maselli et al., 2020) in the North of Tunisia was carried out in the framework of the PRESTO project, funded by the Italian Agency for Development Cooperation. Sentinel-2 MSI NDVI data at 10-m spatial resolution and frequent revisiting time have been used to monitor the green biomass evolution of some selected fields, over a five-year period (2018-2022). This information, joint to agrometeorological data, has allowed the estimation of the actual transpiration of different annual crops during the years and then, by means of a simplified water balance, the evaluation of the related IW requirements. The obtained estimates have been evaluated versus the measurements of IW collected by local farmers, using the most common statistics. The results encourage further investigations on this topic to quantify the amount of water required by the several annual crops, promoting sustainable irrigation practices in the area.

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SOIL HUMIDITY MONITORING BY INTEGRATING MICROWAVE MULTIFREQUENCY SATELLITE DATA THROUGH MACHINE LEARNING ALGORITHMS

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Keywords: microwave sensors, Neural Networks, soil moisture

Abstract

Ever-increasing interest in meteorological events and climate changes has led to a greater focus on the study of hydrological processes and their dynamics. Observations from space are a key- tool in this task as they can provide temporal and spatial data sets and complement ground measurements of geophysical parameters. The launch of a number of satellites having on-board sensors dedicated to the Earth's parameters observation, have already developed long term applications and made provided fundamental contributions in understanding global and regional hydrological processes and enhancing land surface studies.

As everyone knows well, soil moisture (SMC), along with its temporal and spatial variations, is a prominent parameter used in both climatic and hydrologic models. The measurement of SMC is one of the most important targets of remote sensing, and therefore a significant amount of experimental and theoretical studies has been carried out since the late 1970s.

The possibility of improving the retrieval accuracy and the ground resolution of SMC mapping from microwave satellite is extremely appealing. On one hand, microwave radiometers from space, such as the Soil Moisture Active and Passive (SMAP) and the Advanced Microwave Scanning Radiometer 2 (AMSR2) satellites are able to provide very accurate daily SMC products, although with a spatial resolution in the order of kilometers, which is not suitable for local applications (e.g. precision farming, small hydrological basin scale). On the other hand, Sentinel-1 and COSMO-SkyMed Synthetic Aperture Radar (SAR) are high-resolution sensors, but with less frequent revisiting, thus being unable to catch the fast temporal variations of SMC.

The Microwave Remote Sensing Group (MWRSG at IFAC-CNR) is working on microwave remote sensing monitoring of natural surfaces since'80. The group implemented several approaches based on microwave radiometric and SAR data by using machine learning approaches (e.g. artificial neural networks, ANN, and random forest, RF methods) for estimating the main soil and vegetation parameters.

In this paper, a disaggregation technique based on machine learning is proposed: the technique combines Sentinel-1 SAR data with SMC data products generated from AMSR2 by the IFAC's HydroAlgo algorithm (Santi et al. 2012), with the aim of enhancing their spatial resolution from 10 km to about 30m. Two machine learning techniques have been considered for the implementation, namely ANN and RF. The training was carried out by aggregating and coregistering Sentinel-1 data with the HydroAlgo SMC at 10 km resolution.

After the training phase, the ANN and RF algorithms are applied pixel by pixel to the Sentinel-1 images at full resolution for generating the enhanced SMC maps. A flow-chart of the followed methodology is shown in Fig. 1.

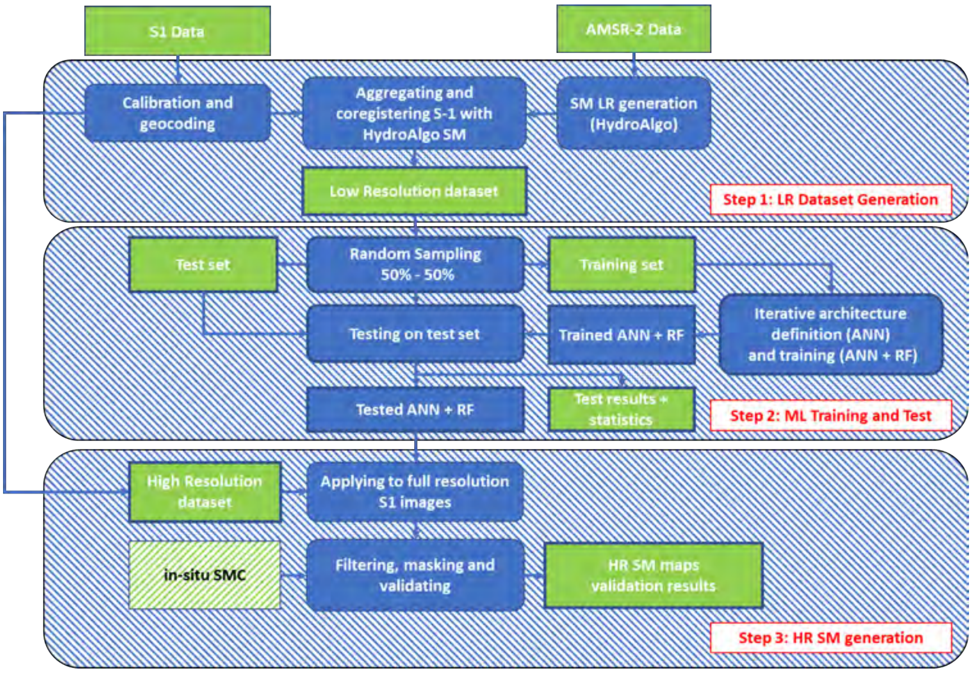

Fig. 1 – Flowchart of the proposed algorithm for estimating SMC at high resolution by integrating AMSR2 and Sentinel-1 data.

The method has been implemented and validated in two agricultural sites located in Central Italy, Pontecosi and Val D'Elsa test areas in Tuscany, where a series of experiments has been carried out between 2019 and 2020 for collecting the main soil and vegetation parameters at the same time of satellite overpasses.

The synergy between AMSR2 and S-1 resulted in an appreciable improvement of both spatial resolution and retrieval accuracy, as pointed out by the validation statistics, with a correlation coefficient R>0.9 between ANN algorithm outputs at 30m resolution and target SMC from in-situ measurements, with RMSE≃0.05 m^3/m^3. The analysis also pointed out slightly better performances of the ANN algorithm with respect to the RF.

