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Pierluigi BRANDOLINI [1*], Francesco FACCINI [1], Guido PALIAGA [2] & Pietro PIANA [3]

MAN-MADE LANDFORMS SURVEY AND MAPPING OF AN URBAN HISTORICAL CENTER IN A COASTAL MEDITERRANEAN ENVIRONMENT

Abstract: Brandolini P., Faccini F., Paliaga G. & Piana P., *Man-made landforms survey and mapping of an urban historical center in a coastal mediterranean environment*. (IT ISSN 0391-9838, 2018).

This paper documents the evolution of the urban geomorphological setting of the historical heart of the city of Genoa (Liguria, Italy). Since the Middle Ages, the city and its harbour have progressively grown, reaching their greatest extent in the 1950s. Today it has an area of 8.5 km^2 and it includes seven small catchments with surfaces ranging from 0.5 to 2.4 km^2. Their urbanized surface ranges from just less than 30% up to more than 80%. Human interventions have almost completely reshaped and modified the original morphology. The identification of artificial landforms built over the former natural landforms was carried out through multi-temporal cartographical and photographical comparison, and the analysis of geo-thematic cartography and documentation by the Basin Master Plan (Piano di Bacino) and Genoa City Hall Plan. In addition stratigraphy data from the regional database were analysed and several geomorphological surveys were carried out in the area. Artificial landforms were mapped by applying an experimental geomorphological classification currently being developed by the Working Groups of the Italian Association of Physical Geography and Geomorphology (AIGEO). The main geomorphic modifications are: slope fillings retained by walls (mainly due to roads and buildings); excavation areas (often connected to historical quarries); sea embankments (for harbour growth) and artificial modifications of the drainage network (culverts, stream diversions and canals). All of these reduced the flow sections. These morphological changes have significantly increased the geo-hydrological risk in Genoa, which is currently one of the most emblematic Italian case studies for recurrent flood events, especially in the light of the modified rainfall regime due to recent climate change.

Key words: Urban geomorphology, Drainage network modifications, Human impact, Geo-hydrological risk, Genoa.

Riassunto: Brandolini P., Faccini F., Paliaga G. & Piana P., *Rilevamento e cartografia delle forme antropiche di un centro storico urbano in ambiente mediterraneo costiero.* (IT ISSN 0391-9838, 2018).

La ricerca riguarda la ricostruzione dell'assetto geomorfologico dell'anfiteatro naturale costiero dove si è storicamente sviluppata la città di Genova (Liguria, Italia). Lo sviluppo urbano e portuale è iniziato nel Medioevo, mentre nel secondo ultimo dopoguerra si è osservata la massima espansione sia lungo la costa sia sui versanti. L'area, con uno sviluppo di circa 8.5 km^2, è caratterizzata da sette piccoli bacini idrografici, con superficie tra 0,5 km^2 e 2,4 km^2. La loro urbanizzazione, variabile tra poco meno il 30% e oltre l'80%, ha quasi completamente rimodellato e quindi modificato le condizioni morfologiche originarie. L'identificazione delle forme di origine antropica è stata condotta attraverso una comparazione cartografica e fotografica multitemporale, l'analisi della cartografia e documentazione geotematica tratta dal Piano di Bacino e dal Piano Urbanistico Comunale, l'interpretazione delle stratigrafie dei sondaggi del database regionale (Regione Liguria) e con l'ausilio di rilevamenti diretti. Le forme di origine antropica sono state cartografate seguendo i criteri della legenda geomorfologica in corso di sperimentazione nell'ambito dei gruppi di lavoro in seno all'Associazione Italiana di Geografia Fisica e Geomorfologia (AIGEO). Le principali modificazioni geomorfologiche sono riconducibili all'esecuzione di riempimenti e relativi muri di contenimento lungo i versanti (principalmente connessi alla realizzazione di strade ed edifici), ad aree di sbancamento (spesso legate a cave storiche di materiali lapidei per le costruzioni), a colmate a mare (per lo sviluppo portuale) e soprattutto alle modificazioni artificiali del reticolo idrografico (corsi d'acqua tombinati in sotterraneo, deviazioni e canalizzazioni degli alvei) che hanno drasticamente ridotto le sezioni di deflusso. Questi cambiamenti morfologici hanno incrementato il rischio geo-idrologico. La città di Genova rappresenta oggi uno dei casi italiani più emblematici in termini di ricorrenza di eventi alluvionali, anche alla luce dei cambiamenti climatici in atto che si manifestano con una variazione del regime delle piogge.

