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Morphological changes of the floodplain reach of the Taro River (Northern Italy) in the last two centuries

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SUMMARY

The quantitative analysis of the planform changes of the unconfined reach of the Taro River, in the Italian Northern Apennines, has allowed the channel evolution in the last 200 years to be outlined.

Nine sets of maps and orthophotos, ranging from 1828 to 2011, have been used to evaluate the medium-term changes in channel morphology along the entire time interval, as well as the short-term changes in the most recent decade. Starting from the digitized channel limits and bars, a number of shell scripts based on GIS commands has been used for fast and automatic calculation of the main morphological parameters (channel length, width, braiding, sinuosity, centerline shifting) and for the drawing of graphs showing in detail their continuous variations along the entire study reach. The analysis of the differences in parameters on subsequent dates has revealed that, at least until the end of the 20th century, continuous reduction in channel width (up to a total of 75%) and braiding (43%), as well as continuous increase in channel length (13%) and sinuosity (29%), took place. This is in agreement with most of the previous studies on other rivers, both in Italy and abroad.

In contrast with the results of other studies, the most recent evolutionary trend of the Taro River shows substantial morphological stability with possible slight narrowing. The identification of the variations along the channel, facilitated by the analysis of the parameter curves and supported by the historical documentation, reveals that these variations can be substantially attributed to human activities. In particular, the continuous narrowing is largely due to the recurrent subtraction of riverbed areas to be used for agricultural and industrial purposes, as well as to the construction of 10 bridges with the relevant bank protections. The intense mining between 1950s and 1980s seems to have caused a sharp incision and partial narrowing only. The morphological changes due to the reduction in the flow regime, which seem to emerge from the sporadic and discontinuous hydrological data, are expected to be negligible and, in any case, are immaterial when compared with the remarkable changes due to human activities.

1. Introduction

The study of the past morphological changes in floodplain unconfined reaches and the relationship with the natural and human-induced controlling factors is widely recognized as a useful tool to define the evolutionary trend in order to plan correct river management or sustainable river restoration. Morphological evolution involves bed level fluctuations, as a consequence of incision and aggrading, as well as planform changes, concerning channel width, position and pattern. The older channel altimetric variations are impossible to assess due to the lack of in-channel elevation values in the old historical maps. In any case, in-channel elevation data are limited also for recent periods as they need accurate measurements directly on the field. On the contrary, planform channel changes can be more easily defined in quantitative terms, both in the older cartography and in the modern orthophotos, through indexes and parameters, which have been long proposed (Thorne, 1997) and experimented by various authors (channel width, braiding, sinuosity, shifting) and whose acquisition and analysis have been considerably improved by the use of Geographical Information Systems (GIS). A much more difficult task is defining the causes of river modifications. Even though there is general agreement on the identification of river adjustment controlling factors, i.e. climatic changes and anthropic activity at catchment and channel scales, the influence of each single factor is difficult to assess, especially when such factors act in combination. Unceasing research on causes-effects assessment in different regions of the world is substantiated by the large number of works on this subject-matter. An updated and exhaustive list

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of works can be found, for instance, in the recent papers by Ziliani and Surian (2012) and Segura-Beltrán and Sanchis-Ibor (2013). With specific regard to Italy, many studies on rivers, both in the Alps and Apennines, have been carried out, as summarized in Gurnell et al. (2009) and Comiti et al. (2011).

This paper presents an analysis of the planimetric changes in the floodplain unconfined reach of the Taro River, one of the Po River largest tributaries in the Northern Italian Apennines. The analysis was performed by comparing a sequence of maps and orthophotos ranging from 1828 to 2011. Six of them (1828, 1881, 1958, 1976, 1999, 2011) were used to assess medium-term changes in channel morphology, while 2003, 2006, 2008 were used to assess the short-term variations in the parameters over the 1999–2011 time interval. As morphometric parameter calculations require a long and repetitive sequence of operations, even if carried out in a GIS environment, a set of shell scripts, mainly based on the GIS commands, were created. These automatically compute the parameters and construct graphics showing the changes in parameters along the entire channel development, speeding up the procedure and allowing, at the same time, a detailed analysis of the planform changes in time and space to be carried out.

In the attempt to explain the measured morphological changes, the available information on hydrological characteristics at gauging stations (rainfall, river discharge and stage) was collected together with the scanty official data on the amount of in-channel gravel mining. The description of past events (construction of bridges with the related up-and down-stream protection structures, human occupation of large portions of the riverbed, effects of in-channel mining) contained in the historical archives or reported in more recent books proved very useful for the reconstruction of past river conditions.