Examples of obtained results

In Fig. 2 an example of the results obtained using this method is shown. The SMC map estimated at low resolution (10 Km) by using the HydroAlgo algorithm and AMSR2 data is compared with the SMC map at high resolution (30m). The high-resolution map was retrieved by using the disaggregation method integrating described above (Santi et al. 2022) and applied on Val d'Elsa dataset only. Red dots indicate the position of in-situ measurements in Val d'Elsa. The comparison shows a good agreement between the two maps and the SMC patterns have been appreciably reproduced.

Further validation using consistent experimental datasets is evidently needed for confirming the obtained results.

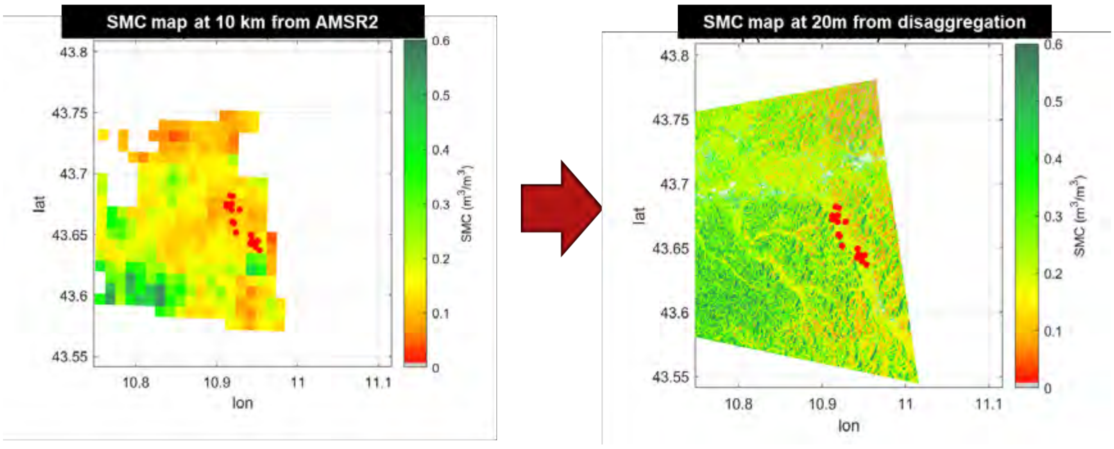

Fig. 2 – SMC maps at low resolution (10 km) retrieved by HydroALGO AMSR-2 (Santi et al. 2012 and 2018), on the left. On the right SMC map disaggregated to SAR resolution (20 m) by ANN based algorithm with inputs the Sentinel-1 backscattering (VV+VH pol.) (Santi et al. 2022). Red dots indicate the position of in-situ measurements (Val d'Elsa)

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COSMO SKYMED X BAND SAR FOR ESTIMATING SNOW WATER EQUIVALENT: A RETRIEVAL APPROACH BASED ON NEURAL NETWORKS, SNOW MODELS AND IN SITU DATA

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Keywords: SAR, Neural Networks, snow parameters

Abstract

Climate, hydrological and meteorological studies and applications require an accurate characterization of snow cover at a global scale which is however still unavailable with the characteristics of accuracy, revisiting frequency, and spatial resolution needed by the potential applications. In-situ systems obviously cannot provide distributed observation at global scale, and the lack of appropriate sensors hampers the possibility of monitoring the snow cover from space at high resolution. The algorithms based on satellite microwave radiometers can provide global retrievals of snow mass with frequent revisiting and high accuracy, but with a ground resolution in the order of kilometres that is not sufficient for several applications. Conversely, the Synthetic Aperture Radars (SAR), although more suitable due to the high resolution, showed challenging capabilities for snow monitoring, since the frequency bands on board the current satellites, i.e. L, C and X bands, are not the optimal, and higher frequencies would be needed. Despite this, a few examples of Snow Depth (SD) and Snow Water Equivalent (SWE) retrieval based on SAR data can be found, pointing out the potential of these sensor for snow observations (e.g. Pettinato et al. 2013 and Santi et al. 2022). In these papers the estimate of SWE was carried out using Cosmo Sky-Med (CSK) X band SAR, basing on the synergy between Artificial Neural Networks (ANN) and a theoretical model (Dense Medium Radiative Transfer of Quasi Mie Scattering, DMRT-QMS, Tsang et al. 2007), which is able to simulate the backscattering behavior in different conditions of snow cover.

This paper shows the potential of CSK X- band SAR for monitoring dry snowpack and estimating SWE in Alpine areas, by combining X-band SAR signal, model simulations and machine learning retrieval methods. The study was carried out on the South Tyrol region, in the eastern Italian Alps, by using a dataset of CSK acquisitions: StripMap HIMAGE collected from 2013 to 20151. Ancillary data consisted of Digital elevation model (DEM) of the area to calculate the local incidence angle (LIA) for correcting the influence of slopes on backscattering. For collecting in-situ SWE measurements to be used as a reference for developing and validating the algorithms, dedicated field campaigns were carried out simultaneously with the satellite overpasses.

In dry snow conditions, previous research (Pettinato et al 2013) pointed out an increasing trend of X band σ° when SWE increases: the trend is more dispersed for shallower snow depths, until 50-60 cm, and better correlated to SWE for deeper snow. However, the relationship between σ° and SWE strongly depends on the other parameters that drive the scattering mechanism, namely the snow density, the grain size and the observation geometry (Paloscia et al. 2017, Santi et al. 2022).

The experimental sensitivity of σ° to SWE for the CSK HIMAGE subset is shown in Figure 1. Both σ° with or without the LIA compensation are shown: the effectiveness of the normalization in improving the correlation between σ° and SWE is evident from the figure: the determination coefficient increased from R=0.49 up to R=0.67.

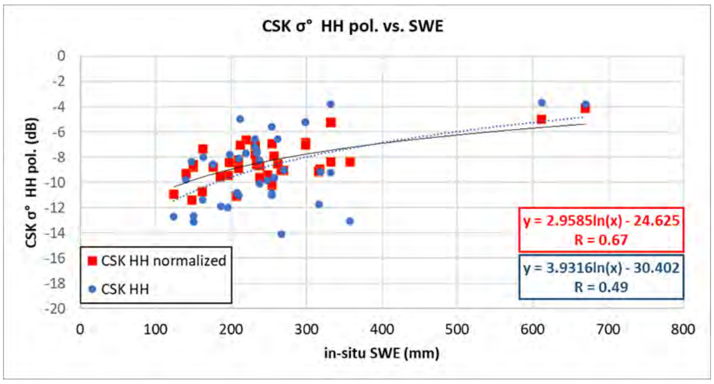

Figure 1. Direct comparison of CSK σ° (X-band, HH pol.) and in-situ SWE. Red points correspond to CSK data with LIA normalization, blue correspond to CSK data without LIA normalization.