Termini chiave: Geomorfologia urbana, Modificazioni del reticolo idrografico, Impatto dell'uomo, Rischio geo-idrologico, Genova.

[1] *Dipartimento di Scienze della Terra, dell'Ambiente e della Vita (DISTAV), University of Genoa, Italy.*
[2] *CNR-IRPI, Turin, Italy.*
[3] *School of Geography, University of Nottingham, United Kingdom.*
* *Corresponding author: P. Brandolini, brando@unige.it*

INTRODUCTION

Research in urban geomorphology is relatively recent and its theory and practice require continuous updates, insights and assessments (Cooke, 1976; Cooke & *alii*, 1982). Methodological approaches to recognise and map landforms, processes and deposits in urban environments are very different to those used in natural environments (coasts, plains and mountains) where geomorphological landforms are usually easier to identify (Cendrero & *alii*, 1987; Ellison & *alii,* 1993; Eyles, 1997). Geomorphological surveys in urban environments entail careful observations of urban morphology, particularly at a medium-large scale (Coates, 1974; 1976). Insights from other sources, particularly historical and geographical documents and borehole data, are essential in order to identify, map and date landforms (Faccini & *alii*, 2008; Lucchetti & Giardino, 2015).

In Mediterranean environments this process is particularly difficult due to the stratification of urban expansion phases (Berti & *alii*, 2004; Bathrellos, 2007). These cities were often founded in ancient times, they expanded in the Middle Ages and they progressively grew in the centuries (Del Monte & *alii*, 2013; 2015; 2016; Brandolini & *alii*, 2017). In the 20th century and particularly after the Second World War they went through uncontrolled urban expansion which has been called an "urban revolution" (Chengtai, 1996).

This paper presents the mapping of man-made landforms in the historical centre of Genoa, within the seventeenth-century walls between the Lanterna (West), the Carignano hill (East) and M. Peralto (North). This is where the medieval centre of Genoa lies; the city was the capital of the Republic of Genoa, an independent state with naval power from 1099 to 1815. The area is only 8.5 km^2 wide; it is characterised by seven small catchments of a size between 0.5 and 2.4 km^2; their degree of urbanization ranges from less than 30% up to more than 80%.

Morphological changes of this territory due to human remodelling such as drainage network modification, excavations and fillings started in the Middle Ages and became particularly significant in the 1960s and 1970s during the city expansion (Brandolini & Sbardella, 2001; Bixio & *alii*, 2015; Bixio & *alii*, 2017). These artificial landforms, which over the centuries were superimposed along narrow alluvial-coastal plain and steep slopes, have almost totally obliterated the former geomorphological conditions.

The aim of this paper is the identification and mapping of artificial erosional and accumulation landforms that affected the historical centre of Genoa in the past. An experimental geomorphological classification currently being developed by Working Groups of the Italian Association of Physical Geography and Geomorphology (AIGEO) was applied and assessed.

