

Roberto Ranzi*, Matteo Balistrocchi**, Stefano Barontini*, Marco Peli*

Land cover changes since the 19th century detected from historic maps for environmental applications: toward a “CORINE 1800” project?

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Summary: The value of cartographic heritage for environmental applications is demonstrated with a test case in the Central Italian Alps. Land cover changes since the early 19th century are detected from sample maps of the Second Military Survey of the Habsburg Empire in Lombardy (1818-1829), available on the portal www.mapire.eu. They are compared with 1954 areal surveys and successive land cover classification until 2018. Issues as land use classes homogenization, data vectorization, georeferencing errors are addressed. The dynamics of main land cover classes (woods, bush, meadows, crops) are investigated on sample areas and the potential use of this exercise for hydrological applications is explored. In fact, the impact of the observed natural afforestation on changes in hydrological losses due to evapotranspiration and its influence as a likely cause for the decrease in runoff monitored since 1845 in the Adda river basin and needs to be assessed in a systematic way. The proposed test case can pave the road for a project extended at European scale, a sort of “CORINE 1800 land cover” Geographic Information System, which could have several environmental, cartographic and socio-economic applications.

Introduction

Land cover changes detection from old maps is fundamental for several environmental and socio-economic applications. As pointed out by Jobst and Gartner (2010) historic geospatial contents are becoming more and more important in documentation and cartographic applications. The accessibility of cartographic heritage resources in digital form (see e.g. Arcanum, 2005; Biszack et al., 2014) makes them attractive for multidisciplinary applications. This study was motivated from the observation of a statistically significant decrease in annual runoff, detected to occur since the mid-19th century in several basins of the Italian Alps (see for instance Ranzi et al., 2017; 2021; Balistrocchi et al., 2021). This is a relevant outcome in view of assessing the impact of climatic and man-induced changes on the hydrological cycle. However, the reasons of this river flow decline are not well understood. It cannot be explained just as a result of precipitation anomalies as significant changes in precipitation were not detected over that period. The decrease in runoff needs to be explained, instead, in terms of enhanced hydrological losses, basically due to increased evapotranspiration. These losses can be the result, in part, of temperature warming, assessed in the Alps to be occurred at a rate of about $0.11^{\circ}\text{C decade}^{-1}$ in the last century but also, on changes in land cover. In this case, new crops with more efficient uptake of soil moisture to feed transpiration, as woods,

* Department of Civil, Environmental, Architectural Engineering and Mathematics, University of Brescia, Italy. Corresponding author: Roberto Ranzi [roberto.ranzi@unibs.it]. Co-authors: [stefano.barontini@unibs.it], [marco.peli@unibs.it]

** Department of Engineering Enzo Ferrari, University of Modena and Reggio Emilia, Italy, [matteo.balistrocchi@unimore.it]

substitute less water-demanding crops, as pastures and meadows. Woodland expansion is a phenomenon that has been acknowledged to occur all over Europe and North America over the last decades (FAO, 2018), and is referred to as afforestation. It is mainly related to the temperature warming at high altitudes but also to socio-demographic and demographic aspects as mountain agriculture is becoming less economically attractive for young generations. If this process is well documented in the last century, the switch from deforestation to stable or increasing forest cover (Munteanu et al., 2014) is a process started in the 19th century and the extensive assessment of such land cover changes at European scale needs a homogeneous land cover mapping and cartographic support. The First, Second and Third Austro-Hungarian Mapping provides quite a homogeneous cartographic documentation of a wide part of Europe, including part of Italy and Greece (Livieratos, 2011; Koussoulakou, 2011), useful in the light of the land cover change assessment (Konkoly et al., 2017). Here, we show how maps from the 19th century produced from the Habsburg Second Military Survey (Timár, 2006; Vichrova, 2012) can be used for hydrological applications concerning the Adda river basin in the Central Italian Alps, to assess the role of land use changes on the expected enhancement of evapotranspiration losses due to afforestation.