The sensitivity of SAR backscatter to SWE of dry snow was analyzed with the support of DMRT-QCA model simulations, for exploiting the CSK sensitivity to the target parameter and assessing the effect of the parameters that drive the scattering mechanism.

Based on the sensitivity analysis results, an attempt of estimating SWE from the CSK acquisitions was carried out by implementing a machine learning retrieval algorithm, based on the feed-forward multi-layer perceptron neural networks (MLP-ANNs) available in the Matlab® Neural Networks toolbox. The training of the algorithm was based on DMRT model simulations with pseudo random inputs (4500 sets) by considering backscattering and incidence angle as inputs of the algorithm and SWE as output. After training the ANN was validated against in-situ measurements (45 sets). The ANN retrieval algorithm has been applied to the CSK images for generating maps of SWE for the entire area covered by the SAR acquisitions. An example of the SWE maps of the region generated for three dates (January 2013, January 2014, and February 2015) by the algorithm is shown in Fig. 2.

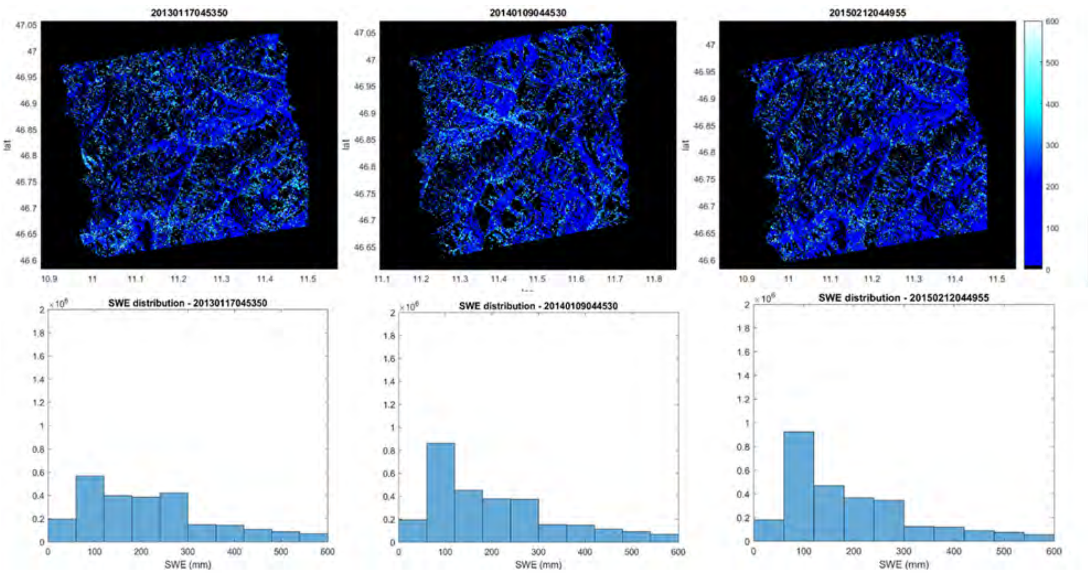

Fig. 2 – SWE maps obtained for three dates (January 2013, January 2014, and February 2015) using the ANN algorithm. In the histograms the SWE distribution at the three dates is shown.

In the histograms the SWE distribution at the three dates is shown. Although a validation for the entire area is missing, the obtained results can be considered encouraging, being the obtained SWE data in line with the season and the meteorological conditions. In any case, the validation carried out on the 45 available ground point measurements resulted in R=0.86 e RMSE=80mm.

Acknowledgments
The authors wish to thank EURAC institute in Bolzano for their support to this research in collecting snow in-situ measurements used for validating the algorithm.

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REMOTE SENSING-BASED DIGITAL TERRAIN MODEL OF A RIVERBED FOR MORPHODYNAMIC STUDIES

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Keywords: remote sensing, bathymetry, DTM, riverbed, classification

1. Introduction

Morphodynamics refers to the study of interactions between bottom topography and fluid hydrodynamic forces, involving sediment movement. Sediment patterns, such as bars, influence various human activities like navigation, construction of fluvial structures, and flood protection, while also enhancing habitat diversity and richness. Morphodynamics aims to understand topography's stability or predict its evolution in rivers, estuaries, and coastal regions to support decision-making in flood control, erosion prevention, and habitat restoration. While theoretical and practical advancements have been made in morphodynamics, models require data for testing and eventual integration into machine learning algorithms.

Remote sensing is a powerful discipline that provides both data and a means to monitor changes in aquatic environments over time. It facilitates deriving crucial parameters like channel width, indicative of bank erosion or migration phenomena, and water turbidity, offering insights into suspended sediment transport processes. Additionally, it aids in automating the classification of emerged and submerged areas to describe their roughness. Datasets collected from remote sensing sources may serve as both input parameters and validation for a recently developed theoretical model (Ragno et al., 2021) for predicting conditions that favour the incipient formation of bars at the river-sea transition zone. In this research, key procedures for generating a Digital Terrain Model (DTM) for both emerged and submerged areas from diverse remote sensing data sources are described. These include riverbed classification and bathymetry derivation from images.

2. Materials and Methods

The proposed approach for generating a continuous DTM of a riverbed, encompassing both emerged and submerged sections, involves integrating datasets from various sources: multispectral imagery, LiDAR and/or photogrammetric surveys, single-beam eco-sounder (SBES) bathymetric surveys, and eventually riverbed topographic cross-sections. Visible and infrared bands from multispectral imagery are useful for classifying the riverbed into three macro areas: water, sand/gravel and vegetation. Bathymetry data within the submerged regions is obtained applying a semi-empirical model, which accounts for the spectral values of multiple visible bands and is calibrated with SBES data gathered in situ. For sand/gravel areas, the DTM can be derived from either photogrammetry or LiDAR surveys. DTM estimation under vegetation remains uncertain if no LiDAR data is available; in such scenarios, we propose a potential solution leveraging photogrammetric data.

Riverbed classification. An aerial or satellite multispectral orthophoto can be used to classify the riverbed by analysing its four spectral bands: blue, green, red, and near-infrared. Initially, a threshold may be applied to the near-infrared band to distinguish wet surfaces from emerged areas. The latter are further classified to differentiate vegetated regions from those comprising sand/gravel using a supervised procedure, which can be performed with the maximum likelihood classifier algorithm implemented in a GIS environment. Additionally, shadows cast by bridges and vegetation are masked to prevent potential complications during subsequent processing stages.