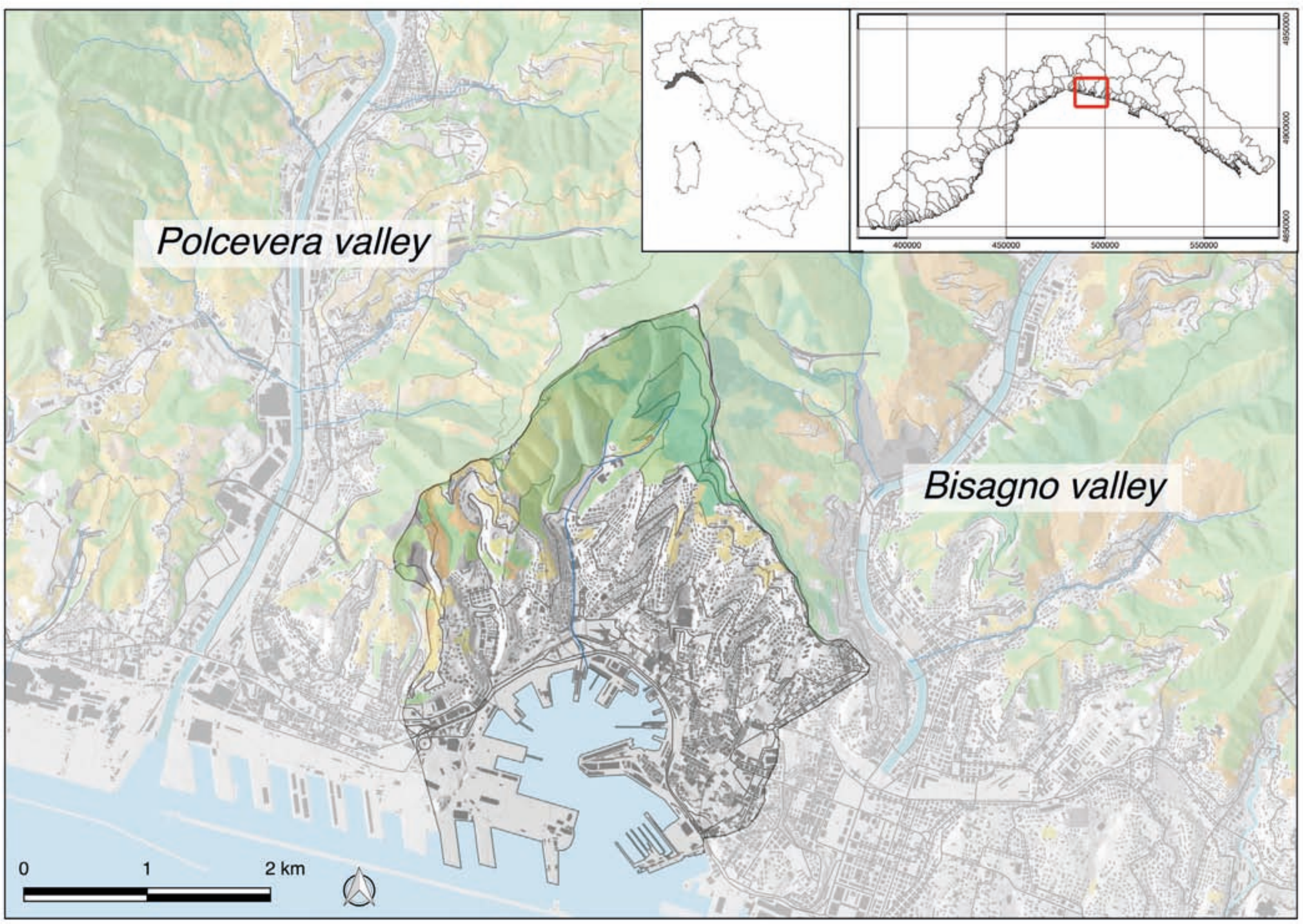

FIG. 1 - Geographical location of the study area.

