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Mapping Flooded Paddy-Rice Fields in the Landscape between Turin and Milan: A GIS-Based Method for Detecting Scenic Routes for Experiential Tourism

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Abstract

The current research aims to explore the potential of ESA Sentinel-2 time-series satellite imagery, for detecting the seasonal landscape changes of paddy-rice fields, in the north-west of Italy, by using GIS mapping tools. On a regional scale context, paddy-rice mapping has several implications for agricultural monitoring, precision farming, food production, water management and climate change. However, it also concerns theirs high scenic value in the landscape perception, which can be a great resource for sustainable tourism. The defining characteristic of paddy-rice is that rice plants grow on flooded soils. In the field of slow tourism, such a temporary site-specific condition of the landscape can become an unconventional tourist destination. The research has been applied to territories in between cities: Turin and Milan, where the phenomenon of paddy-rice flooding, in the spring season, generates an outstanding scenic perception of the rural landscape. The research shows the effectiveness of the GIS workflow to compute the vegetation indices, which are sensitive for mapping flooded paddy-rice fields. The final outcome is a thematic map highlighting the scenic routes in the existing road network that allows experiencing such seasonal landscape conditions.

Keywords: seasonal landscape, vegetation index, paddy-rice, mapping scenic routes, Sentinel-2

1 Introduction

Seasonal landscape changes are strongly interlaced with the annual cycle of plants and human actions impacting the earth. In the last decades, many research efforts have been developed in the field of the earth observation, with the aim of finding new ways to monitor environmental phenomena that occur on the earth's surface. Since 2014, the European Commission, in cooperation with other partners such as ESA and EUMETSAT, has started the ambitious programme for earth observation named: Copernicus. This program consists of seven Sentinel satellites in orbit, which supply geospatial data and geo-information referring to six thematic streams: land monitoring, marine environment monitoring, atmosphere monitoring, security, emergency management and climate change (European Commission, 2015).

2 Seasonal landscape changes and sustainable tourism

The current research aims to investigate the relationships between the seasonal landscape changes related to paddy-rice fields and sustainable tourism. Seasonal landscape changes can affect specific environments such as forests, paddy-rice, vineyards and grasslands that, over the seasons, can assume a high scenic value in landscape perception. Such site-specific phenomena that occur seasonally, such as autumn foliage colouring, spring-blooming of lavender fields and grasslands, and flooding of paddy-rice fields are major attractions for the tourism sector and contribute to increasing the attractiveness of the places (Spotts & Mahoney, 1993), (Hall et al. 2011), (Chen et al., 2016), (Rozenstein & Adamowski, 2017). Paddy-rice fields mapping can play an important role in the field of experiential tourism and perception of agricultural landscapes. In fact, the unique feature of paddy-rice fields is that rice plants grow on flooded soils. On regional-scale contexts, such a temporary condition of the landscape can become an unexpected and unconventional tourist destination. Furthermore, the growth of a new form of tourism, such as experiential tourism, requires new digital tools for supporting personal user's travel-planning. The flooding stage is a time-defined period that is also related to different parameters (temperature, water availability, weather forecasts etc.) that individual farmers consider for their cultivation schedule. On regional-scale contexts, the scenic value of large portions of the rural landscape can be detected through remote sensing and mapped by using GIS techniques. Paddy-rice mapping is a very challenging topic that affects many research fields such as food production, water management, agricultural monitoring, precision farming, water management, and climate changes (Dong & Xiao, 2016b), which are also strongly interlaced with UN SDGs (United Nations, 2015). Examples of these SDGs include: SDG n.2 for sustainable agriculture, SDG n.9 for building resilient and sustainable infrastructure, SDG n.11 for safe, resilient and sustainable human settlements, SDG n.13 actions for climate change, SDG n.15 for sustainable use of the land and environment. Referring to SDGs, the current research will show the application of digital earth observation and GIS mapping techniques, as a tool to support new strategies for sustainable tourism. In this research field, a global-scale continuously updated map showing where and when the flooding of the paddy-rice fields occurs is required. In this framework, the open-access availability of the huge quantities of Sentinel satellite imagery is a vital data source for supporting research activities and decision-making for sustainable tourism management.

