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## Urban geomorphology of a historical city straddling the Tanaro River (Alessandria, NW Italy)

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### ABSTRACT

The integration of field surveys, bibliographic research and multitemporal analysis of historical maps, aerial photographs and satellite images in a GIS environment, allowed the current and past geomorphological features of the old city of Alessandria and its surrounding areas, NW Italy, to be identified and mapped. Their analysis provided an overview of the geomorphological evolution of the city that is strictly related to the historical vicissitudes occurred since the Middle Ages. Nowadays, the most representative landforms and deposits characterizing the urban landscape result from human interventions and are associated with ancient military facilities and infrastructures, a historical man-made channel network no longer recognizable, the Tanaro riverbed channelization, and the urban sprawl occurred from the second half of the nineteenth century onwards. This study represents a useful tool for urban planning and management and for raising the citizens' awareness of the urban-landscape geomorphological features and evolution, and therefore the geo-hydrological risk.

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Alessandria; Tanaro River

### 1. Introduction

The analysis of landforms and geomorphological processes is widely known to be an essential tool in land management, urban planning, and geo-hydrological risk mitigation (Alcántara-Ayala, 2002; Cooke, 1976).

More than half of the world's population are living in urban areas that generally developed transforming step by step the landscape and destroying the former landforms (Bathrellos, 2007; Cooper et al., 2018; Crutzen, 2002; Gregory, 2006; Ritchie & Roser, 2019; Tarolli & Sofia, 2016; Thornbush & Allen, 2018). As a result, the severe impact of the urban sprawl on the natural environment often triggered difficult relationships of coexistence between urban systems and ever-changing geomorphological processes (Goudie, 2018; Mandarino et al., 2019a), even due to the exacerbation of phenomena most probably associated with climate change (Acquaotta et al., 2018, 2019; Faccini et al., 2018; Witze, 2018).

On this light, the study of landforms and Earth surface evolution processes in urban areas has become an increasingly substantial need. The growing 'urban geomorphology' focuses just on the analysis of the anthropogenic intervention intended as an environment-changing process that results in modifying the pristine landforms, creating anthropogenic landforms and influencing the ever-changing geomorphological processes (Thornbush, 2015). Finally, these elements

brought to the transformation of the natural environment into an anthropogenic landscape (Cooke, 1976; Thornbush & Allen, 2018).

Thus, urban geomorphology investigates the human impact on landscape during the Anthropocene in many various geographical settings (Brandolini et al., 2019; Brown et al., 2017; Cooke et al., 1982; Douglas, 2005; Espinosa et al., 2018; Jeong et al., 2018; Knight, 2018; Martín-Díaz et al., 2015; Thornbush, 2015; Waters et al., 2016; Zwoliński et al., 2018).

This discipline does not represent a superimposition to other disciplines such as urban planning and urban geography, but it constitutes a further contribute to investigate urban systems as a whole. Furthermore, urban geomorphology allows researchers, technicians, and public authorities to face urban management issues with different approaches and solutions considering in detail the geomorphological features, aiming to mitigate human impacts and geomorphological hazards and risks within urban landscapes.

Some very recent researches concerning urban geomorphology were carried out in a number of Mediterranean cities, in terms of geomorphological mapping, geomorphological heritage and characterization of anthropogenic landforms (Brandolini et al., 2018, 2019; Del Monte et al., 2016; Luberti et al., 2018, 2019; Mozzi et al., 2018). Most of these case studies are located in alluvial-coastal areas with more or less

pronounced hills behind them (Brandolini et al., 2017, 2018; Luino et al., 2019; Roccati et al., 2019).

This paper aims to describe the geomorphological features of the city of Alessandria, NW Italy, and present the related geomorphological map. This city arose during the Middle Ages in a strategic location straddling the Tanaro River, a main right-bank tributary of the upper stretch of the Po River, and near the confluence of the Bormida River with the Tanaro. The city has been characterized by a large and majestic fortification system for long, of which at the present day only the military fortress called ‘Cittadella’ remains. Rivers and channels have always played a fundamental role in both commercial and military terms in the Alessandria development (Benzi et al., 1998; Boido, 2013; Castronovo & Lusso, 2011). Nowadays, the former appears severely modified by human interventions, in particular in the urban reach, and basically no noticeable traces of the latter remain in the urban area.

The historical vicissitudes that characterized this city, together with the intense urban development occurred in the twentieth century obliterated the pristine landforms that were most probably entirely associated with fluvial dynamics. This evolution resulted in a man-made landscape in which human activity assumed a dominant role in modeling landforms.

These elements make Alessandria a representative case study in both physical-geographic and historical-economic terms. Furthermore, this lowland city allows for the test of urban geomorphological mapping in an urbanized floodplain environment, where the identification of landforms that characterized the landscape before man-made modifications results rather difficult because of the physiographic setting itself.

The research focused on the old town of Alessandria, including the urban stretch of the Tanaro River and the Cittadella, with the aim of investigating in detail the geomorphological evolution of the city’s historical core.

### 1.1. Study area

The city of Alessandria, NW Italy, is located in the central-eastern part of the Piemonte Region, in an alluvial floodplain area and close to the confluence of the Tanaro and Bormida Rivers, at about 95 m a.s.l. (Figure 1). Its municipal district spreads over 203.57 km<sup>2</sup> and has 93,980 inhabitants (Istat, 2018).

The city was officially founded in 1168 CE, during the Middle Ages, but a former urban settlement had already existed for a long time (Benzi et al., 1998; Boido, 2013; Castronovo & Lusso, 2011; Lusso, 2013). It originally developed straddling the Tanaro River (Figure 2(a)). Later, in the eighteenth century, a large military fortress called ‘Cittadella’ was built in the place of the Borgoglio village along the left bank and

the city grew along the right bank towards the Bormida River, becoming the so-called ‘city between the two rivers’ during the last centuries (Figure 2(b)).