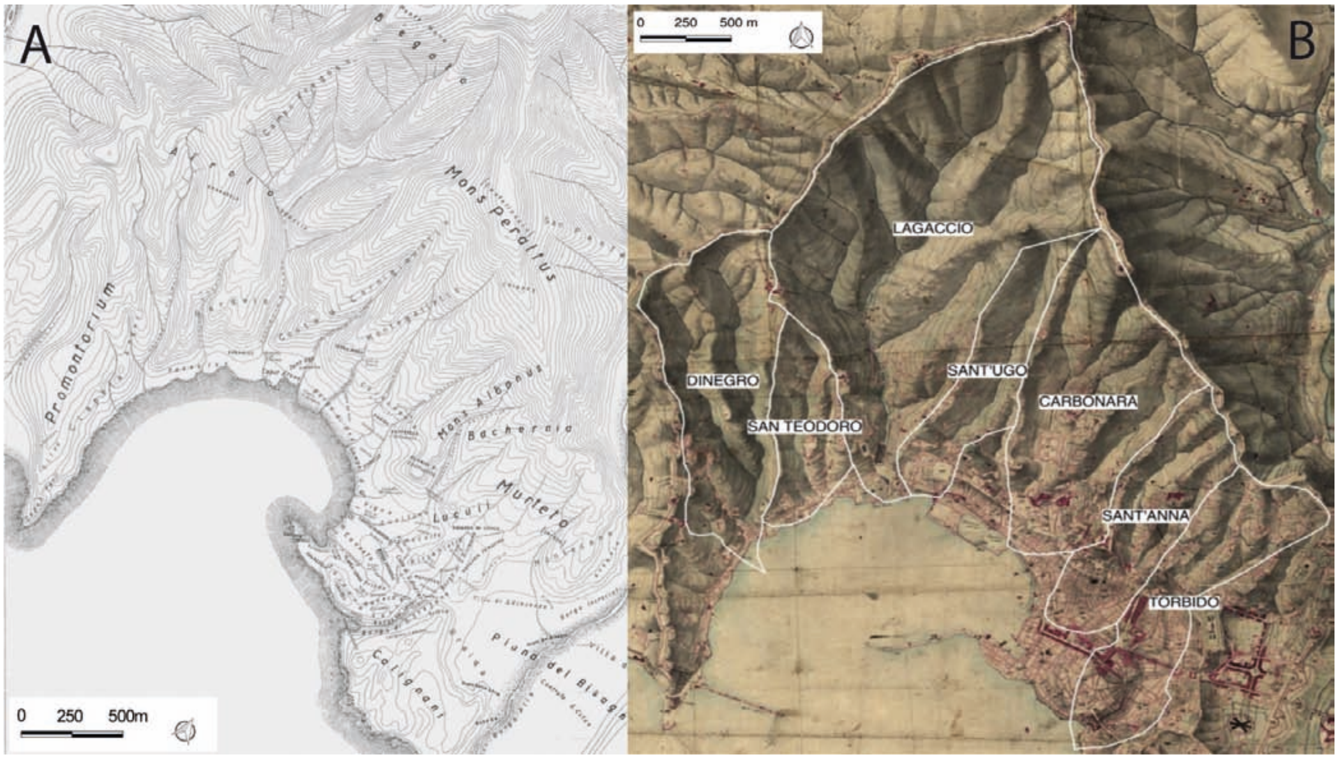

Fig. 2 - A. The morphology of the historic Genoese gulf (“amphitheater“) before urbanization outlined in the “Genova Zero” map (after Barbieri, 1938). B. “Stati Sardi di Terraferma” map of 1815/1823 (after Italian Geographical Military Institute archives) with the main divides of the catchments, included in the historical amphitheatre of Genoa (white line).

Morphological changes increased flood risk in the historical centre of the city. Genoa has been recurrently affected by flash floods also due to recent changes in the rainfall regime, which has made these events more frequent than in the past. This paper offers some practical insights into the field of urban planning and the reduction of the geo-hydrological risk in a historical centre which, since 2006, has been recognised by UNESCO as a “World Heritage Site” (Brandolini & *alii*, 2011; 2012a; 2012b; Faccini & *alii*, 2005; 2015b; 2015d).

STUDY AREA

The old town covers an area located between the catchments of the Polcevera (W) and the Bisagno Streams (E) (fig. 1). It is a roughly triangular-shaped area surrounded by the seventeenth-century walls: this system of fortifications starts from the Promontory of the Lighthouse up to M. Peralto (489 m asl), where Fort Sperone is located (Forti, 1971; Sacchini & *alii*, 2018); the eastern walls run along the eastern bank of the Bisagno Stream in order to protect the hill of Carignano, along the eastern ridge.

This sort of morphological ‘amphitheatre’, which is c. 8.5 km^2 wide, includes seven small and steep catchments, today barely identifiable due to high urbanisation (fig. 2); they are shown in the “Genova Zero” map made by Barbieri in 1938: from W to E it is possible to identify the catchments of Dinegro, or S. Lazzaro (1.33 km^2), San Teodoro (0.45 km^2), Lagaccio (2.36 km^2), Sant’Ugo (0.8 km^2), Carbonara (1.1 km^2), Sant’Anna (0.72 km^2) and Torbido (1.17 km^2).