Value of land use classification for assessing actual evapotranspiration

The estimate of the historical hydrologic balance is of great interest for a wide number of studies, ranging from climatological to land planning, social and economic history studies. In fact, the knowledge of the historical hydrologic balance is a structural guide that contributes to understand the choices made by populations and rulers to design the water networks, and that contributes to understand the different levels of coevolution and symbiosis inherent to the development of anthropogenic and multifunctional landscapes. In view of these applications, ancient maps will play a key role in the reconstruction of the historical hydrologic balance, because they provide important information on the land use, which is at the basis of the estimate of the important component of the hydrologic balance that is the basin evapotranspiration. Before detailing this concept, it is worth reminding the basic definitions.

The evapotranspiration is the rate of water that passes from the liquid state in the soil or at its surface to the vapour state, by direct evaporation or by plants transpiration. It might be assessed at different time scales (day, decade, month, year) and spatial scales (plot, field, slope, ecosystem, landscape), depending on the purpose of the calculations and on data availability. The evapotranspiration is conditioned by a great number of physical and biological constraints, which are grouped into (1) the evaporative capacity of the atmosphere, (2) the transpirative capacity of the plants and (3) the water availability in the soil or at its surface. In order to manage these issues, two concepts were introduced in the hydrologic practice. The first is the maximum evapotranspiration that can take place at the selected time and spatial scale, if no constraints are exerted by water availability, and the second is the actual evapotranspiration, that is the evapotranspiration which actually takes place, depending on the limitations imposed by water availability.

The maximum evapotranspiration is traditionally presented by means of two approaches. The first was the potential evapotranspiration (Thorntwaite, 1948) that is regarded as a climatic property, largely controlled by the weather and marginally controlled by the crop. This concept was later recalled and put into relationship with “a short crop” in the Conclusions of the discussion on evapotranspiration held in 1955 at Wageningen University during the Informal meeting on physics in agriculture. There, the potential evapotranspiration was defined as “the rate of evaporation from an extended surface of short green crop actively growing, completely shading the ground, of uniform

height and not short of water” (Anonymous, 1956). In this definition it was firstly introduced the reference to a short green crop, that is the core of the definition of the second concept, the reference crop evapotranspiration (later referenced as evapotranspiration). This is the “rate of evapotranspiration from an extended surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water” (Doorenbos and Pruitt, 1977). The reference surface was subsequently defined as “A hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23” (Allen et al., 1998). The reference evapotranspiration is then reduced to the maximum evapotranspiration rate of the investigated crop, by means of empirical cultural coefficients that account for the crop kind and are modulated on its phenological state. Finally, the maximum evapotranspiration is reduced to the actual evapotranspiration accounting for the amount of water which is stored within the hydrologic active soil. This is, as a rough first estimate, the rooted soil depth. In fact, at the end of a precipitation, the soil is wet down to the depth that has been interested by the infiltration front. After this instant the water content redistribution starts, that is a complex process during which gravitational, capillary and retentivity effects contemporarily act at partitioning the stored water into three main fluxes, i.e., percolation, lateral flow, evapotranspiration. The amount of water that can be (in some sense) retained by the soil in the hydrological active soil layer is usually referred to as field capacity and it is largely influenced both by the soil structure and, particularly, by the crop use and management conditions. Reference estimates of the field capacity for various cases of crop use and management are given in repertories and might be applied both at the contemporary land use, and at the ancient land use, provided that, by means of the legenda and of the cadastral notes, the ancient land use is recognized.

In this framework it emerges that the knowledge of the ancient land cover is a key passage for the definition of the historical water balance. In fact, the land cover gives information both on the crop, thus allowing to modulate the reference evapotranspiration accordingly to the crop coverage and to its phenological condition during the years, and on the soil field capacity, by means of the understanding of the root depth of the cultivations and therefore of the hydrologically active soil layer.