Bathymetry derivation. Water depths are estimated using a nonlinear solution employing the ratio of log-transformed water reflectance bands with different absorption, as proposed by Stumpf et al. (2003). This model, widely used (Apicella et al., 2023) for estimating Remote Derived Bathymetry (RDB) products, is based on the assumption that light attenuates exponentially with depth in the water column, with this attenuation being wavelength-dependent, and relies on in situ bathymetry data for calibrating and validating results. In our study, Ground Truth Points (GTPs) for calibrating and validating the RDB model are obtained from an existing SBES survey. Mean Sea Level (MSL) serves as the vertical datum for the bathymetry data. To ensure consistency, the original high spatial density SBES survey is resampled to match the spatial resolution of the orthophoto's multispectral bands. This adjustment prevents different depth values from being associated with the same pixels. The available GTPs are then randomly split into two distinct calibration and validation datasets, each containing half of the survey points.

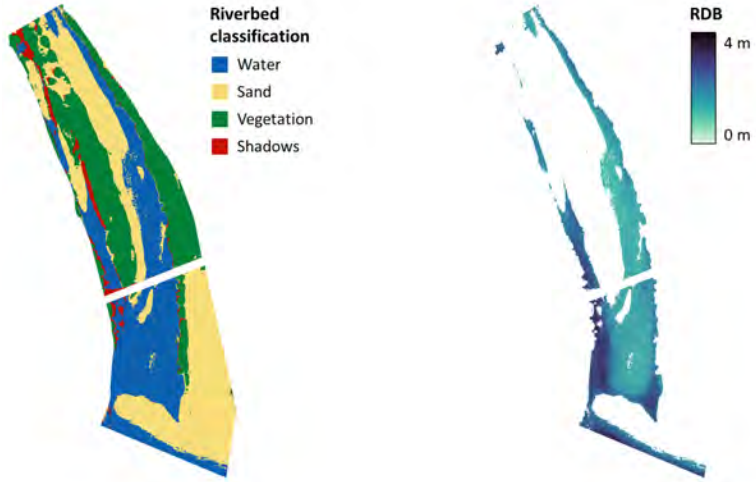
Water surface. It can be approximated as a tilted plane, ideally derived from LiDAR elevation data. This is because LiDAR's laser pulses, primarily intended for land surveying, do not penetrate the water surface. To achieve this, a linear segment tracing the main path of the watercourse has first to be identified. Subsequently, Voronoi polygons are generated to construct the tilted plane from LiDAR elevation data along this central line. In the absence of a LiDAR survey, the tilted plane may be created through interpolation or extrapolation from the elevation of sand/gravel regions within a buffer around wet areas.

DTM reconstruction. The orthometric height of submerged areas is obtained as the difference between the water surface and the RDB bathymetry. For sand/gravel regions, photogrammetric or LiDAR elevation data is considered. The elevation beneath vegetation can be directly derived from LiDAR, otherwise by interpolation or extrapolation from the elevation of sand/gravel areas within a buffer surrounding vegetated regions. The DTM is subsequently generated through interpolation techniques, including triangulated irregular network triangulation and cubic spline. The resulting elevation model provides continuous surface representation for both dry and submerged sections of the riverbed.

3. Results

The method has been applied to the estuary of the Roya River. Figure 1a displays the results of the riverbed classification, distinguishing submerged areas (blue), sand/gravel (yellow), vegetation (green), and shadows (red). The RDB obtained applying Stumpf's semi-empirical method is shown in Figure 1b. Figure 2 presents a comparison between the resulting DTM and surveyed SBES and photogrammetric data along a transect. SBES data (in light blue) serve as bathymetry ground truth, while photogrammetric profiles (in yellow) are used as a reference for areas comprising sand/gravel. The DTM's profile is denoted by the red line. The graph provides evidence of the DTM's reliable performance, demonstrating its capability to depict a credible terrain surface. In areas with vegetation, the discrepancy between the two profiles is attributed to the fact that the photogrammetric survey accounts for the height of the vegetation.

The accuracy of the obtained DTM is conditioned by the quality of remote sensing data employed (instrument accuracy, spatial and temporal resolutions). Future work involves refining and automatizing the described procedure and using it for morphodynamic studies.



(a) (b)

Figure 1: Example of riverbed classification (a) and RDB obtained for submerged areas (b).

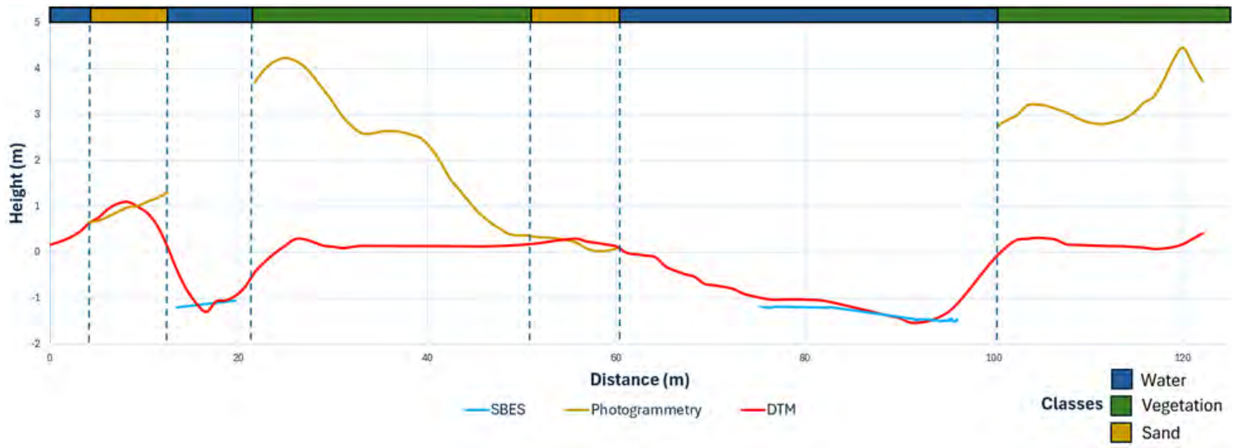


Figure 2: Comparison between derived DTM (red) and the surveyed SBES (light blue) and photogrammetry (yellow) along a transect.

