Exploitation of satellite data for the monitoring river morphological evolution: study case of the Po River (Italy)

Exploitation des données satellitaires pour le suivi de l'évolution morphologique des rivières : un cas d'étude sur le fleuve Po (Italie)

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RÉSUMÉ

Le suivi de l'évolution morphologique des rivières est essentiel pour comprendre la dynamique actuelle des rivières et estimer les éventuelles tendances futures. En raison du nombre élevé d'acquisitions nécessaires, et surtout dans le cas de longs tronçons de rivière, les enquêtes traditionnelles sur le terrain ou par drone sont excessivement lourdes et coûteuses. Dans ce contexte, les données satellitaires constituent une ressource cruciale. En effet, certaines agences spatiales fournissent gratuitement des données avec une couverture mondiale et un temps de revisite court (moins d'un mois). Dans cette étude, des données satellitaires multispectrales du domaine public acquises par Landsat 4-5-TM, Landsat-8-OLI et Sentinel-2-MSI entre 1986 et 2020 ont été utilisées. Les images satellites ont été traitées pour extraire le canal humide d'un tronçon de 40 km du fleuve italien Pô. Ces données ont été utilisées pour détecter les changements morphologiques en comparant des séries d'images acquises en correspondance avec des niveaux d'eau fixes. De cette façon, il a été possible d'étudier les effets des travaux de restauration de la rivière effectués pendant la période d'observation.

ABSTRACT

Monitoring the morphological evolution of rivers is essential to understand the current river dynamics and estimate possible future trends. Due to the high number of acquisitions required, and especially in the case of long river reaches, traditional field or drone surveys can be onerous and expensive. In this contest, satellite data are a crucial resource. Moreover, some space agencies provide free data with global coverage and a short revisit time (less than one month). In this study, public domain multispectral satellite data acquired by Landsat 4-5-TM, Landsat-8-OLI and Sentinel-2-MSI from 1986 to 2020 were used. The satellite images were processed to extract the wet-channel of a 40 km reach of the Italian Po River. These data were then analysed to detect morphological changes by comparing a series of images acquired in similar hydrological conditions (i.e., similar water levels). In this way, it was possible to also investigate the effects of river restoration works that occurred in the observation period.

KEYWORDS

Landsat, Po River, morphological monitoring, satellite data, Sentinel-2

1 INTRODUCTION

Hydro-morphological monitoring of rivers is performed by field campaigns and remote sensing. Local surveys and airborne or drone remote sensing allow to obtain very accurate maps, but with the drawback of limited availability in frequency and coverage and high costs. Satellite remote sensing allows for continuous monitoring of vast areas with long historical archives of observations (more than 40 years in some cases), high revisit time and limited or no costs. For monitoring hydro-morphological changes in medium-sized rivers (width in the range of 20-200 m), very high-resolution satellite (VHR) images (space resolution of the order of 0.5 m) are suitable. However, VHR images are too expensive and the temporal resolution of freely available ones (e.g. Google Earth-Pro) is insufficient. Free data are available at moderate spatial resolutions (10-30 m). For example, the Landsat program of the NASA and USGS and Sentinel-2 of the ESA provide multispectral images with variable resolutions (10, 20, 30, 60 m) according to the band, with revisit times of 9 and 5 days, respectively. According to Jiang et al. (2014), satellite monitoring is possible when rivers are wider than three image pixels, therefore Landsat and Sentinel-2 data can be used for rivers wider than about 90 m and 30 m respectively.

2 STUDY CASE

The Po River is the longest watercourse in Italy (651 km) and drains a catchment area of approximately 74,091 km^2. The presence of flood protection works, the extraction of aggregates, the presence of dams for hydropower production and agricultural use, and the construction of wing dykes for navigation purposes led to bed incision and evolution from multi to single-thread channel. The study focuses on a 40 km reach between Boretto and Borgoforte, having an average bankfull width of 200-500 m and a single-thread meandering pattern. Within the study reach, a wing dyke was lowered in 2013 to reactivate a secondary channel to increase the ecological quality and reduce bed erosion during extreme events.

3 AUTOMATIC CLASSIFICATION OF WATER SURFACES

In this work, we used freely available, archive satellite images of Landsat-4 and 5, (L4/5, from 1986 to 2011), Landsat-8 (L8, from 2013 to 2020) and Sentinel-2 (S2, from 2015 to 2020). After atmospheric correction, the data were processed to classify the water surfaces (Cavallo et al., 2021a) through a threshold-based method on the Modified Normalized Difference Water Index (MNDWI).