3 Study area

The current research has been centred on the *in-between* territories the cities of Turin and Milan, in the north-west of Italy, south of the Alps (province of Vercelli 45°19'26"40 N, 08°24'59"04 E); a complex landscape made up of open spaces, mobility infrastructure, towns, rural settlements, and natural protected areas, which is the result of a long process of interaction between natural elements and human activities. The historically rural landscape, used in intensive agriculture (rice cultivation, vineyards, orchards etc.) is supported by a network of artificial waterways, such as the Cavour canal, built between 1863 and 1866, which is a vital resource for this territory (Segre, 1983), (Monti, 2002), (Occelli et al. 2012), (Rolando & Scandiffio, 2016), for both food production and tourism. Furthermore, the historical network of local roads is widespread, well maintained and ensures the accessibility to the scenic landscape of paddy-rice fields over the year. The pilgrimage path, Via Francigena (from Canterbury to Rome), that is ridden by many pilgrims over the year, crosses these territories from the Alps to Po valley, and it is a great resource for slow tourism. The study area has been selected within the towns Vercelli and Santhià, where there is a high concentration of paddy-rice fields between the Cavour canal, the river Sesia, and the high-speed railways connecting Turin and Milan (Fig.1).

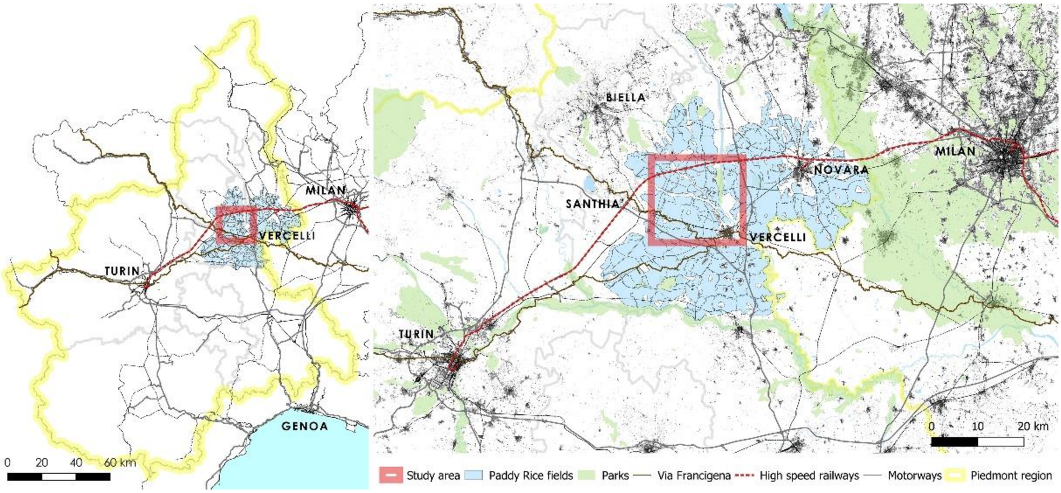

Figure 1: On the left, scheme of the Piedmont region in the northwest of Italy, with evidence of the study area in-between the cities of Turin and Milan, where a high concentration of paddy-rice fields is localized. On the right, the study area has been highlighted in the rural landscape of the paddy-rice fields. The study area has been localized in-between the towns of Vercelli, Santhià and the high-speed railways connecting Turin and Milan.

Furthermore, Italy is the largest rice producer in Europe (FAO, 2004). To better understand the importance of rice production in the Piedmont region, regional and national data were compared. In 2019, the paddy-rice land cover in Italy was 220.027,24 ha; while the paddy-rice land cover in the Piedmont region was 111.632,07 ha, split up the province of Vercelli 67.577,86 ha, the province of Novara 32.104,14 ha, and the province of Biella 3.651,82 ha (Ente Risi, 2021). The three mentioned provinces have covered more than 92% of the regional paddy-rice land cover and 47% of the Italian paddy-rice land cover. All these factors contribute to the uniqueness of these territories and support new investigations for local economies and tourism management.