Land use changes over two centuries in the Adda river basin

River basins in the Central Italian Alps have undergone relevant land cover changes since the end of the Second World War, as documented by Balistrocchi et al. (2021) who analysed the trends in seven main land cover classes (woodland, bushland, grassland, fruit trees, croplands, urban and others, including water surfaces and uncultivated lands) in the Adda, Oglio and Chiese river basins between 1954 and 2018. The earliest land cover classification is based on the so-called GAI flight. This survey was carried out in 1954 and produced high resolution B/W aerial orthophotos, which were recently scanned, orthorectified and georeferenced. Then, they were visually interpreted by ERSAF of Lombardy Region, obtaining a vectorial polygon layer, where land cover classes were set according to the legend currently adopted in Lombardy Region (www.geoportale.regione.lombardia.it).

Such land cover classes can be reclassified through a conversion table in the key-classes from the CORINE land project (<https://land.copernicus.eu/pan-european/corine-land-cover>), making it possible to easily compare such a past land cover with the more recent surveys carried out by Lombardy Region (DUSAF). The only exception in the above-mentioned class list is the land cover that has been classified as ‘pasture’ in CORINE classes: this aspect could not be detected in the photos and

was consequently classified as ‘grassland’. The most recent review of the land cover in the Lombardy Region (DUSAF 6.0) dates back to 2018 and was reclassified in order to make it homogeneous to the GAI flight legend. These spatial data were cross-referenced in a sample check with current satellite imagery, thus revealing a satisfactory level of reliability (see the Figure 1b and 1d below).

The land cover layers were then clipped to the watersheds of interest, obtaining the results shown in Table 1. The Adda, the Oglio and the Chiese river basins were delimited with regard to outlets located immediately downstream of their major lakes: Lecco, Sarnico and Gavardo, respectively. Since not all the river basin area lies in Lombardy, some portions were not available for the analysis. Thus, the total analysed area is compared to the river basin area in Table 1. This analysis appears to be particularly significant for the Adda and the Oglio river basins, for which a large portion of their area is considered.

Land cover class	Adda river basin			Oglio river basin			Chiese river basin		
	Area (km ²)		Change (%)	Area (km ²)		Change (%)	Area (km ²)		Change (%)
	1954	2018		1954	2018		1954	2018	
Woodland	1546.2	1730.0	+11.9	643.8	852.0	+32.4	273.1	342.4	+25.4
Bushland	289.4	261.0	-9.8	210.2	131.8	-37.3	53.6	32.6	-39.1
Cropland	106.0	18.2	-82.8	63.3	13.7	-78.4	13.2	5.3	-60.3
Fruit trees	28.6	29.1	+1.7	7.0	11.4	+62.2	0.3	0.7	-185.9
Grassland	734.1	568.0	-22.6	441.4	321.7	-27.1	146.4	102.4	-30.1
Urban	54.0	174.7	+223.7	17.9	83.2	+365.6	3.7	21.3	+475.3
Other	1274.5	1252.1	-1.8	417.0	386.4	-7.3	45.9	31.4	-31.6
Total analysed	4032.7	4033.0	-	1800.6	1800.2	-	536.1	536.1	-
River basin area	4508		-	1840		-	934		-

Table 1: Comparison of area classification for the Adda, Oglio and Chiese river basins.

As can be seen, similar land cover dynamics are outlined. In terms of percentage increase, the urban land cover demonstrates to be associated with the largest increases, featuring values of the order of 300%. Urban growth mainly occurred at the expense of croplands, which experienced a dramatic decrease averagely of the order of 70%. Regarding the natural land covers, woodland is characterized by a significant increase, compensated by the corresponding decrease in bushland and in grassland. Woodland increase is of the order of 20%, that is far smaller than that of the urban land cover in terms of percentage change.