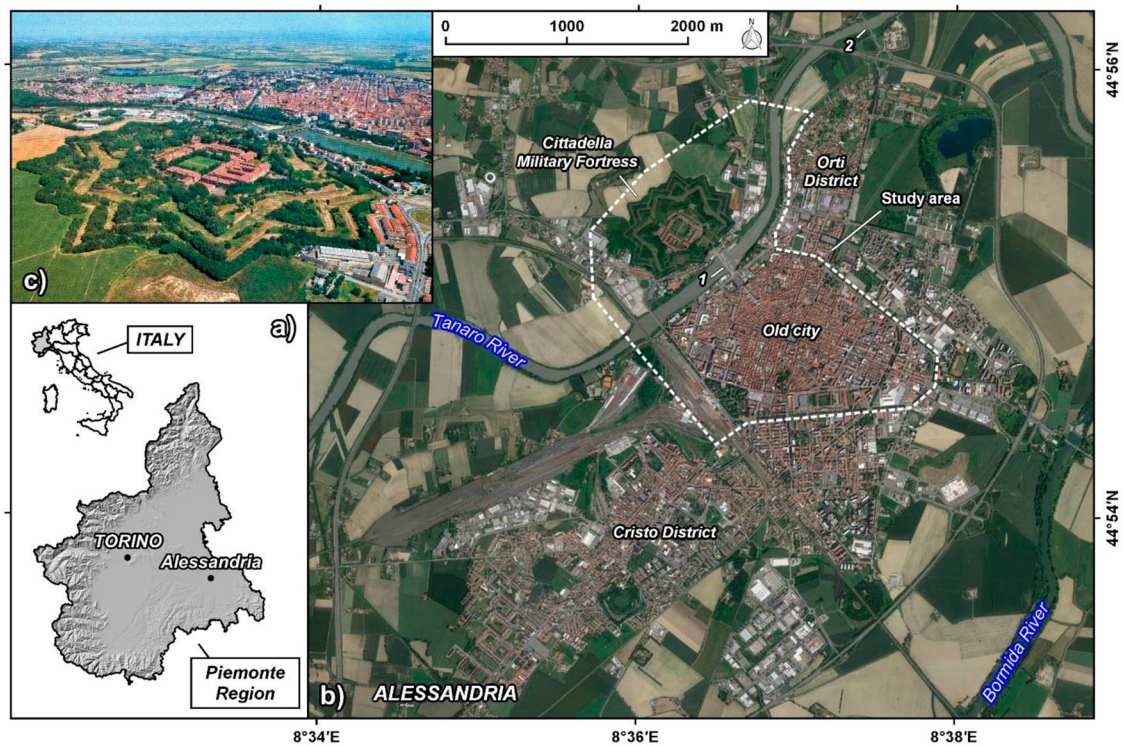
Alessandria experienced a rapid and massive urban sprawl due to the socio-economic growths after the industrial revolution, in the nineteenth century, after the World Wars, and even over the last decades. Numerous industrial areas developed in the second half of the twentieth century and are still expanding around the city that anyway is on the whole located in an intensive agricultural landscape. Thanks to its location in the center of the Turin-Genoa-Milan industrial triangle, the city constitutes an important motorway and railway intersection.

A typical Po Valley climate with cold, wet and foggy winters and hot and sultry summers characterizes Alessandria (Cortemiglia, 2012; Lusso, 2013). The mean cumulative annual rainfall is approximately 600 mm, mostly concentrated in autumn and spring. Considering the period 1991–2010, the mean annual temperature is 12.2°C, with the lowest monthly average temperature of 1.1°C and the highest of 23.2°C recorded in January and July, respectively (Piemonte, 2019a).

From the geological point of view (Figure 3), the Alessandria floodplain is a structural depression that was filled with lacustrine and mainly fluvial deposits by the Tanaro, Bormida, Orba, and Scrivia Rivers since the beginning of the Quaternary, in a generalized subsidence regime and after the last marine regression (Cortemiglia, 1998; Piana et al., 2017). These deposits, of the order of some tens of meters at Alessandria, reach their maximum thicknesses of approximately 100–150 m in the southern part of the floodplain (Piemonte, 2019b; Braga & Casnedi, 1976; Cortemiglia, 1998 and references therein), and consist of alternated layers of gravelly, sandy, silty and clayey sediments (Boni & Casnedi, 1970). This area represents one of the four largest deep aquifers of the Piemonte Region (Piemonte, 2019b).

The main features of the Alessandria floodplain are assumed to be already formed at the beginning of the Middle Pleistocene (Cortemiglia, 1998). The hills bordering the flat area of Alessandria are substantially constituted of sedimentary rocks dated back to the Pliocene or belonging to the Tertiary Piedmont Basin (Festa & Codegone, 2013).

During the Quaternary, tectonic and climatic events drastically changed the physiography of the region (Biancotti & Cortemiglia, 1982; Carraro et al., 1994; Ferraris et al., 2012) and resulted in the formation of a series of wide fluvial terraces currently characterizing the Alessandria floodplain. Furthermore, the alluvial floodplain surface is notably marked by traces of ancient meanders and fluvial scarps testifying the recent evolution of rivers. Running waters and humans currently represent the main dominant morphogenetic



**Figure 1.** (a) Location of the study area. (b) Urban settlement of Alessandria; 1: Meyer Bridge, former Cittadella Bridge; 2: Orti Bridge, former Forlanini Bridge (aerial view from Google Earth). (c) Aerial oblique photograph of Alessandria before the Cittadella Bridge demolition, in the foreground the Cittadella military fortress (from Lusso, 2013).

agents in the floodplain environment. The main geomorphological issues affecting the city are those related to fluvial dynamics. Several floods of the Tanaro and Bormida were documented over the last centuries (Table 1) and probably the most intense occurred on November 6, 1994, causing damage to facilities and infrastructures and 44 casualties in total in the Tanaro Valley, 14 of them in Alessandria (Luino & Susella, 2014).