4 Methodology: the GIS workflow

In this perspective, the current research explores how satellite imagery from ESA Sentinel-2 mission (European Space Agency, 2015) can be applied for computing vegetation indices and consequently mapping the spatial distribution of the flooded paddy-rice fields during the spring season. The workflow exploits the specific physical feature of rice plants, that they grow on flooded soils (Xiao et. al., 2006). In this study, the GIS workflow was created by using the graphical modeller, in order to improve the effectiveness of the processing. The following scheme shows the GIS workflow, from the input to the outputs (fig.2). In the following sections, the workflow will be analyzed step by step.

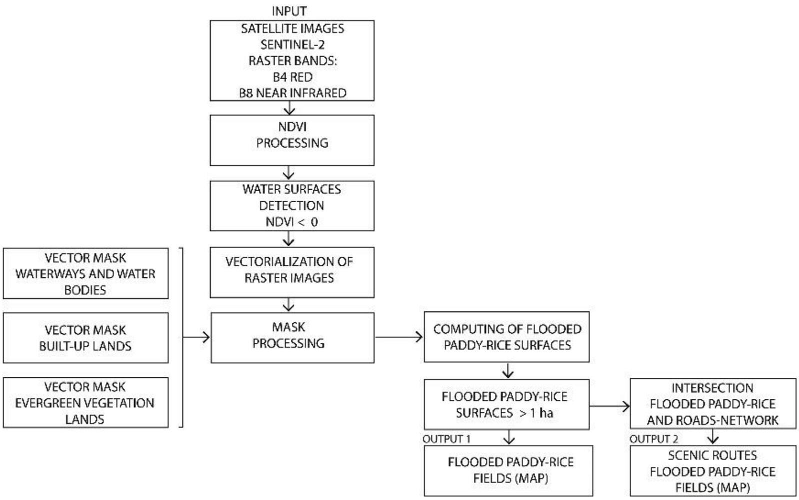

Figure 2: Scheme of the GIS workflow. Satellite images from Sentinel-2 have been considered as input data (Bands: Band 3 Green 543-578 nm – Resolution 10 m, Band 4 Red 650-680 nm – Resolution 10 m; Band 8 Near Infrared 785-899 nm – Resolution 10 m.

4.1 Data source and vegetation indices

Sentinel-2 is a European wide-swath, high-resolution, multi-spectral imagery mission that contributes to the ongoing multi-spectral observations and benefits Copernicus services and applications such as land management, agriculture, forestry and disaster relief (European Space Agency, 2015). Sentinel-2 contributes to land monitoring, by providing input data such as multi-spectral imagery with high resolution (10 m, 20 m and 60 m), which supports the computing of Vegetation Indices (VI), such as Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI). In the scientific literature, several approaches have been identified to observe landscape seasonal changes at ground level, particularly forests (Motohka et al., 2010) (Motohka et al., 2011), but also paddy-rice mapping, by exploiting satellite imagery (Dong & Xiao, 2016b), (Kaplan & Avdan, 2017), computing vegetation indices (e.g. NDVI, NDWI, EVI, LSWI etc.), and using multi-spectral bands (Xiao et al. 2006) (Dong et al. 2016a). During the flooding period, the land surface of paddy-rice fields is a mixture of water and green rice plants, with water depths usually between 2 and 15 cm (Xiao et. al. 2006). This specific condition of paddy-rice fields can be captured, by computing vegetation indices. NDVI exploits the surface reflectance of near-infrared 785-899 nm and red 650-680 nm; NDWI exploits the surface reflectance of near-infrared 785-899 nm and green 543-578 nm. (McFeeters, 1996). NDVI and NDWI have been calculated according to the following equations:

$$(1)\ \ \mathrm{NDVI} = \frac{\mathrm{B8\ NIR} - \mathrm{B4\ Red}}{\mathrm{B8\ NIR} + \mathrm{B4\ Red}} \qquad (2)\ \ \mathrm{NDWI} = \frac{\mathrm{B3\ Green} - \mathrm{B8\ NIR}}{\mathrm{B3\ Green} + \mathrm{B8\ NIR}}$$

The NDVI and NDWI values can range between -1 and +1. The pixel-based recognition of the flooded paddy-rice fields have been conducted with high-resolution bands (10 m), using thresholds: NDVI < 0, and NDWI > 0, to compare the results of both indices. In order to verify the threshold method, a comparison was made between the pixel-based recognition (1st of June 2018) and ground observations (2nd of June 2018). The comparison between the pixel-based recognition and the ground observation shows good match for both indices in the selected locations (fig. 3). Both thresholds perform very well in respect to the scope of current research; the NDVI threshold allows to capture a wider area than NDWI. Therefore, the NDVI threshold has been assumed for the processing of the current research.