From a geological point of view the area is characterised by flysch formations belonging to the tectonic units of Antola and Ronco (Upper Cretaceous) and by post-orogenic deposits (APAT, 2008; AA.VV., 2008). The Antola Unit is represented by the formation of Mt. Antola Flysch - mainly consisting of marly limestones, occasionally silty, with thin interlayers of shales - and by the formations of Montoggio shales, a basal complex represented by blackish or greenish shales, cropping out in some limited areas along the western ridge. Although the Antola Unit has been affected by several deformations, it shows a general asset of bedding with dip direction towards SE and dip angle ranging between 30° and 60° (Limoncelli & Marini, 1969; Marini, 1981). The Ronco Unit, represented by the homonymous formation and featured by siltstone, marly limestone and shales, crops out in the western sector along the watershed between the ‘amphitheatre’ and the Polcevera valley (Comune di Genova, 2014).

The post-orogenic deposits, represented by the formation of the Ortovero clays (Pliocene), are in the medieval historical centre and the old harbour area, with a graben structure with WNW – ESE direction (Marini, 1976; Fanucci & *alii*, 1982).

At approximately 45 m, 75-80 m and 90-100 m asl, along the slope and the ridge with the Polcevera and Bisagno valleys, the relict of some almost flat surfaces, that cut pliocenic deposits, identifiable as quaternary marine terraces, are observable (Limoncelli & Marini, 1969; Fanucci & Tedeschi, 1983; Fanucci & Nosengo, 1979; Brandolini & *alii*, 1996).

Genoa has a Mediterranean climate, with dry and hot summers, and relatively mild winters, while rainfall is mainly concentrated in spring and autumn (Acquacotta & *alii*, 2018a). The mean annual temperature is 15.8 °C, and the mean annual rainfall is 1268 mm with 101 rainy days (>1 mm) (Sacchini & *alii*, 2012). The historical weather station of Genoa University, established 1833 and located in the study area, provides evidence of statistically significant climate trends (Faccini & *alii*, 2015d). The mean annual temperature shows a positive trend, while the number of rainy days has a negative trend (Acquacotta & *alii*, 2018b). The amount of annual rainfall does not show any significant trend and therefore the rainfall rate has increased. This data show that the rainfall is concentrated in fewer days, particularly between the second decade of October and the first decade of November (Faccini & *alii*, 2015a). This is confirmed by the many flash flood events which affected Genoa in the last 50 years (Faccini & *alii*, 2016).

The history of Genoa probably dates back to the pre-Roman period and the first fortified settlement was founded on the hill of Castello along the Eastern edge of the natural 'amphitheatre' (Grossi Bianchi & Poleggi, 1980; Melli & *alii*, 2006). The *castrum* was located above the primitive harbour which was naturally protected by the peninsula of Il Mandraccio. In the Middle Ages the historical centre progressively expanded around the port and in the inland area where *Strada Nuova* (via Garibaldi), built in 1550, and the late *Via Nuovissima* (Via Balbi, built in 1606) constituted for centuries the northern limit of the city centre (Pesenti & *alii*, 1990; Bixio & *alii*, 2015).

MATERIALS AND METHODS

In order to identify and map (1:5000) morphological changes due to human intervention, the experimental geomorphological classification currently being developed by the Working Groups of the Italian Association of Physical Geography and Geomorphology (AIGEO) was adopted (Gruppo Nazionale Geografia Fisica e Geomorfologia, 1993; Servizio Geologico Nazionale, 1994; Baroni & *alii*, 2010; 2015; Mastronuzzi & *alii*, 2017). However, we have added a strong emphasis on artificial landform types (erosional and accumulation).

Detailed analysis of geo-thematic cartography was carried out (fig. 3), in particular the Basin Master Plan for Geo-hydrological reduction and the Genoa City Hall plan (Città Metropolitana di Genova, 2015; Comune di Genova, 2014).