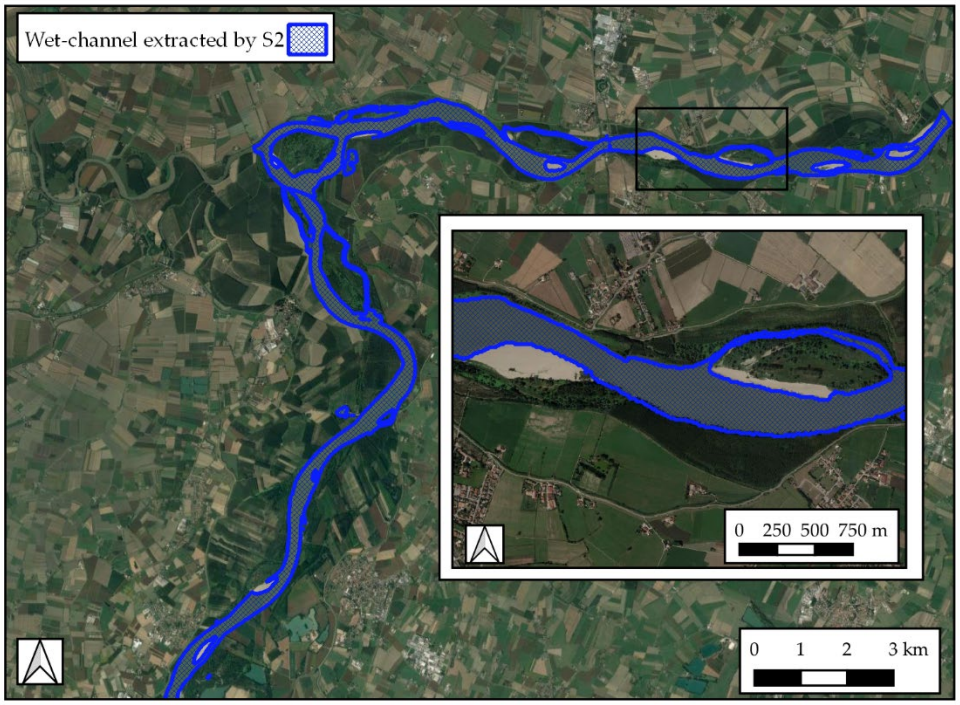

Figure 1. Comparison between the wet channel extracted from S2 image of 03/09/2020 (H=14.88 m a.s.l.) and VHR image extracted by Google Earth Pro, dated 04/09/2020 (H=14.69 m a.s.l.).

For the validation, classification results were compared with very high resolution (VHR) multispectral images (spatial resolution about 0.50 m) of the WorldView-02 and GeoEye-01 satellites (provided by ESA in the framework of the Third Party Mission within the project 'Tracking riverine morphodynamics from satellite imagery: the case of the Po River, Italy') and Google Earth Pro images. Eight couples of VHR images and almost contemporary (maximum temporal distance of three days) cloud-free L8, L4/5 and S2 images were analysed. The classification accuracy resulted in the range of 94%-98% and the precision in the range of 93%-98%.

To evaluate the possibility of jointly using the L8 and S2 datasets, the coherence of the wet channel classification obtained by the two datasets was checked. A total number of 25 S2 and L8 cloud-free images, acquired in the same days, were compared. The accuracy resulted in the range of 95%-97% and the precision in the range of 93%-97%.

4 MONITORING HYDRO-MORPHOLOGICAL CHANGES

The planimetric surface of the wet channel is given by the width of the cross-section in correspondence with the free surface. This is strictly dependent on the water level, according to a relationship that expresses the geometry of the cross-section. The differences in the shape and size of the planimetric surface of the wet channel, in two moments with the same water level, give a clear indication of the occurrence of morphological changes in the wet channel contour. Consequently, to detect eventual hydro-morphological changes, satellite images referring to similar water levels H were grouped and compared (Cavallo et al., 2021b). These groups were composed of at least three images within the interval H±ΔH, with ΔH≤4 cm, meaning a change of less than 2% of the minimum discharge measured at Borgoforte (218 m^3/s). The water stages were extracted from the annals of the *Agenzia Regionale per la Prevenzione, l'Ambiente e l'Energia dell´Emilia-Romagna*.

As an example, in Figure 2 are reported some of the water surfaces extracted from images acquired in days with a water level of 13.26 m asl (±4cm) before and after the wing dyke's lowering (2013).

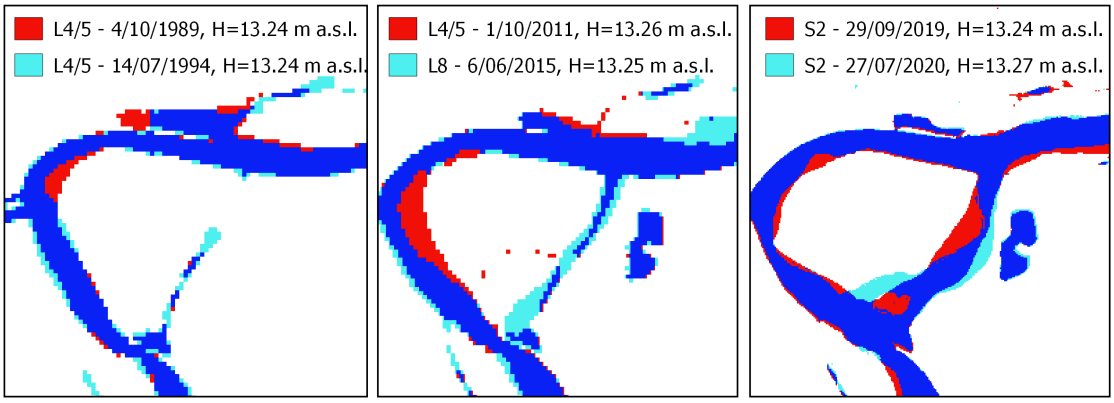

Figure 2. Time changes of the wet channel: blue = area covered by water in both the first (t0) and the last day (t1) of the interval; red = water present only at (t0), cyan = water present only at (t1).

5 CONCLUSIONS

The analysis demonstrated that Sentinel-2 and Landsat data can be effectively used for monitoring planimetric changes in intermediate-sized rivers (width higher than 30-90 m). The analysis confirmed that, during the last 35 years, the Po River between Boretto and Borgoforte has a more or less stable morphology and that the lowering of a wing dyke contributed to reactivating a secondary channel.

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