Figure 3: location a) lat: 45.514488, long: 8.270235. Location b) lat: 5.542138, long: 8.275017. The figure shows the comparison between satellite pixel-based recognition of flooded paddy-rice (1st of June 2018) and ground observation (2nd of June 2018). In the figure, it is also possible to compare NDVI and NDWI thresholds.

In the current research, the flooding monitoring was carried out in spring 2020, over three months (March, April and May are the traditional flooding months in this area), selecting the satellite imagery within a cloud cover of 5% in order to avoid misleading information. The following images refer to Sentinel-2 image of a typical day (11th April 2020), selected at the beginning of the flooding season (Product: Sentinel-2A, cloud cover 1,30 %, zone: 32TMR, min lat: 45.0852, max lat: 46.0535, min lon: 7.70695, max lon: 9.12617) (fig. 4a). The NDVI has been performed according to equation (1). The NDVI values (between -1 and +1) have been visualized by using a colour ramp from red to green (fig. 4b).

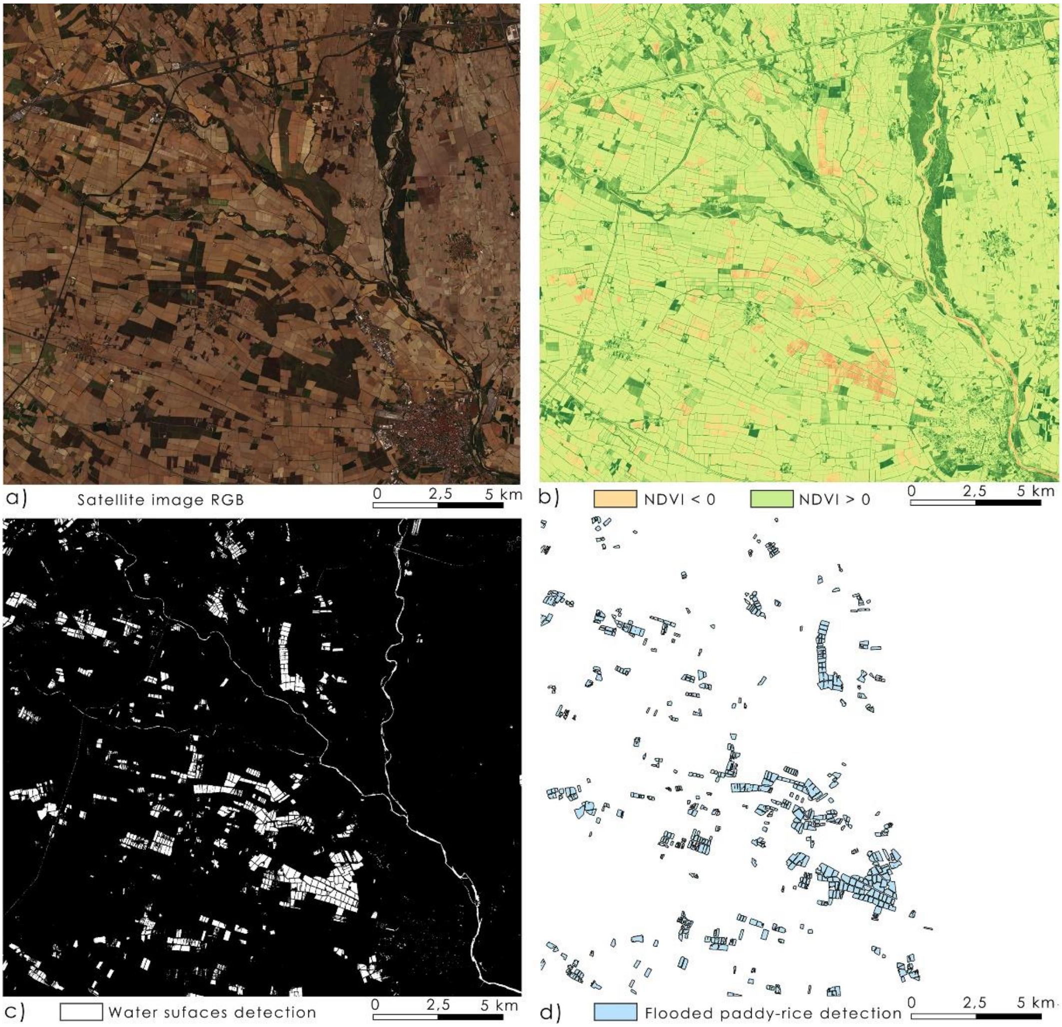

Figure 4: a) Satellite images from Sentinel-2 RGB. b) NDVI processing. High values have been mapped by dark green; low values, which correspond to the water surfaces, have been mapped by red. c) Pixel-based detection by using the threshold NDVI < 0. This threshold allows the detection of water surfaces, but also other heterogeneous objects. d) The mask and vectorization process enables the isolation of the flooded paddy rice-fields into the map.

4.2 The mask processing

In a regional-scale context, the performed vegetation indices thresholds enable the detection of different typologies of water surfaces and other heterogeneous objects such as flooded paddy-rice fields, rivers, waterways, wetlands, permanent water bodies, and particular roofs in built-up areas (Dong & Xiao, 2016b) (fig. 4c). Delete misleading information from the whole pixel-based recognition was performed by applying the vectorization process to the thresholded raster images. The mask process has been successfully performed by using the open-access available vectorial datasets (e.g. regional open data and open street map datasets).