Acknowledgements

This work was carried out within the framework of the project "RAISE - Robotics and AI for Socioeconomic Empowerment" and has been supported by the European Union – NextGenerationEU. The authors would like to express their gratitude to Dr. Lorenza Apicella for her valuable contribution during the initial phase of the research activity. Gratitude is also extended to Gter Ltd for supplying the SBES and photogrammetric data.

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REMOTE SENSING & *GIS* FOR THE DRAGONE PLAIN SOUTHERN ITALY

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Keywords: water resources; remote sensing; *GIS*; vulnerability; decision-making processes, hydrogeology

Abstract
In light of significant climate changes (i.e., temperature rise, rainfall decreases, desertification) and heavy land use (i.e., heavy anthropization, widespread agricultural livestock farms, the need for precise water resource management has never been more pressing. However, effective water resource management requires continuous monitoring and decision-making processes. This is where the exciting potential of remote sensing and *GIS* science comes into play. With their advantages in terms of spatial, spectral, and temporal availability of data covering large and sometimes inaccessible areas in short periods, these technologies are functional tools for monitoring natural resources such as water bodies. They enable time and cost-effective monitoring, providing useful information on water potential, quality, contamination, quality variation, and their spatial distribution, as well as the impact of changes in land use and land cover on them. Remote sensing and *GIS* science are also referred to by European and Italian management rules as land-water resource management tools (European Directive 2000/60/EC; Ministerial Decree 471/99; Legislative Decree 152/06).

Fig. 1 The Dragone plain on the upper left; the Cassano Irpino springs on the bottom left; Hydrogeological scheme and monitoring network of Terminio-Tuoro (Aquino et al., 2021; Trocciola et al., 2021) on the right

The *Dragone* Plain of the *Terminio-Tuoro* carbonate massif in the *Monti Picentini* Regional Park (Fig. 1) is one of the largest existing endoreic runoff areas in the Southern Apennines, a strategic water supply resource for southern Italy. *Volturara Irpina*, *Montella*, *Castelfranci,* and *Caposele* springs with *Serino* are the largest

water reservoir in southern Italy and the second largest in Europe with about 2000 l/sec, distributing water to *Avellino* province but also to *Napoli* and *Benevento* and *Basilicata* and *Puglia* regions (Fig.1).
The *Dragone* Plain receives surface runoff water after flowing through the fertile soils, and from the numerous streams furrowing the slopes of the surrounding mountain crown, forming, especially in winter, a catchment area of about 6,8 km^2 (Aquino et al., 2006) called "*Dragone* Lake".

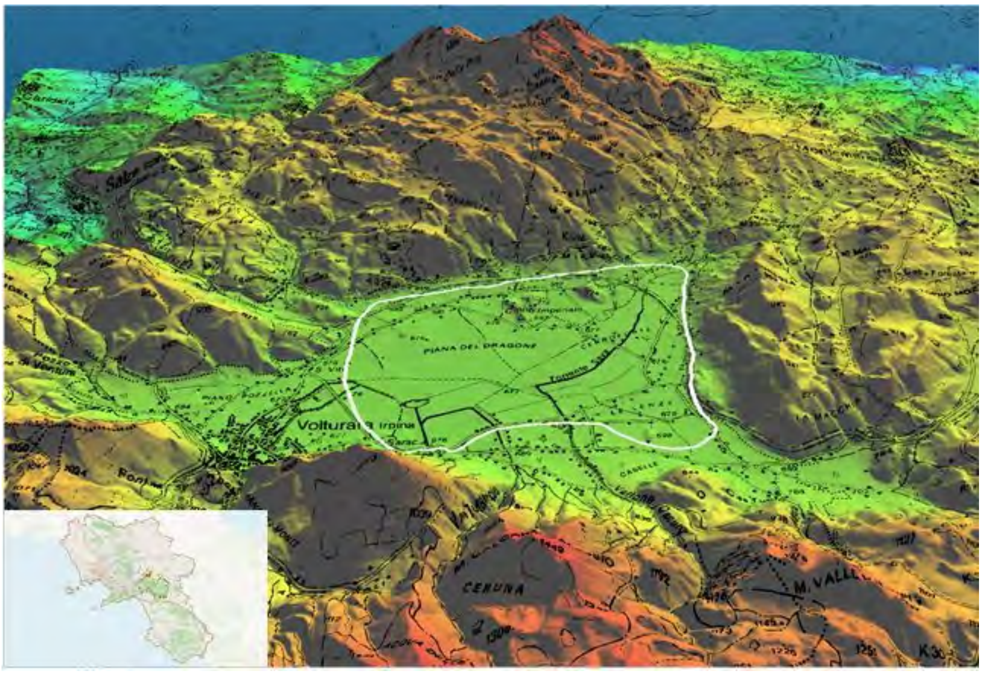


Fig.2 The Dragone plain 3D view: the study area is a depression with a nearly horizontal bottom within Sabato and Calore rivers valleys at an average elevation of 680 m above sea level and an extension of 686 hectares (SIC IT8040014, white contour) and whose centroid is located at Latitude 40° 53' 25.9218" N and Longitude 14° 56' 47.1305" E - WGS84 (Digital elevation model with 5 m resolution and other geographic dataset from Campania Geoportal website and GeneGIS GI, https://parcoregionalemontipicentini.it)

A network of collecting canals conveys water to the *Bocca del Dragone* swallow-hole, formed following the 1456 earthquake: under normal conditions, it can absorb 900 liters of water per second and is the starting point of the complex underground hydrographic network. Consequently the plain is highly vulnerable to pollution (Cusano et al., 2023): "patchy" scattered landfills; rural houses with dispersing septic tanks; load of pesticides (products of synthetic origin, in some cases even carcinogenic); organic load from livestock farms; absence of suitable sanitation infrastructure (sewer collectors, purifiers, lift plants); high over-exploitation by derivation of new deep wells for industrial and hydro-potable use are critical issues. The purpose of this study is to depict the dynamics of expansion and contraction as a function of climatic, geomorphological, and geochemical variables in both temporal and spatial aspects. More specifically, we aim to calculate the volume of water accumulated in the lake in relation to rainfall data through GIS & remote sensing methodology, based on systematic and spatially distributed information sources such as satellite image series (Fig. 2). The plain climate is quite continental: relevant rainfall with more 1500 mm annual values during six low-sun months. The dataset shows maximum daily rainfall amounts frequently exceeding 100 mm, with accumulated values even exceeding 200 mm in case of durations of 4-6 days (max: 343 mm in six days in January 2023 in *Cassano Irpino*) (fig. 3). Meteoric input over natural runoff results in flooding of surrounding areas, washing them.