As already reported by previous researches (Arattano et al., 1995; Bellardone et al., 1998; Luino & Susella, 2014), the urban reach of the Tanaro riverbed experienced a progressive narrowing over the last two centuries that resulted in a more and more notable bottle-neck effect during floods for flowing-waters coming from upstream. The present-day flood defense system in the Tanaro River urban reach was created after 1994 flood to contain a maximum discharge of  $3,800 \text{ m}^3/\text{s}$ . Moreover, both the historical Cittadella Bridge and the downstream Forlanini Bridge were replaced by a single-span bridge in order to avoid the formation of in-channel obstacles to the flow, after years of intense debate about the demolition of the former.

## 2. Methods

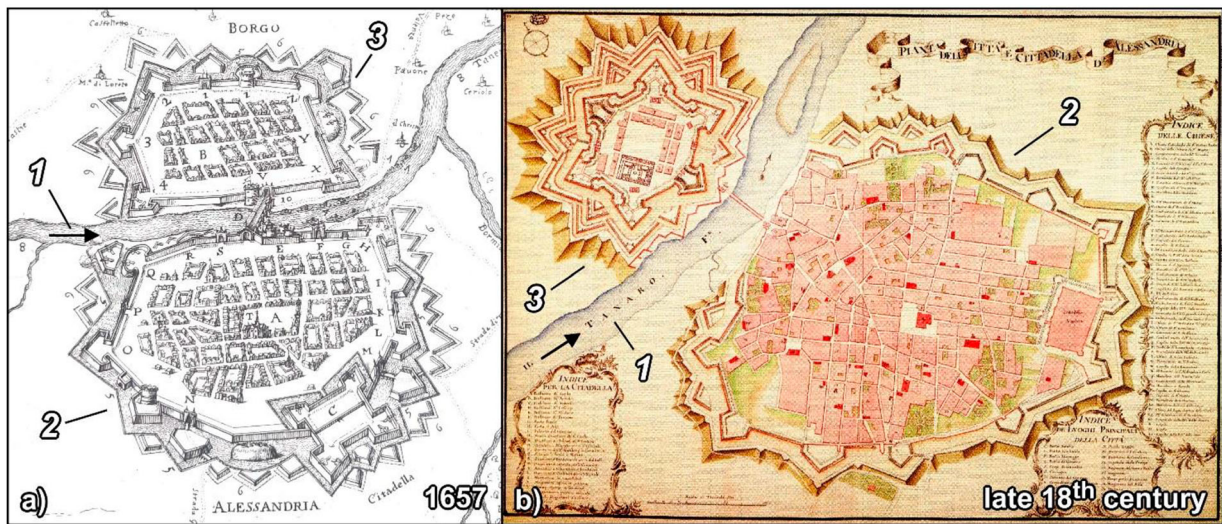
The geomorphological map of the Alessandria old town, represented at 1:10,000 scale, was realized by means of bibliographic research, field surveys and

multitemporal analysis of historical maps and aerial photographs and satellite images.

A relevant activity of bibliographic research and historical archives consultation was carried out in order to find the oldest possible information concerning the landscape geomorphological features, particularly before the most significant man-made modifications. This was a crucial and very difficult task due to the data shortage and dispersion, both in terms of the type and location. A large number of papers and historical books were consulted (e.g. Arattano et al., 1995; Benzi et al., 1998; Boido, 2018, 2013; Castronovo & Lusso, 2011; Motta, 1995; Rapetti & Arditi, 2012; Vassallo, 1997) and relevant information was also obtained from paintings, pictures, and interviews with elderly people. Moreover, further information was collected from technical reports, documents of the River Management Authority, official databases concerning geo-environmental data (Aipo, 2019; Piemonte, 2019c) and the Alessandria Municipality Master Plan.

Numerous historical and recent topographic maps were considered and analysed (Table 2). Some of them, a number of multitemporal aerial photographs series, and the Google Earth images (Table 2) were imported in a GIS environment to perform a detailed analysis of the landscape changes over time and to identify and accurately pinpoint both the obliterated and currently-recognizable forms through a photointerpretation activity. The information concerning the





**Figure 2.** (a) Historical map dated back to 1657, showing the former urban settlement straddling the Tanaro River (1); the Alessandria historical core (2) is along the right bank and Borgoglio (3) along the left bank (from the Alessandria Municipality archive). (b) Historical map dated back to the late eighteenth century, showing the Tanaro River (1), the Alessandria historical core (2) and the Cittadella military fortress (3) (from the National Archive of Torino). The arrow indicates the flow direction.