Mask processing was carried out using several datasets: built-up areas, permanent water-bodies, waterways, and wooded land cover datasets. The application of the masks to the pixel-based recognition is a fundamental step of the workflow as it enables isolating the flooded paddy-rice fields from the other detected heterogeneous surfaces. In terms of tourism attractiveness of flooded paddy-rice fields, it has been computed for the surface of each areal entity and applied the following threshold: flooded paddy-rice surface > 1 ha. This threshold allows the detection of the most significant sections of flooded paddy-rice fields in the study area. The first outcome of the GIS workflow is the flooded paddy-rice map, which shows, on a certain date of the year, the spatial distribution of the flooded paddy-rice fields (fig. 4d).

5 Experiencing the flooded paddy-rice fields through scenic routes

The final goal of the research is the processing of a thematic map that shows the scenic routes in the existing road network. This tool informs a range of end-users decisions in the field of tourism and environmental contexts. The scenic routes map should be perceived as a "trip-advisor" tool, able to support tourists, interested in the perception of this scenic phenomenon, in the route-choice. The scenic routes detection is the result of the overlapping between the roads-graph, available through the open-access vector datasets (e.g. Open Street Map dataset), and the flooded paddy-rice fields map. The roads-graph has been overlapped with the flooded paddy-rice fields map, with the aim to identify single stretches of the road network that intersect with flooded areas. An offset distance of 50 m from the road axis for the both sides was established to determine the geometrical intersection between the flooded areas and the offset lines of the roads. The thematic map visualises the single stretches of the road network where the flooded paddy-rice fields are within sight (fig. 5). The workflow can be reiterated over the flooding period of paddy-rice fields to redetermine the map of scenic routes every week.