Fig.3 Seasonal rainfall values in the Dragone Plains
(Campania live e Centro Polifunzionale Regione Campania websites).

Over a span of three years, different dated 30 Level 2A Copernicus Sentinel 2 images were downloaded between 2018 and 2021 over the study area from https://www.sentinel-hub.com/ platform. The *NDWI* index (Normalized Difference Water Index, McFeeters, 1996) was used to map flooded areas and identify precipitation peaks from Sentinel 2 data. Also, *NDWI* rasters were compared with the *SWI* index (Sentinel-2 Water Index, Jiang, et al. 2020), rasters in order to establish the best index for detecting flooded areas. Contours generated from such *NDWI* or *SWI* rasters were eventually used to choose the best altimetric value in the volume calculation.

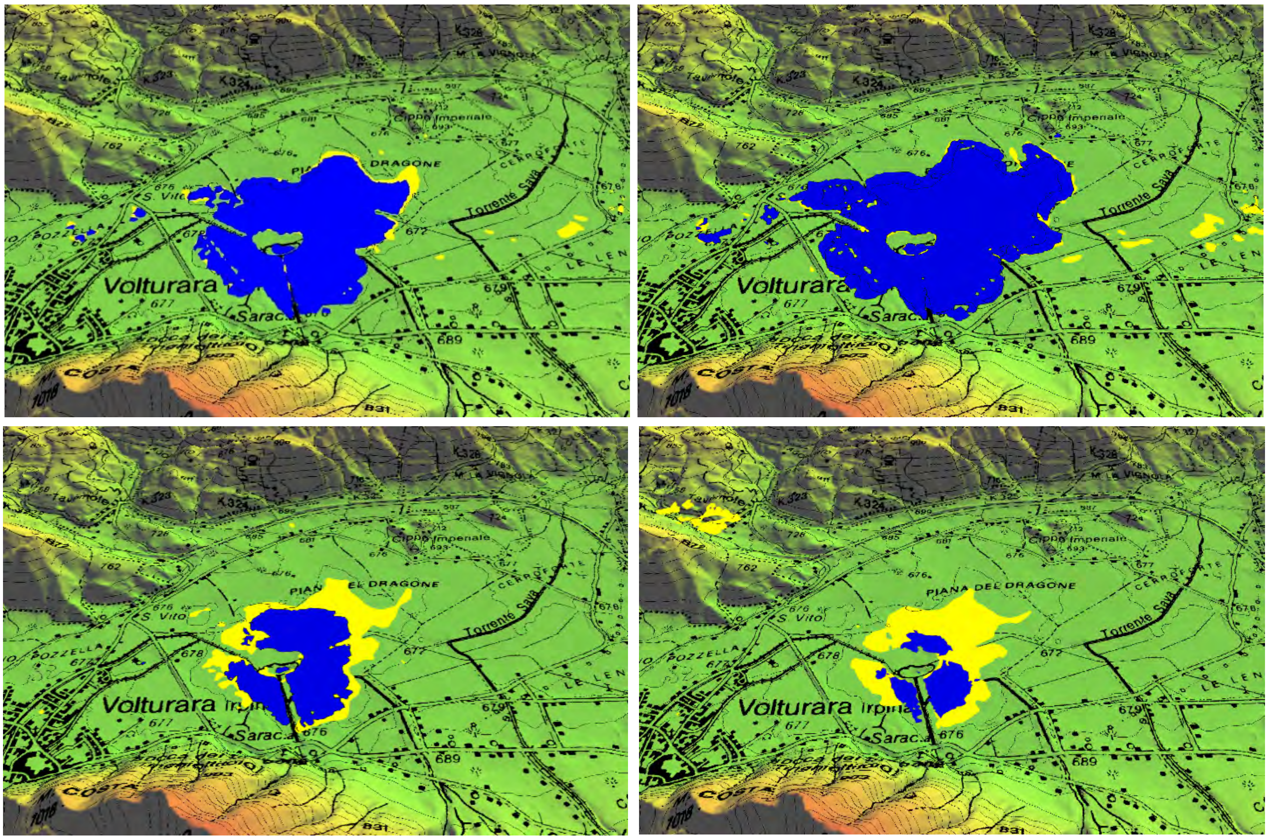


Fig. 4 NDWI (in blue) and SWI (in yellow) index values of the Dragone Plain, obtained through the Global Mapper's 'Vectorize Raster' command, results: 2021_01_27 (upper left); 2021_02_11 (upper right); 2021_04_27 (down left) and 2021_05_02 (down right).

Tab. 1 Altimetric statistic parameters values for *SWI* and *NDWI* indexes for all dates examined

WATER INDEX	DATE	PERIMETER m	SURFACE m^2	MIN_ELEV m	MAX_ELEV m	AVG_ELEV m	MODE_ELEV m	SURFACE area 3D m^2
SWI	2021_01_27	8267.3	1142447	667.5	672.2	669.4	669.6	1202621
SWI	2021_02_11	8390.7	1586640	664.4	673.2	669.6	670.0	1647110
SWI	2021_04_27	6352.4	610250	667.7	670.7	669.1	669.0	612368
SWI	2021_05_02	4687.7	496188	667.7	671.6	669.0	669.0	498131
NDWI	2021_01_27	8146.3	1089322	667.5	672.2	669.3	669.2	1148313
NDWI	2021_02_11	8148.3	1633169	664.4	673.2	669.6	670.0	1690205
NDWI	2021_04_27	3689.8	375203	667.7	671.6	669.0	668.5	376890
NDWI	2021_05_02	1351.3	78667	667.9	671.6	669.1	668.2	78676

The divergences visible with overlapping raster water indexes are made even more explicit in Table 2, which shows altimetric statistic parameter values for all examined dates.
The volume calculation procedure was performed using the Global Mapper software's "Calculate Cut-and-Fill Volume" command, due to its detailed parameter choice and excellent graphic results.

Table 2 shows an example of applying several volume calculations with a progressive *Base height value* level corresponding to the calculated flooded area expressed in km^2 (*Fill area*) and m^3 (*Fill volume*) based on the *NDWI* raster for the 2021-02-11 date.