2. The study reach

The Taro River, located in the Italian Northern Apennines, in the Parma Province, flows from the Apennines main divide to the Po River for about 126 km. The first 72 km, up to the Town of Fornovo, drain a steep mountainous region, where allochthonous geological formations – Cretaceous in age – prevail (Molli, 2008). The remaining 54 km are located in the Po plain, formed by successions of marine and continental deposits, Plio-Quaternary in age (Ori, 1993). Of the total drained area of about 2026 km^2, 800 km^2 are in the floodplain sector (Fig. 1).

In Fornovo, the Taro River receives the Ceno Torrent, the most important of its tributaries, which drains a basin of about 526 km^2. Close to its confluence in the Po River, the Taro River receives the Stirone Torrent, which drains an area of about 300 km^2.

The river characteristics and evolution appear strongly conditioned by the structural setting of the area. In fact, the course of the Taro River coincides with a great fault, whose activity caused the uplifting of the western side by some tenths of meters during the Plio-Quaternary (Bernini and Papani, 1987). The main effect is the progressive shift of the channel eastward, as testified by the presence (in the middle and low plain) of paleochannel tracks almost exclusively on the western side of the present channel.

As regards the channel pattern, presently the unconfined study reach is typically braided in the upper part for about 19 km, while it is single-thread mainly meandering in the lower part for about 29 km. The middle tract of about 6 km is transitional, with wandering characters.

Along the basin divide, the mean annual precipitation is about 2600 mm (max in November with 296 mm, min in July with 68 mm), and the mean annual temperature is 12.0 °C (max in July with 18.6°, min in January with 1.0°). Close to the mouth, the mean annual precipitation is about 750 mm (max in November with 101 mm, min in July with 51 mm) and the mean annual temperature is 12.7 °C (max in July with 23.4°, min in January with 1.3°).

The mean annual discharge at the gauge station of S. Quirico, the closest to the river mouth, is 31 $m^3\,s^{-1}$ (Arpa Emilia-Romagna, 2015).

3. Methodology

In this study, GRASS (Geographical Research Analysis Support System), a Free Software/Open Source GIS released under GNU General Public Licence, was used (GRASS Development Team, 2014; Neteler and Mitasova, 2008). In addition to data digitization, display and georectification, GRASS was used for the automatic calculation of the channel parameters and their graphical representation through a number of shell scripts.

3.1. Data sources

Of the nine data sources used in this work, the first three (1828, 1881 and 1958) needed to be rectified and georeferenced. As base map for co-registration, we used the very detailed 1976 map images with 0.635 m resolution. The Cartographic Office of the Emilia-Romagna Region warrants that these images have high dimensional conformity and isotropy and a negligible georeferencing error thanks to a 800 dpi scan and to the use of at least 25 GCPs (Ground Control Points) in georectification for each map sheet. For co-registration we used a minimum of 25 GCPs that could be precisely identified on each couple of temporal images. We selected the GCPs along both sides of the channel, external to and not too far from it, considering that better accuracy can be obtained by concentrating the points near the features of interest (Hughes et al., 2006). A second order polynomial transformation matrix was adopted and for cell values resampling the "nearest neighbor" interpolation method was chosen. Positional accuracy was estimated by RMSE. As georectification was carried out for each single image, different RMSEs were obtained for different images having the same date. The highest single image RMSE was applied to all the images of a specific date. Adopting the United States National Standard for Spatial Data Accuracy methodology (FGDC, 1998) for estimating Positional Accuracy of points at 95% confidence level (corresponding to a Circular Error at 95% confidence level, or CE95), the RMSEs were multiplied by 1.7308 assuming that the error is normally distributed and independent in each x- and y-component.

The other datasets are available in georectified and georeferenced form. As reported in each specific documentation set, the Positional accuracy (CE95) for each dataset is $\leqslant$4 m.

The characteristics of the data sources are summarized in Table 1.

Actually, in the considered time interval, other maps are available, but they are of no use in this contest as they were obtained from previous maps by updating roads and buildings only, without any updating of the stream network.

3.2. Computed parameters

The calculation of the planform characteristics by the GIS based shell scripts requires manual digitization of only two channel features: banks, represented by the top of the scarp delimiting the channel at bankfull stage, and longitudinal bars, including islands. Just for completeness, also the lateral bars were digitized, even though they were not included in the calculation of any of the considered parameters. The entire digitization process was carried out