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# Abstract

# Monitoring freshwater environments by satellite data

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Freshwater ecosystems are in extremely critical conditions. Intense water pollution, alteration of the hydrological and sediment regimes and of the channel morphology induced by anthropogenic activities and climate change are drastically degrading the biodiversity of these environments.

Remote sensing images from satellite platforms can provide a significant contribution in the continuous monitoring of ever-changing environments, such as wetlands and rivers.

In this PhD dissertation, the use of multitemporal multispectral Landsat4/5-TM (30 m spatial resolution), Landsat-8-OLI (30 m), Sentinel-2 (10 m), and SAR (Synthetic Aperture Radar) Sentinel-1 (15 m) and CosmoSkyMed (3 m) images were used to monitor freshwater environments. Three different case studies were developed: a wetland, reaches of a perennial river of the main network and reaches of non-perennial rivers of the minor network.

All the used datasets are freely downloadable from the web, except for the CosmoSKyMed database that has been made available thanks to the project: "HABISAT- Habitat modelling in intermittent rivers by satellite data exploitation". The general approach was to distinguish between the different significant soil covers of water, bare soil and vegetation from remotely sensed images. Very high-resolution images, orthophotos and/or geolocated ground pictures were used as the ground truth for the derivation of the spectral signature of the different covers in the various contexts, as well as the calibration and validation of the classifications. The very high-resolution images were available on the web (Google Earth Pro) or provided by the European Space Agency (ESA) in the framework of the ESA third-party mission (© TPMO 2019) within the two projects: "Monitoring and modelling of surface water environments at large spatial and temporal scales by the integration of satellite remote sensing and local surveys" and "Tracking riverine morpho-dynamics from satellite imagery: the case of the Po River, Italy". In one case, an orthophoto was obtained from a photographic survey performed ad hoc with UAV.

The potential of the multispectral imagery of the Landsat-8-OLI and Sentinel-2-MSI satellite missions were investigated in monitoring the winter evolution of land cover in the Albufera wetland (Spain). An automated pixel-based classification method was used to identify four classes: (1) open water, (2) mosaic of water, mud and vegetation, (3) bare soil and (4) vegetated soil. The automatic classification of the four classes was obtained through a rule-based method that combined the Normalized Difference Water Index (*NDWI*), Modified Normalized Difference Water Index (*MNDWI*) and Normalized Difference vegetation index (*NDVI*). The overall accuracy was found to be 0.96 and 0.98 for Landsat-8 and Sentinel-2, respectively. The observed dynamics of the land covers were highly variable in space. For example, the presence of the open water condition lasted for around 60–80 days in the areas closest to the Albufera Lake and progressively decreased towards the boundaries of the park. The study demonstrates the feasibility of using moderate-resolution multispectral images to monitor land cover changes in wetland environments.

Focusing on a reach of the Italian Po River, the multispectral Landsat4/5-TM, Landsat-8-OLI and Sentinel-2-MSI and SAR Sentinel-1 data were used to track the morphological evolution from 1986 to 2020. A simple classification method based on *MNDWI* was implemented to extract the wet channel and its variations over time from multispectral data. The overall accuracy, always greater than 0.90 for all the missions, was consistent through time. A supervised deep learning algorithm was used to extract the wet channel from SAR data. The performances resulted slightly lower than those of the multispectral monitoring but with the advantage of increasing the revisit time especially in cloudy periods. Morphological changes and the effects of river restoration works where detected through a comparison of wet channel shapes at fixed water levels.

Novel tools were developed to monitor the flow conditions of non-perennial rivers with multispectral Sentinel-2 and SAR Cosmo SkyMed data. The tool was applied to the monitoring of three small rivers in the Campania region: Sciarapotamo, Mingardo and Lambro. A SWIR-NIR and Red, false-colour combination of multispectral bands was used to highlight the presence of water. Comparisons with field data acquired in various flow conditions showed that it is possible to identify the condition of continuous water flow

("Flowing") from that characterized by the presence of isolated ponds of water ("Ponding") and the condition of dry bed ("Dry bed"). Despite the higher spatial resolution of the Cosmo data, the results are no more detailed than those obtained with the multispectral analysis. For all the archive multispectral images (since 2015), the occurrence of flowing, ponding or dry bed conditions were identified. The obtained dataset allowed to train a random forest (RF) model to reconstruct the daily flowing conditions on the basis of cumulated rainfalls and temperatures.

This PhD dissertation showed how satellite data can effectively help fill the knowledge gap on flooding extension and timing, morphological changes and flow regimes of freshwater environments. The resulting body of knowledge will help optimize the management and protection of aquatic ecosystems.