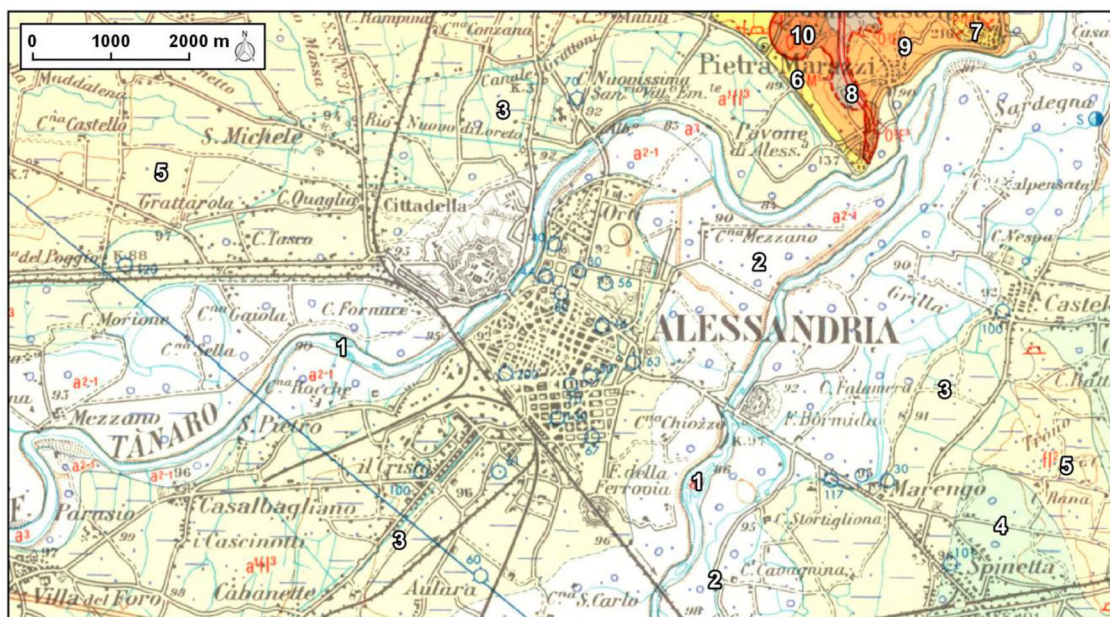
underground geological aspects was collected from scientific literature (Braga & Casnedi, 1976; Cortemiglia, 1998; Festa & Codegone, 2013; Piana et al., 2017; Tropeano, 1989), the Geological Map of Italy at 1:100,000 scale (Boni & Casnedi, 1970), local technical reports, and drilling data (Piemonte, 2019c). These last, in particular, were very useful to attest the presence and thickness of fill deposits.

Finally, a geomorphological field survey campaign supported the remotely-sensed data analysis and allowed us to map new elements, in particular

along the main fluvial stem observable in the main map.

The geomorphological evidences were organized into a series of manually-digitized layers, each containing a different landform type, grouped into two classes according to genetic criteria: anthropogenic landforms and fluvial landforms. The latter were distinguished between ‘active’ and ‘inactive’ landforms.

In general, landforms and surfaces were mapped according to the new criteria proposed by the Italian Association of Physical Geography and



**Figure 3.** Geological map of the Alessandria floodplain (from the Geological Map of Italy at 1:100,000 scale, sheet n. 70, 1969). 1: Fluvial deposits (present-day), 2: Fluvial deposits (Holocene), 3: Silt-dominated fluvial deposits (Holocene-Pleistocene), 4: Fluvial deposits with low superficial alteration (Pleistocene), 5: Fluvial deposits with yellowish superficial alteration products (Pleistocene), 6: Sandstone (Pliocene), 7: Conglomerate (Pliocene), 8: Chaotic complex (Miocene), 9: Marl (Miocene), 10: Conglomerate, sandstone and marly mudstone (Oligocene).

**Table 1.** List of major floods of the Tanaro River in Alessandria since 1800; \*measured downstream of the Tanaro-Bormida confluence (Arattano et al., 1995 and references therein; Piemonte, 2018; Luino & Susella, 2014).

Date	Water level (m)
May 17, 1846	4.40
October 2, 1846	4.60
December 2, 1852	4.20
October 20, 1857	5.10
March 19, 1873	4.15
May 27, 1879	5.25
June 4, 1900	4.20
May 13, 1926	3.80
November 8, 1951	3.95
November 6, 1994	7.20
November 25–26, 2016	7.72*

Geomorphology, together with the Italian Institute for Environmental Protection and Research (Campobasso et al., 2018). However, the artificial ground and the fluvial landforms were identified according to the classification adopted by the British Geological Survey (Rosenbaum et al., 2003) and the classification developed in the frame of the Reform Project (Rinaldi et al., 2015), respectively. The legend was furtherly integrated in order to describe in detail the local setting. In particular, the large variety of the past and present anthropogenic channels was mapped through linear elements with customized styles, and a new symbol was developed to represent the bank protection with adjacent embankment.

### 3. Results

The implemented methods allowed us for the identification, classification, and mapping of numerous fluvial and anthropogenic landforms in the old city of Alessandria and its immediate surroundings. Moreover, it allowed us to pinpoint and map some elements whose traces are now completely unrecognizable.

The old town has been characterized for long by an artificial channel network developed over time along a number of main lines, and probably derived from the modification of old small natural ditches draining the floodplain.

According to Boido (2013), the first man-made channel, called ‘Betale’, was built in the late thirteenth and early fourteenth century. It derived water from the Bormida River to improve the urban hygienic conditions, provide driving force to watermills and factories, and irrigate cultivated fields. Moreover, at the end of the sixteenth century this channel became relevant also for defense purposes as it was used to flood the moat that surrounded the city in case of an enemy attack (Boido, 2013, 2018; Castronovo & Lusso, 2011). The lack of detailed geographical information does not allow us to map the urban hydrographical setting in the Middle Ages and in the Renaissance (Boido, 2013).

Previous researches outlined the most probable location of urban channels in the late sixteenth and

**Table 2.** Summary of the most representative historical and recent cartographic data used in this research; the term ‘observed’ stands for the traditional analogic analysis of the paper map, out of a GIS environment (WMS = Web Map Service).