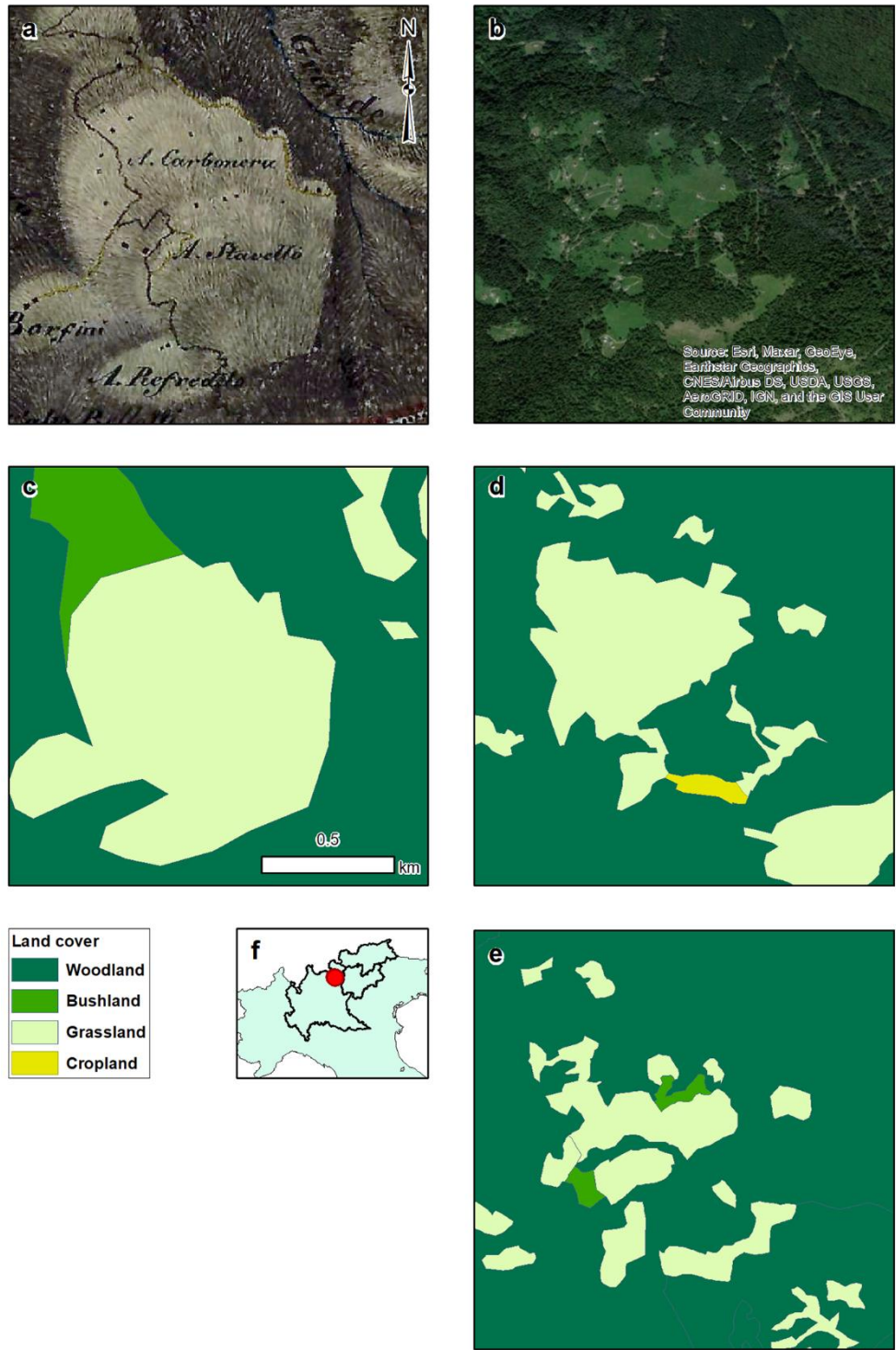


Figure 1: Land cover depicted by (a) the Second Military Survey map compared with (b) the current land cover as shown by a satellite image (accessed on 15 April 2020), and land cover classifications carried out with reference to (c) the Second Military Survey (first half of 19th century), (d) the GAI flight (1954), (e) the Lombardy Region survey DUSAF 6.0 (2018) in (f) an area of about 2.25 km² located near the divide between Adda and Oglio river basins (area centred around 595600E 5118320N, coordinate system UTM 32N, datum WGS 1984).

Nevertheless, in terms of absolute values, it appears to be the most impacting one, yielding a total areal expansion of 461 km² over the total analysed area of 7282 km². In contrast, the urban land cover absolute increase is limited to about 200 km². With respect to these outcomes, a further significant advance can be obtained by means of the spatial information provided by the georeferenced maps of the Second Military Survey, where these land cover classes can be identified and delimited.