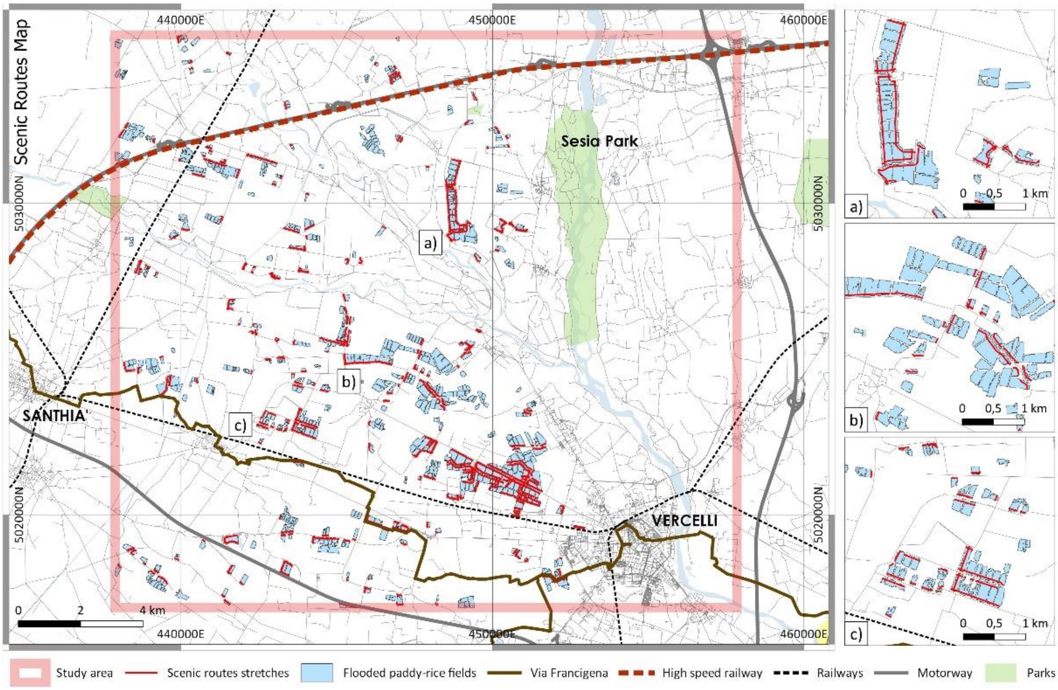

Figure 5: On the left, The Scenic Routes Map. SR WGS84/UTM 32 N. The map highlights the scenic routes stretches in the existing roads-network. On the right, the detailed sections (a, b and c) highlight the single stretches of the roads-network from where flooded paddy-rice fields are perceivable.

6 Discussion

The research shows the effectiveness of the workflow, combining earth observation tools and GIS mapping techniques for detecting flooded paddy-rice fields and determining the scenic routes map for sustainable tourism. Firstly, the application of the GIS modeller to the workflow allows reiterating the process every 3 days (time for Sentinel-2 data acquisition at mid-latitude) over the spring season, showing the variability of landscape conditions in a dynamic map. The high frequency of Sentinel-2 data acquisition would enable mapping the seasonal changes of paddy-rice fields to support the creation of a widespread tourist-destination offer, year-round. In the current research, the workflow has been applied to a limited extension area (about 20 km by 20 km), but the method is replicable and scalable in other territories around the world, where such scenic landscape conditions occur seasonally. Secondly, the applied NDVI threshold can be further improved, to perform mapping of the different rice-growing stages, with higher detection accuracy, even considering formulas which combine multiple vegetation indices. Finally, this method uses the vectorization processing of raster images in the mask processing, coherently with the targets of the research. This aspect could be considered as a limit for large areas, where no uniform vectorial datasets are available yet, and can require long processing. In a regional-scale context, such as the performed one in the research, the available vectorial datasets can be used successfully in the mask processing.

7 Conclusions

Over the year, many seasonal phenomena occur regularly in different environments (e.g. the spring blooming of grasslands and lavender, the autumn colouring foliage). New mapping tools, which combine earth observation and GIS mapping tools, can inspire the development of new strategies for sustainable tourism, which may also contribute to SDGs, particularly addressing the revitalization of inner-areas economies, promoting more efficient use of the places, reducing emissions, and overpressures on the environment. New digital services may contribute in capturing the seasonal conditions of the landscape and enhancing the tourist experience of the places especially if they are localized in marginalized and remote landscapes. Better integration of earth observation tools and GIS mapping tools can contribute to the "digital earth" by supplying tools that support sustainable actions for the future of our planet.