Year	Datum	Scale	Kind of use
Late sixteenth and early seventeenth century	Urban map	–	Observed (from Boido, 2013, p. 43)
1657	Urban map	–	Observed (from the Municipal Archive of Alessandria)
Late eighteenth century	‘Pianta della Città e Cittadella di Alessandria’	–	Observed (from the National Archive of Torino)
Napoleonic Era	Urban underground drainages map	–	Observed (from the Municipal Archive of Alessandria)
1822	‘Plan de la ville et de la cittadelle d’Alexandrie’	–	Observed (from the Municipal Archive of Alessandria)
1832	Sewer system map and new drainages project by Leopoldo Valinzone	–	Observed (from Boido, 2013, p. 88)
1851	‘Gran Carta degli Stati Sardi in Terraferma’, sheet n. 55 Alessandria	1:50,000	Imported in GIS (after georeferencing procedure)
1878	‘Gran Carta d’Italia’ (Italian Institute for Military Geography), Sheet n. 70 - 4 South-Est ‘Alessandria’ and n. 70 - 4 North-Est ‘Pecetto di Valenza’	1:25,000	Imported in GIS (after georeferencing procedure)
1887	‘Pianta di Alessandria’	1:5,000	Observed (from the Municipal Archive of Alessandria)
1933	Updated version of the 1878 map	1:25,000	Imported in GIS (already georeferenced)
1954	Aerial photographs (GAI flight)	–	Observed (from the archive of the Research Institute for Geo-Hydrological Protection)
1988	Orthophoto	1:10,000	Imported in GIS (from the National Geoportale WMS)
1991	Regional Technical Map	1:10,000	Imported in GIS (already georeferenced)
1995–1998	Municipal Master Plan of Alessandria	–	Observed (from the Alessandria Municipal Offices)
2007	Orthophoto	1:10,000	Imported in GIS (from the National Geoportale WMS)
2012	Orthophoto	1:10,000	Imported in GIS (from the National Geoportale WMS)
2015	Orthophoto	–	Imported in GIS (from the Regional Geoportale WMS of Piemonte)
2019	Google Earth images	1:1,000-10,000	Imported in GIS (through the Quick Map Service QGIS plugin)



early seventeenth century, on the base of the oldest available cartographic representation of them (Boido, 2013).

The aforementioned channels were progressively and almost completely culverted, sometimes filled and decommissioned from the first half of the seventeenth to the end of the eighteenth century, in particular under the domination of the Savoy when the city experienced large urban changes. In this period, the village of Bergoglio, located on the left bank of the Tanaro River, was razed to the ground and replaced by the Cittadella military fortress, built between 1732 and 1745 (Marotta, 1991) (Figure 2).

During the Napoleonic Era, the city waters were drained to the Tanaro River by an underground drainage system deriving from the seventeenth-century channel system. Moreover, a new channel for moat flooding, called 'Pisone', was projected in the southern part of the city, aiming to improve the fortification system. However, only its urban stretch was definitely built due to the Napoleon's fall (Boido, 2013).

The most relevant hydrographic element of the old city in the nineteenth and the first half of the twentieth century is the Carlo Alberto channel (Boido, 2013; Rapetti & Arditi, 2012). It was built in the period 1834–1847 for agricultural, industrial, water supply and urban-hygiene purposes, and even today derives waters from the Bormida River approximately 26 km upstream of Alessandria.

It flowed within the walls in the southern and south-eastern part of the old city, partly following the preexisting moat-flooding Napoleonic channel (Figure 4). Moreover, it was connected to an underground channel network that somewhat followed the seventeenth-century channels. In the 1880s it was diverted in a new channel built approximately 150–200 m southward to allow for the expansion of factories and residential areas. Then, in the period 1931–1934 it was finally moved away from the city for urban-hygiene reasons and after having been decommissioned in response to changes in the social and economic fabric of the city.

At the present day, its traces are no longer recognizable in urban areas. It flows into the Tanaro River upstream of Alessandria and its ancient paths are now partly or completely filled and transformed into drains (Figure 4). These areas, together with the moat-flooding Napoleonic channel, constitute the infilled ground.

On the left bank of the Tanaro River, downstream the Cittadella, we mapped an ancient culverted channel, whose path is uncertain. Moreover, on the right bank downstream of the old city, there is the exit of a culverted channel representing an overflow of the sewage system of the city.

Most of the study area was classified as landscaped ground because it was extensively remodeled over

time (Rosenbaum et al., 2003) due almost completely to urban sprawl and, only in small areas close to the riverbed, to agriculture. As documented by stratigraphic data, the shallow underground of the Alessandria old city is constituted of a thin layer of anthropogenic deposits that result from the urban evolution itself, superimposed in general on silty and sandy fluvial sediments.