In order to better investigate the magnitude and the significance of land cover trends, the landscape condition depicted in the first half of the 19th century would be a valuable asset. An excerpt of the first results is reported in Figure 1, where a square area with a side length of about 1.5 km located near the divide separating the Adda and the Oglio river basins (Figure 1f) is investigated (Aprica Pass).

In Figure 1a and 1b the map excerpt provided by the Second Military Survey is compared to the current satellite image, evidencing a satisfactory agreement. In addition, the land cover classification carried out according to the legend of the Second Military Survey and the land cover classifications depicted by the GAI flight and by the Lombardy Region DUSAF 6.0 are reported in Figure 1c, 1d and 1e, respectively. The comparison clearly shows the continuous expansion of woodland and the corresponding retreat of grassland and bushland occurred in this area since the middle 19th century. This land cover trend must be addressed with respect to a larger portion of the investigated river basins, to obtain a reliable quantitative assessment of afforestation. However, this result suggests that afforestation is a phenomenon that has already begun in the second part of the 19th century in the Central Italian Alps. Moreover, the satisfactory agreement between the Lombardy Region DUSAF 6.0 and satellite images is demonstrated by comparing Figure 1b and 1d.

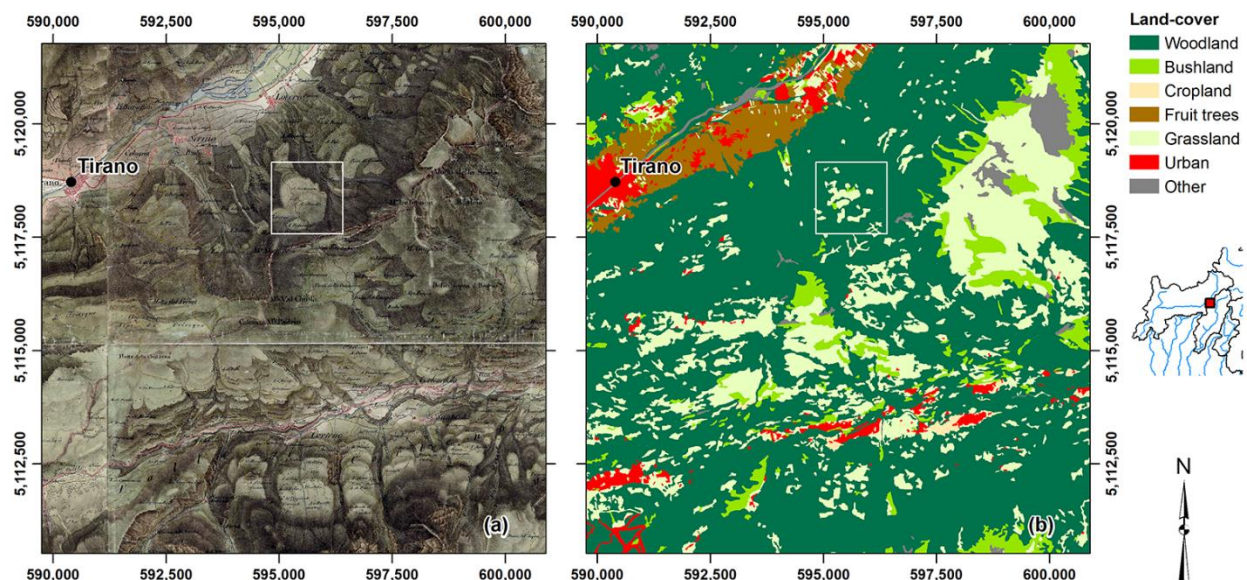



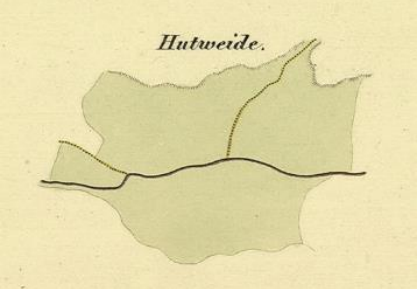



Figure 2: The Adda and the Oglio valleys near Tirano and the Aprica Pass around the area illustrated in Figure 1 (white square) as shown by (a) the Second Military Survey (first half of the 19th century) and by (b) the land cover classification of DUSAF 6.0 (2018) shown in the coordinate system UTM 32N, datum WGS 1984 (courtesy of Gábor Timár, from mapire.eu).