References

Chen, B., Qiu, Z., Nakamura, K. (2016). Tourist preferences for agricultural landscapes: a case study of terraced paddy fields in Noto Peninsula, Japan. *Journal of Mountain Science*, 13, 1880–1892. https://doi.org/10.1007/s11629-015-3564-0

Dong, J., Xiao, X., Menarguez, M. A., Zhang, G., Qin, Y., Thau, D., Biradar, C., & Moore, B. (2016a). Mapping paddy rice planting area in northeastern Asia with Landsat 8 images, phenology-based algorithm and Google Earth Engine. *Remote sensing of environment*, 185, 142–154. https://doi.org/10.1016/j.rse.2016.02.016

Dong, J., Xiao, X. (2016b). Evolution of regional to global paddy rice mapping methods: A review. *ISPRS Journal of Photogrammetry and Remote Sensing*, 119, 214–227. https://doi.org/10.1016/j.isprsjprs.2016.05.010.

Ente Risi, (2021). Retrieved from: http://www.enterisi.it/servizi/seriestoriche/superfici_fase01.aspx

European Commission (2015). *Copernicus Europe's eyes on the Earth.* Copernicus Brochure, European Commission, Directorate-General for Communication, Retrieved from: https://www.copernicus.eu/sites/default/files/documents/Brochure/Copernicus_Brochure_EN_WEB.pdf

European Space Agency (2015). Sentinel-2 User Handbook. Retrieved from: https://earth.esa.int/documents/247904/685211/Sentinel-2_User_Handbook

FAO (2004), International year of rice 2004, Retrieved from: http://www.fao.org/rice2004/en/p7.htm

Hall, C.M., Scott, D., Gössling, S. (2011). Forests, Climate Change and Tourism. *Journal of Heritage Tourism*, 6, 353–363. https://doi.org/10.1080/1743873X.2011.620252

Kaplan, G., Avdan, U. (2017). Object-based water body extraction model using Sentinel-2 satellite imagery. *European Journal of Remote Sensing*, 50:1, 137-143. https://doi.org/10.1080/22797254.2017.1297540.

McFeeters, S., K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features, *International Journal of Remote Sensing,* 17:7, 1425-1432 doi:10.1080/01431169608948714

Monti, P. (2002). *Storie d'acqua. Le canalizzazioni del Vercellese e gli ecomusei del Piemonte*. Pavone Canavese: Priuli & Verlucca.

Motohka, T., Nasahara, K.N., Murakami, K., Nagai, S. (2011). Evaluation of Sub-Pixel Cloud Noises on MODIS Daily Spectral Indices Based on *in situ* Measurements. *Remote Sensing,* 3, 1644-1662. https://doi.org/10.3390/rs3081644

Motohka, T., Nasahara, K., N., Oguma, H., Tsuchida, S. (2010). Applicability of Green-Red Vegetation Index for Remote Sensing of Vegetation Phenology. *Remote Sensing,* 2(10), 2369-2387. https://doi.org/10.3390/rs2102369

Occelli, C., Palma R., Sassone M. (2012). *La ciclostrada del canale Cavour. Una via a bassa velocità tra Torino e Milano.* Boves: Araba Fenice.

Rolando, A., Scandiffio, A. (2016), *The Central Park in between Torino and Milano*. In AA.VV. Proceedings of 53rd IFLA World Congress, Tasting the Landscape. Turin.

Rozenstein, O., Adamowski J. (2017). Linking Spaceborne and Ground Observations of Autumn Foliage Senescence in Southern Québec, Canada. *Remote Sensing,* 9(6), 630. https://doi.org/10.3390/rs9060630.

Segre, L. (1983). *Agricoltura e costruzione di un sistema idraulico nella pianura piemontese* (1800-1880). Milano: BCI.

Spotts, D.M., Mahoney, E.M. (1993). Understanding the Fall Tourism Market. *Journal of Travel Research,* 32, 3–15. https://doi.org/10.1177/004728759303200202

United Nations (2015). Transforming our world: the 2030 Agenda for Sustainable Development. Retrieved from: https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

Xiao, X.M., Boles, S., Frolking, S., Li, C.S., Babum J.Y., Salas, W, Moore, B., (2006). Mapping paddy rice agriculture in South and Southeast Asia using multi-temporal MODIS images. *Remote Sensing of Environment*, 100, 95–113. https://doi.org/10.1016/j.rse.2005.10.004