Tab. 2 Areas and volumes by contours for *Dragone* Lake

Base height (sea level) m	Fill area (F) km^2	Fill volume m^3
669.2	0.444	233972.77
669.4	0.593	342579.06
669.6	0.745	480777.34
669.8	0.862	645259.83
670.2	1.392	1161700.70
670.7	1.564	1911435.70
671.0	1.137	1943993.10
671.4	1.143	2400167.30
671.6	1.145	2629054.40

In our experiments, the value of base height that best approximates the *NDWI* raster contour referred to 2021-02-11 is 670.7, as shown in Figure 6.

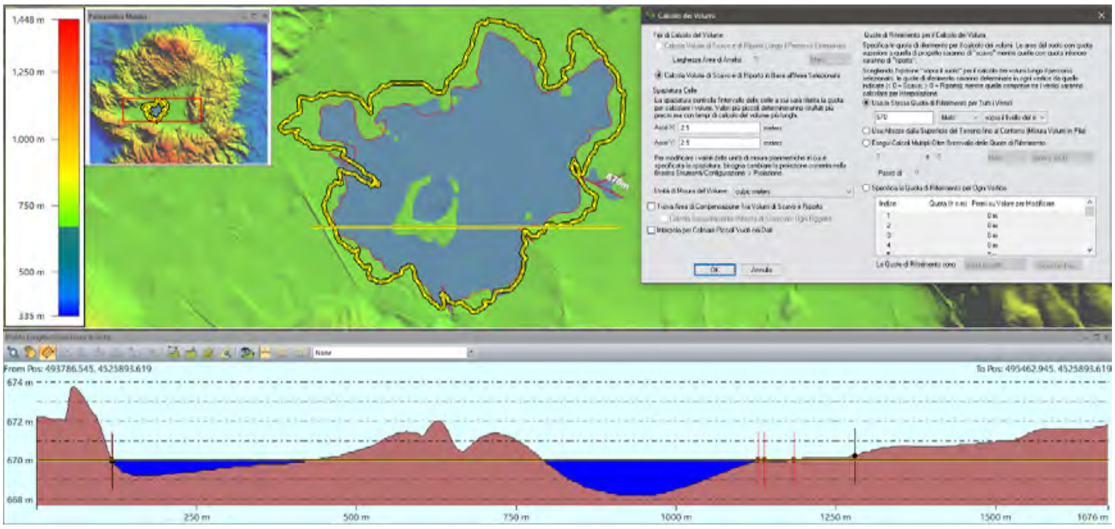
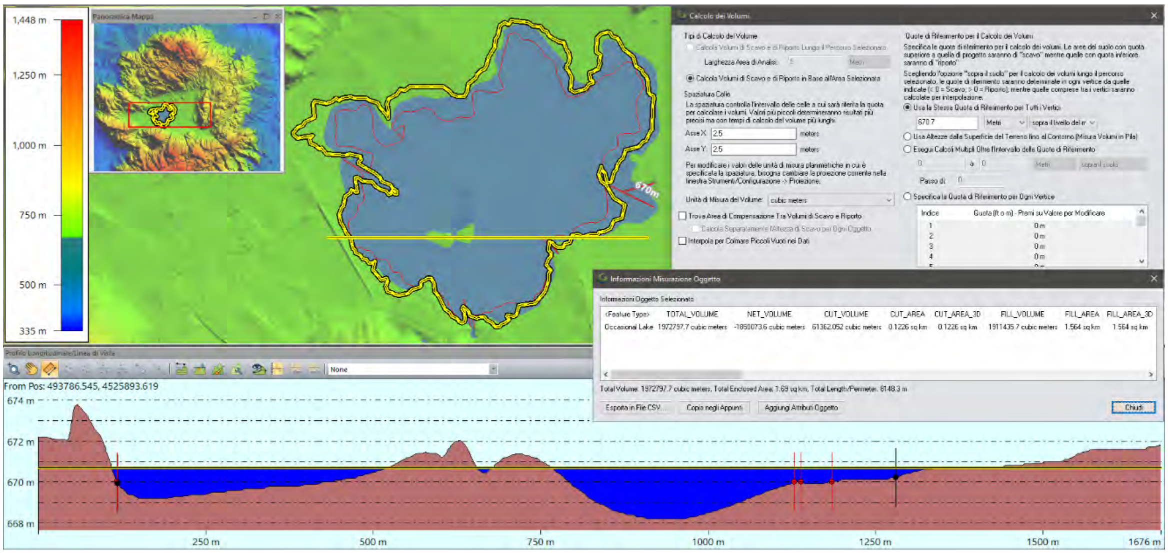


Fig. 5 Volume calculations based on Global Mapper "Calculate Cut-and-Fill Volume" commands with a base height value of 670.0 m above sea level and longitudinal profile along the bottom of the plain with the "Path Profile" tool.

Fig. 6 Volume calculations based on Global Mapper "Calculate Cut-and-Fill Volume" commands with a base height value of 670.7 m above sea level and longitudinal profile along the bottom of the plain with the "Path Profile" tool

In Figures 5 and 6, the yellow line represents the *NDWI* raster contour, the red line represents the 670.0 m elevation curve, and the blue area is the calculated flooded area at 670.0 m and 670.7, respectively.



The bottom of the figures shows a longitudinal profile of Dragone Lake corresponding to the yellow straight line overleaping flooded area.

Our study represents a pioneering step in the field, focusing on calculating volume in relation to the optimal water index. By utilizing a digital terrain model with a higher geometric resolution (e.g. 1 m), we can enhance the accuracy of our calculations and the efficiency of satellite data utilization. This innovative approach opens up new possibilities for future research.

Our vision is to enhance the model by incorporating hydrometeorological, evaporation, and anthropogenic factors, such as irrigation. This expansion will enable us to predict the volumes involved in subsurface runoff more accurately. This potential for future research holds promise for more effective water resource management in the face of changing environmental conditions.