A preliminary mapping of the fill areas was carried out by overlaying the 'landfills and damps' layer with boreholes data on the urban and port area of the Regional Database

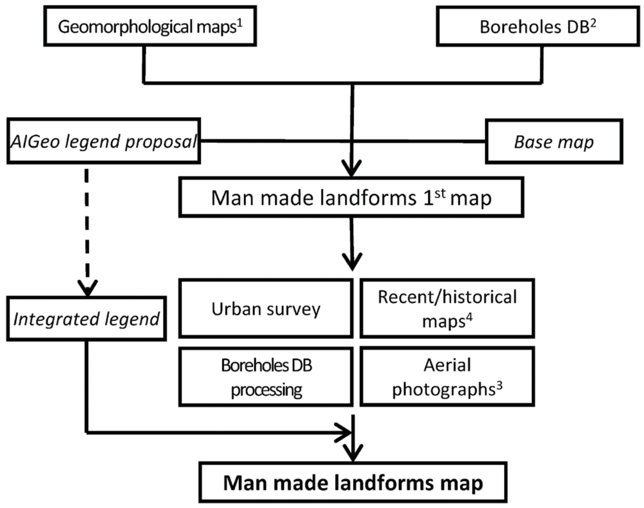

FIG. 3 - Flow chart summarizing the methodology used for the production of the man-made landform map: [1]from geological studies linked to Basin Master Plan for Geo-hydrological risk reduction and Genoa City Hall Plan; [2]from Liguria Region Boreholes Database, Genoa Municipality Geological Office, Consultant Geologists; [3]from Italian Military Geographical Institute and Liguria Region archives; [4]from Italian Military Geographical Institute, Genoa Municipality, Liguria Region and National Archive.

(available on line at: http://www.ambienteinliguria.it/). We selected the stratigraphy with at least 2.5 m of fills. This first analysis confirmed the already mapped landfill areas and the identification of new ones.

A second more complex phase involved the detailed analysis of the boreholes stratigraphy, the multi-temporal cartographical comparison, the analysis of aerial photographs and urban field surveys.

The stratigraphy was interpreted and elaborated by selecting different landfill thickness classes (2.5-5 m; 5-10 m; > 10 m) and by identifying gaps (underground voids), historical buried structures in the stratigraphy and, where available, the depth and type of bedrock.

The multi-temporal map comparison, aimed at the reconstruction of the original morphology, allowed us to identify and map excavations, historical quarries, modifications of the hydrographical network, sea embankments, traces of ancient aqueducts and walls.

The most significant maps for the purpose of this study were: the maps from Italian Military Geographical Institute (IGMI) archives (1:9.450 scale manuscript maps from 1815-1827, 1:25.000 scale topographical maps from 1878 – 1939); the Ignazio Porro 1:2.000 scale map (surveyed in 1836 and showing the contour lines); the map of the Napoleonic cadastre (1805/1814) and the map of the city by Michele Poggi (1898).

The "Forma Genuae" by Piero Barbieri gave an interesting contribution to this research: it consists of 24 sheets (scale 1:10.000) on the urban evolution from "Year Zero" to 1938.

The analysis of aerial photographs mainly focussed on documents produced between the 1930s and the 1980s, in particular data from the IGM historical flight (1936), the

RAF flight (1944), the historical regional cover of GAI, the historical flight of Genoa (1964), the regional cover dated 1973/74 and the historical centres flight dated 1979/80.

The geomorphological surveys in the urban environment involved: i) morphological observations to recognize and map the landfill areas indicated by the borehole database; ii) identification of walls, artificial scarp edges, historical springs, cisterns and tunnel entrances.

RESULTS

The multi-temporal map comparison showed that in the Middle Ages Genoa went through significant urban growth. The urban surface stretched over the eastern part of the gulf, in the lower part of the Torbido, Sant'Anna and Carbonara catchments. Between the end of the Middle Ages and the first half of the 19th century no major changes occurred in the urban plan of the city. The population doubled between 1861 and 1911; a significant phase of urban expansion towards the coast, the Bisagno (E) and Polcevera Valleys (W) began. Between the post-war period and the 1980s, and particularly in the 1960s and 1970s, the city expanded towards the hills. The seven catchments of Genoa historical centre were almost completely built up, with a degree of soil consumption ranging c. 40-90% (fig. 4 and tab. 1). In the last 20 years urbanisation has slowed down and some parts of the historical centre have been renovated.