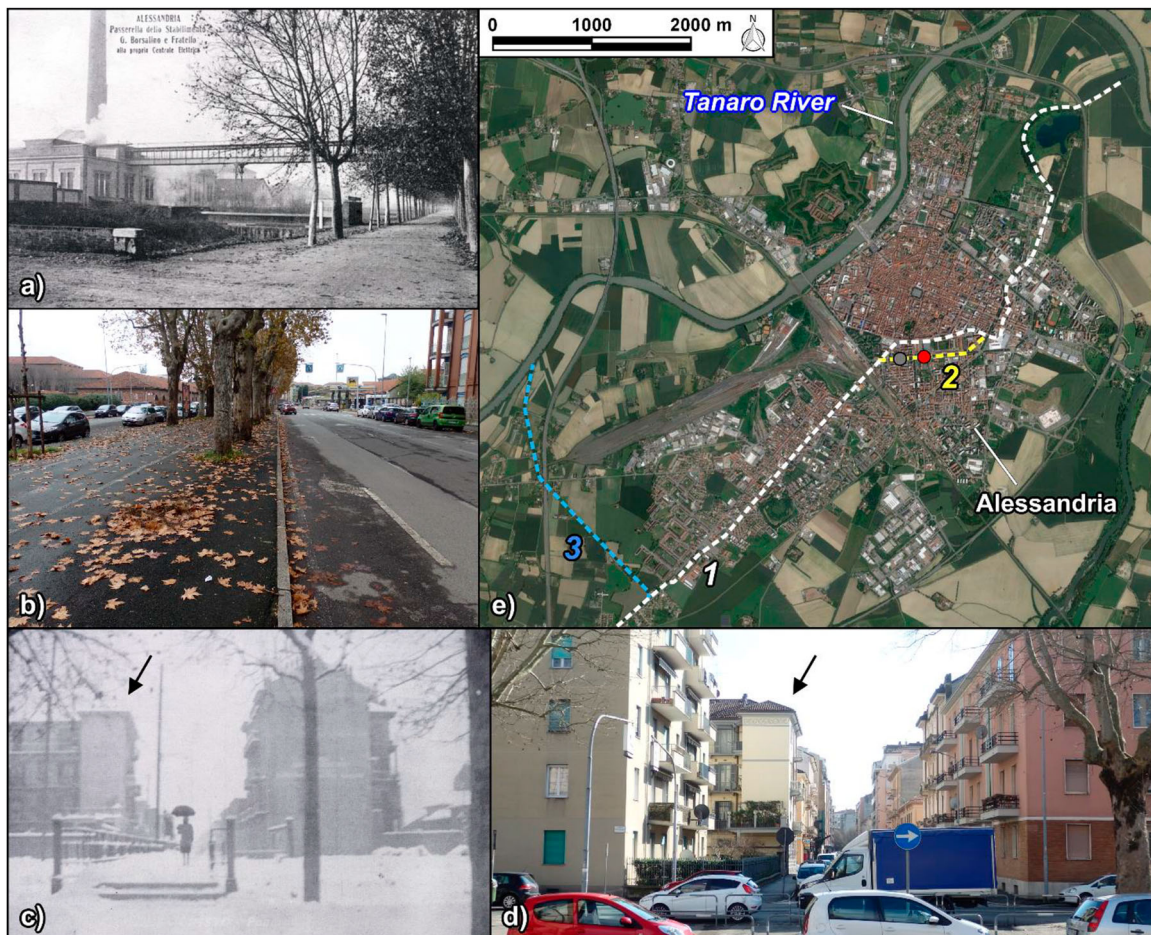
The railway infrastructure dated back to 1850s, the levees built around the 2000s, and some fillings represent the made grounds in the study area.

The Tanaro River urban reach shows bank protection structures with adjacent levees (Figure 5(a–c)). These anthropogenic elements were mapped through an original linear symbol resulting from the combination of the bank protection structure and the levee symbols (Campobasso et al., 2018). The use of these distinct symbols was not suitable due to scale-related readability reasons, and because it was necessary to underline the spatial continuity between erosion- and flood-protection structures.

The active channel is composed by gravelly and pebbly deposits; downstream of the Meyer Bridge, a progressive stabilization of lateral sedimentary bodies resulted in the formation of a narrow bench presenting finer sediments. Upstream and downstream of the urban reach, the area adjacent to the riverbank is a recent terrace (Rinaldi et al., 2015). At the Meyer Bridge there is a consolidation check dam that constituted the slab foundation of the historical Cittadella Bridge built in 1891 and torn down in 2009 (Figure 5(d)).

The Figure 6 shows an ideal geomorphological cross section summing up substantially all the main landforms and deposits of the Alessandria old city.

The comparison of historical maps, aerial photographs, and satellite images allowed us to outline in detail the urban sprawl occurred around the old city of Alessandria from the nineteenth century onwards. Before this period, no representative variations of the old-city continuous urban fabric are documented with respect to the bastions location. In 1851 the city spread over 1.2 km<sup>2</sup> and was completely included within the walls, except for the railway line that was just built (Figure 7(a)). In the 1870s Alessandria was still included within walls, covering an area of 1.52 km<sup>2</sup>, and the Cristo and Orti suburbs were just outlined upstream and downstream of the old city, respectively (Figure 7(b)). In general, both the variation of social and economic conditions and the relaxation of military restrictions on building close to the fortifications due to the loss of military strategic importance of the city, resulted over time in an occupation of large areas for industrial and residential development purposes. Thus, the 1933 map shows the town considerably spread outside the bastions and in place of them, for a total of 2.73 km<sup>2</sup>, and the suburbs quite



**Figure 4.** (a) The Borsalino Boardwalk across the Carlo Alberto Channel, 1915 (from Picchio, 2004). (b) The site (a) at the present day. (c) Boardwalk across the Carlo Alberto Channel connecting the city center and the outskirts, 1926 (from Picchio, 2004). (d) The site (c) at the present day; the arrow indicates the same building in (c). (e) The Carlo Alberto Channel paths over time, see the text for explanation. The dashed lines represent: (1) the channel path up to the 1880s; (2) the 1st channel diversion, used from the 1880s to 1934; (3) the 2nd channel diversion, used from 1934 onwards. The red and grey dots indicate the location of photographs (a), (b) and (c), (d), respectively. Photos (b) and (d) by A. Mandarinò.

widened (Figure 7(c)). Moreover, new constructions appear along both banks of the Tanaro River, in areas left uninhabited for long in order to have a free field of fire (Marotta, 1991).

In 1991, Alessandria covered about 10.1 km<sup>2</sup> and the map highlights in detail the urbanized area extension (Figure 7(d)). Through the comparison with previous maps, a relevant urban sprawl is noticeable in all directions that resulted in the creation of an only large urban area including the Orti and Cristo suburbs that in the meanwhile became districts. Moreover, an increase of urban area is documented also on the left bank of the Tanaro River, around the Cittadella.