A further visual example of the land cover changes occurred in the Adda and Oglio river basin between the first half of the 19th century and 2018 is illustrated in Figure 2, where the comparison between the Second Military Survey map (Figure 2a) and the land cover classification depicted in 2018 by DUSAF 6.0 survey (Figure 2b, already shown by Balistrocchi et al., 2021) is illustrated at a wider scale. This area includes that analysed in Figure 1 (white square in Figure 2) and covers the Adda valley around Tirano and the Aprica Pass. At this scale, the urban land cover expansion affecting the Central Italian Alps since the second half of the 20th century is clearly evidenced.

Toward a “CORINE 1800” project

This sample test shows how land use mapping from 19th century cartography can be applied for hydrological purposes. Land use classes used in Habsburg military surveys were not as detailed as those used in modern GIS but are sufficient, for instance, to assess the effect of different crop coefficients on evapotranspiration. It is not difficult to imagine applications at European scale in the field of agriculture and forestry (Munteanu et al., 2014), hydrogeological risk assessment, river morphology (Scorpio et al., 2018; Ranzi et al., 2019), and not only. Thus, it is worth to design a potential project with the objective of generating a land cover map of Europe in the 19th Century, a sort of “CORINE 1800” land use and land cover map. In such a multidisciplinary project, experts in cartography, land use/cover, hydrology, geosciences, environmental sciences, biology, agriculture and forestry are needed in order to explore how the land cover and land use changes modified some aspects of the European environment. The first issue to be addressed is the scale of such mapping, which, considering the available cartography available at that time for the whole Europe will be between 1:50,000 and 1:100,000 scale. The second issue will be the legend detail, a question addressed quite in detail by Konkoly et al. (2017) who identified, for instance, four forest and wooded vegetation categories in the Habsburg Second Military Surveys, but only two in the first and third, as appears also in our analysis of the sample map of the Adda River in Lombardy (see Table 2). For agricultural areas three land cover categories were identified in the three surveys. It is likely that the homogeneous land cover types must be limited according to the number of recognizable types in most of the historical maps based on their legends. A third main issue is the georeferencing error, expected to be of the order of ten to some tens of metres, thus suggesting some caution in the assessment of land cover changes to avoid misclassification errors due to referencing errors.

Table 2. Sample land cover classes in the Second Military Survey and Corine Land Cover

2nd Military Survey	Corine Land Cover 2018*	Corine 1800
	<p>211 Non-irrigated arable land</p> <p>242 Complex cultivation patterns</p> <p>243 Land principally occupied by agriculture with significant areas of natural vegetation</p>	<p>Cropland</p>
	<p>231 Pastures</p>	<p>Pastures (Grassland)</p>
	<p>311 Broad-leaved forests</p> <p>312 Coniferous forests</p> <p>313 Mixed forests</p>	<p>Woodland</p>
	<p>321 Natural grasslands</p>	<p>Grassland</p>
	<p>324 Transitional woodland-scrub</p>	<p>Bushland</p>

*<https://land.copernicus.eu/pan-european/corine-land-cover/clc2018>

Conclusions

An example was shown about a potential application of digital cartography to address a question of hydrological relevance: to which extent are land use changes responsible of the observed increase of hydrological losses and decrease of runoff since the mid-19th century in Alpine rivers? Afforestation changes were observed not only from 1954 to 2018 but also from the first half of the 19th century until 1954, owing to the analysis of maps of the Habsburg Second Military Survey in a test site in Lombardy where runoff decrease is observed to occur since 1845. Questions as the scale of representation, legend categories, georeferencing need to be addressed in view of a possible extension of land use and land cover mapping at European scale in a sort of “CORINE 1800” project that the availability of digital products of cartographic heritage makes today realistic.

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