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AERIAL HYPERSPECTRAL IMAGING APPLICATION FOR WATER AND HYDROLOGICAL ANALYSIS

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Keywords: hyperspectral aerial images, water indices, water quality, turbidity, Chl-a, runoff, infiltration, imperviousness, permeability

Abstract

In the past decades remote sensing techniques and hyperspectral imaging technology have been widely used for several analyses on water resources, like the assessment of water quality or estimating hydrological parameters such as runoff coefficient, infiltration value and etc. (Behling et al., 2015, Mbuh, 2019, Jianxin et al., 2020, Lima et al., 2023). While the satellite imagery is widely used for mapping and monitoring the changes in quality of water and understanding the spatio-temporal variation of hydrological parameters at small scale (Thakur et al., 2017, Haji Gholizadeh et al., 2016), hyperspectral aerial images have a spatial resolution up to 1 meter and allow for more accurate analysis and the possibility to study water bodies of small size (Haji Gholizadeh et al., 2016). The assessment of water quality can be done by measuring the qualitative parameters of waterbodies, like suspended sediments, coloured dissolved organic matter (CDOM), chlorophyll-a and pollutant (Behling et al., 2015, Olmanson et al., 2016). Through the specific spectral signature of materials, the optically active water quality characteristics can be measured and be related to empirical or analytical models (Mbuh, 2019). A number of water quality indicators can be estimated. The apparent visible wavelength (AVW) indicates the dominant wavelength (color) of the water-leaving radiance, and its higher values can indicate higher turbidity levels (Vandermeulen et al., 2020). The Chl-a concentration is derived based on a semi-empirical model termed OC6 (ocean color model utilizing six hyperspectral bands, O'Reilly and Werdell, 2019). Water turbidity index is derived by a semi-analytical approach and classified the water to three categories based on turbidity level (Dalin et al., 2023). On the study area of Ferrara, aerial hyperspectral images were acquired with the sensor AisaFENIX384 by Specim with 364 spectral bands in the VNIR and SWNIR spectral ranges and a spatial resolution of 1 meter. Three indicators of water quality were calculated on the water bodies, that is the chlorophyll-a concentration (Figure 1), the water turbidity level index (Figure 2) and the (AVW).

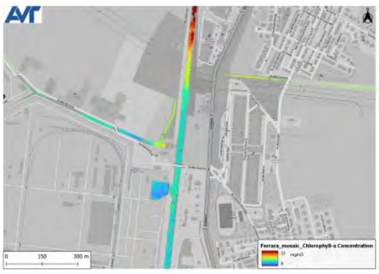

Figure 1. Ferrara: Chlorophyll-a Concentration.

Figure 2. Ferrara: Water Turbidity Level.

Figure 3. Ferrara: Water Turbidity Level.

In addition to water quality, the products derived by hyperspectral aerial images are used to assess the parameters contributing to water balance and hydrological cycle, which are important in the management of water resources (Thakur et al., 2017, Khanbilvardi et al., 2014). Land cover and land surface materials have a high influence on hydrological process and parameters such as infiltration, runoff. Therefore, hyperspectral images can play an important role to assess the related values and indices in a spatially continuous way (Behling et al., 2015, Khanbilavardi et al., 2014). Using machine learning techniques, a detailed surface material map can be produced, both in terms of spatial accuracy and number of classes. Materials are generally divided into two macro-classes: materials on roofs and materials on the ground. The most wanted materials on the ground in cities are asphalt, cement, grass, and water. In Ferrara, the materials such as gravel, sand, cobblestone and bare soil were added. Materials on roofs generally include: red roof tiles, solar panels, metal, glass, sheathing, asbestos cement, eco-friendly fibre cement, etc. Given the information on the surface materials, some hydrological properties are assigned to each material, then indicators for runoff coefficient, infiltration, imperviousness are estimated. The indices are dimensionless numbers between 0 and 1 and calculated as a subset of urban ecological indicators that represent varying degrees of urban surface differentiation (Behling et al., 2015). Depending on the purpose and requirements of the study, the indices can be represented on different ways, e.g. based on urban administrative divisions (i.e. district, block units), or on squared/hexagonal grids with different size, according to the specifications of the final users. Figure 4, Figure 5 and Figure 6 show the calculated indices in Ferrara. The indices are used by the final users in the municipalities for assessment of flooding risk.

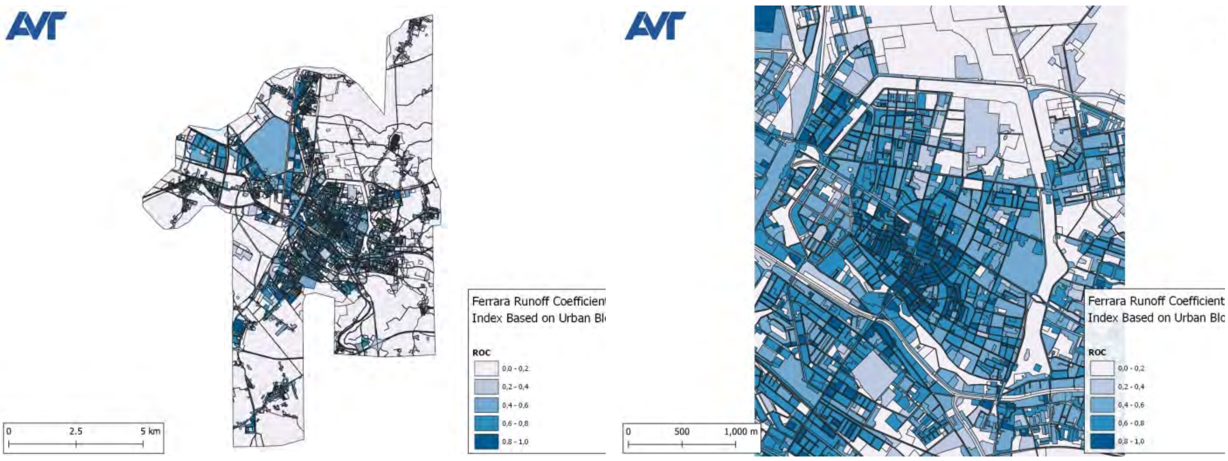

Figure 4. Runoff Coefficent Index based on urban blocks in Ferrara. View on the city (left) and zoom in city centre (right).

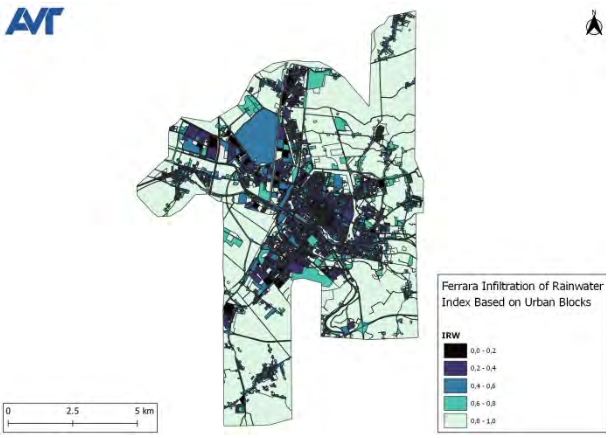

Figure 5. Infiltration of rainwater index in Ferrara.

Figure 6. Imperviousness index in Ferrara.

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ISBN 978-88-8286-471-2

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