From 1991 to the present day, Alessandria experienced a further urban area increase related mainly to the construction of shopping centers in areas close to the Tanaro and Bormida Rivers.

In the vicinity of Alessandria, these watercourses experienced large channel adjustments over the last centuries, partly due to human interventions. In the late sixteenth and early seventeenth century, the Tanaro riverbed was straightened just upstream of

Alessandria (Boido, 2013; Oberti et al., 2014). Moreover, the Bormida River abandoned two large meanders very close to the old city and to the Tanaro confluence in 1812 and 1814, respectively, moving southward, and was straightened south of Alessandria in 1817–1818 (Boido, 2013; Tropeano, 1989).

The most recent progressive occupation of riverine areas is documented also by the fillings that were mapped along the riverside in the study area. From the early nineteenth century to the 1870s, the Tanaro active channel presented a localized multi-thread channel and a fortified islet, called the ‘Galateri Islet’, downstream of the Cittadella Bridge. This was progressively annexed to the left bank and was urbanized in the second half of the twentieth century (Bellardone et al., 1998). This process resulted in the loss of about 13 ha of the riverbed area and in a riverbed narrowing from a maximum width of about 320–140 m, and a minimum from 140 to 110 m, measured in 1878 and 2019, respectively.

Something similar happened between the railway bridge and the Cittadella Bridge, where the area





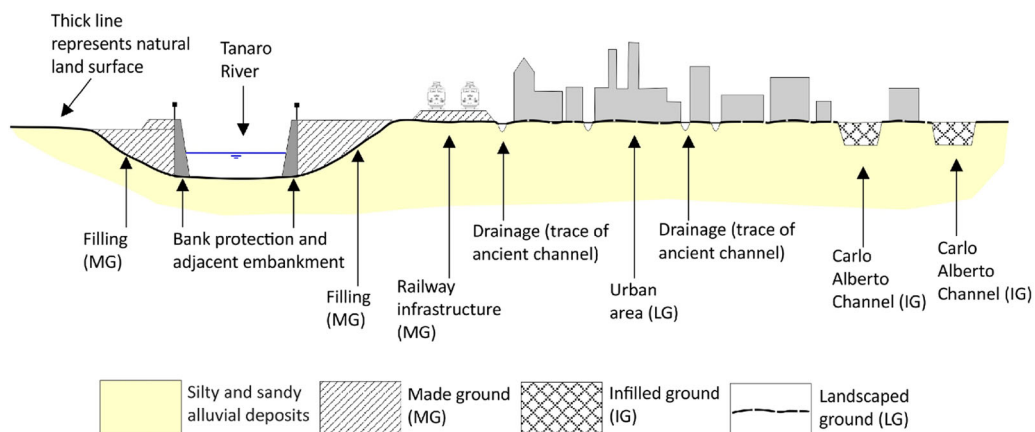
**Figure 5.** Different types of river-related anthropogenic structures along the Tanaro River urban stretch. (a) Trapezoidal cross-section levee with a concrete wall on top. (b) Concrete-wall levee. (c) Trapezoidal cross-section levee. (d) The Meyer Bridge and the consolidation check-dam representing the slab foundation of the demolished Cittadella Bridge. Photos by A. Mandarino.

previously belonging to the fortification system was progressively filled and urbanized in the same period. In this reach a reduction of 3 ha, from 14 to 11 ha, of the riverbed area was registered between 1933 and the present day. Therefore, the Tanaro urban reach experienced a generalized riverbed narrowing over the last few centuries (Arattano et al., 1995; Bellardone et al., 1998). This evolutionary trend generally follows the morphological evolution already documented by previous researches for other neighboring rivers

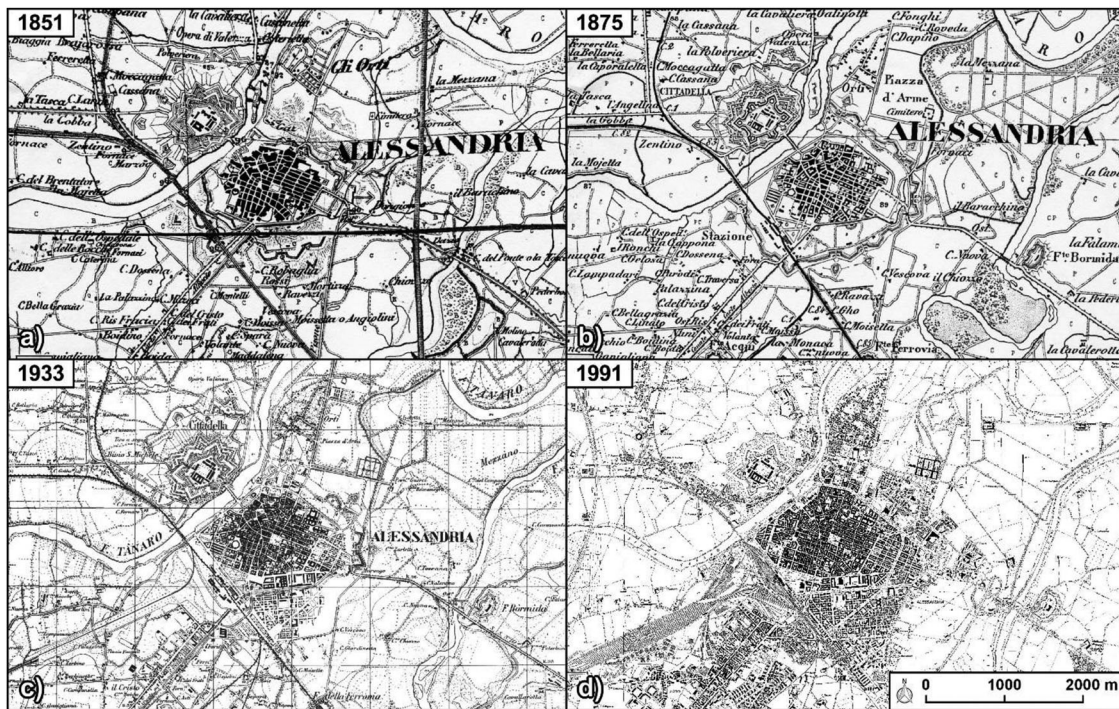
(Mandarino et al., 2019b; Mandarino et al., 2020; Pellegrini et al., 2008; Rinaldi et al., 2010; Tropeano, 1989).

Nowadays, the widespread presence of several facilities and infrastructures close to the riverbed represents a serious urban planning and management issue in terms of geo-hydrological risk mitigation (Cencetti et al., 2017; Gardiner, 1991; Luino & Susella, 2014; Mandarino et al., 2019a; Pepe et al., 2019).

After the late nineteenth and twentieth century urban sprawl, the most severe flood occurred on



**Figure 6.** Schematic, not to scale geomorphological cross section describing the main landforms and deposits of the Alessandria old town.



**Figure 7.** Comparison of historical maps dated back to 1851 (a), 1875 (b), 1933 (c) and 1991 (d), showing the urban settlement of Alessandria.

November 6, 1994 (Luino, 1999; Luino & Susella, 2014). It flooded a large portion of the Alessandria urban settlement, damaging, in particular, some suburbs and the Orti district (Figure 8). The flood water propagation was heavily influenced by man-made structures, in particular bridges and the railway embankment. This last one collapsed at some places West of the Cittadella, causing the fast flooding of suburbs located around the Cittadella. Then, the flood wave reached perpendicularly the Tanaro riverbed downstream of the Cittadella and ran over the levee located on the right bank that collapsed at several points (Bellardone et al., 1998). As a result, the Orti district was the most damaged zone of the city, where water levels higher than 3 m were registered (Arattano et al., 1995). At the Cittadella Bridge, submerged by some tens of centimeters, a water level of about 7.2 m was reached (Arattano et al., 1995); few km downstream of Alessandria the maximum discharge was estimated in about 4800 m<sup>3</sup>/s (Autorità di Bacino del Fiume Po, 1995), but certainly, it was underestimated (Luino & Susella, 2014).

The 1994 flood represented the starting point for the flood-defense system development for the whole southern part of Piemonte Region (Chicca, 2014). Considering, in particular, the Tanaro River urban reach, a large number of interventions were carried out over the last 25 years, aiming to reduce the flood hazard and stabilize the riverbed. These resulted in a new anthropogenic fluvial landscape. In contrast, the simultaneous progressive urbanization of the areas close to the riverbed involved an increase of the elements at risk.

From a social point of view, the river assumed, in general, a negative connotation over the last few decades and the riverbed seems to be now completely disconnected from the urban and social fabric of the city.

#### 4. Conclusion

This research allowed for the description of the geomorphological features and evolution of the old city of Alessandria and its surrounding areas.

This study was performed through the integration of field surveys, bibliographic research, and multitemporal analysis of historical maps, aerial photographs, and satellite images in a GIS environment. In addition to site-specific elements with related symbols, which could be useful for further geomorphological applications, the integrated use of a number of geomorphological legends developed for different purposes (Campobasso et al., 2018; Rinaldi et al., 2015; Rosenbaum et al., 2003) allowed us to classify and map in detail all the identified landforms and deposits in a complex, lowland, and urbanized geomorphological setting, as the Alessandria area is.

The study area experienced several and large topographic transformations over time that, on the one hand, progressively obliterated both the pristine natural landforms and the ancient anthropogenic landforms that followed one another over time and, on the other hand, resulted in the present-day anthropogenic landscape.

The Tanaro and Bormida Rivers, together with the man-made channel network developed over time





**Figure 8.** The Tanaro flood occurred on 6 November 1994: (a) Ponte della Cittadella during the flood; (b) Spalto Rovereto flooded, near the football stadium; (c) Spalto Rovereto, inhabitants rescued from a large caterpillar; (d) damage in a court of Via Cappelletta; (e) Orti district: marble plaque bearing witness to the height (3.20 m) reached by the waters during the flood.

within the walls and now substantially disappeared, have always played a crucial role in the history of ‘the city between the two rivers’.

Their current features and evolution over time substantially reflect the urban sprawl experienced by Alessandria in particular from the second half of the nineteenth century onwards. Moreover, this urban development is woefully testified by the complete demolition of the historical majestic walls surrounding the old city that certainly would have now represented an important urban element of historical and artistic value. The most recent morphological changes documented in the study area occurred along the Tanaro River and furtherly modified the urban riverine landscape in order to reduce the flood hazard and stabilize the riverbed after the 1994 flood. However, during the last few years further areas adjacent to the riverbed were occupied with facilities and infrastructures, resulting in an increase of the elements at risk. These anthropic interventions seem to be very much at odds with each other; certainly aiming to mitigate river-related risks, an inversion of tendency in urban-development policies is needed.

This research resulted in a geomorphological map of the old city of Alessandria and its surrounding areas. It potentially represents a useful tool for the city’s urban

planning and management and for the increase of the citizens’ awareness about the geomorphological features and evolution of the urban landscape, and therefore the geo-hydrological risk (Brandolini et al., 2008; Faccini et al., 2005, 2015).

### Software

The all data processing and the entire map sheet design was performed by using the free and open source software QGIS.

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No potential conflict of interest was reported by the author(s).



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