The urban expansion has deeply modified the former geomorphological setting and, as mapped in fig. 5, man-made landforms are mainly due to culverting of streams (drainage network modification), excavations of slopes and valleys fillings (slope modification) and land reclamation from the sea with embankments for piers and breakwaters (coastline modification).

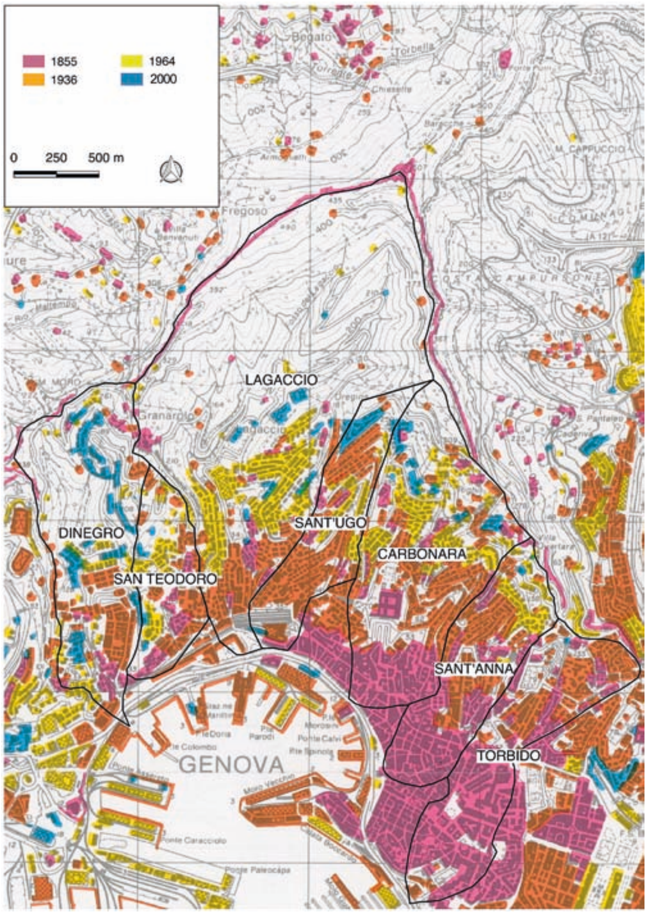

FIG. 4 - Urbanization of Genoa city from 1855 to 2000 (modified after Regione Liguria, 1986) within the seven catchments included in the historical amphitheatre (black line).

Drainage network modification

The former watersheds, the original drainage network and main morphometric characteristics of the seven catchments of the historical centre were reconstructed through a detailed analysis of the Stati Sardi di Terraferma maps (1815-1827) and the elaboration of a DTM obtained from current cartography (topographycal maps by Regione Liguria).

The slopes elevation ranges between the sea level and 500 m asl in a very short distance. The slopes show significant steepness, between 20% in the Rio Torbido and 50% in the Rio Lagaccio catchment. These are small catchments (San Teodoro is less than 0.5 km^2, while Lagaccio is c. 2.5 km^2) showing drainage networks with just 1st and 2nd order streams, except Rio Lagaccio which reaches the 4th order (fig. 6 and tab. 1).

TABLE. 1 - Main modification and morphometric features of catchments. Legend: a = Soil consumption (%); b = Artificial bed/main channel (%); c = Artificial bed/channel network (%), d = Area (km^2); e = Mean slope (%); f = Max altitude (m asl); g = main channel length (km); h = Strahler number order; i = channel network cumulative length (km); l = Drainage density (k/km^2)

catchment	a	b	c	d	e	f	g	h	i	l
Dinegro	42,1	69,0	83,0	0,97	37	296	2,0	2	3,8	4,0
San Teodoro	58,8	70,3	92,2	0,38	31	218	1,0	1	1,0	2,7
Lagaccio	27,8	76,9	36,7	2,61	49	503	2,9	4	10,0	3,8
Sant'Ugo	73,4	100	100	0,5	34	336	1,7	1	1,7	3,3
Carbonara	61,1	89,9	94,1	1,15	35	365	1,8	2	3,7	3,2
Sant'Anna	81,1	100	100	0,61	29	215	1,5	1	1,5	2,4
Torbido	84,5	100	100	0,76	22	132	2,2	1	2,2	2,9

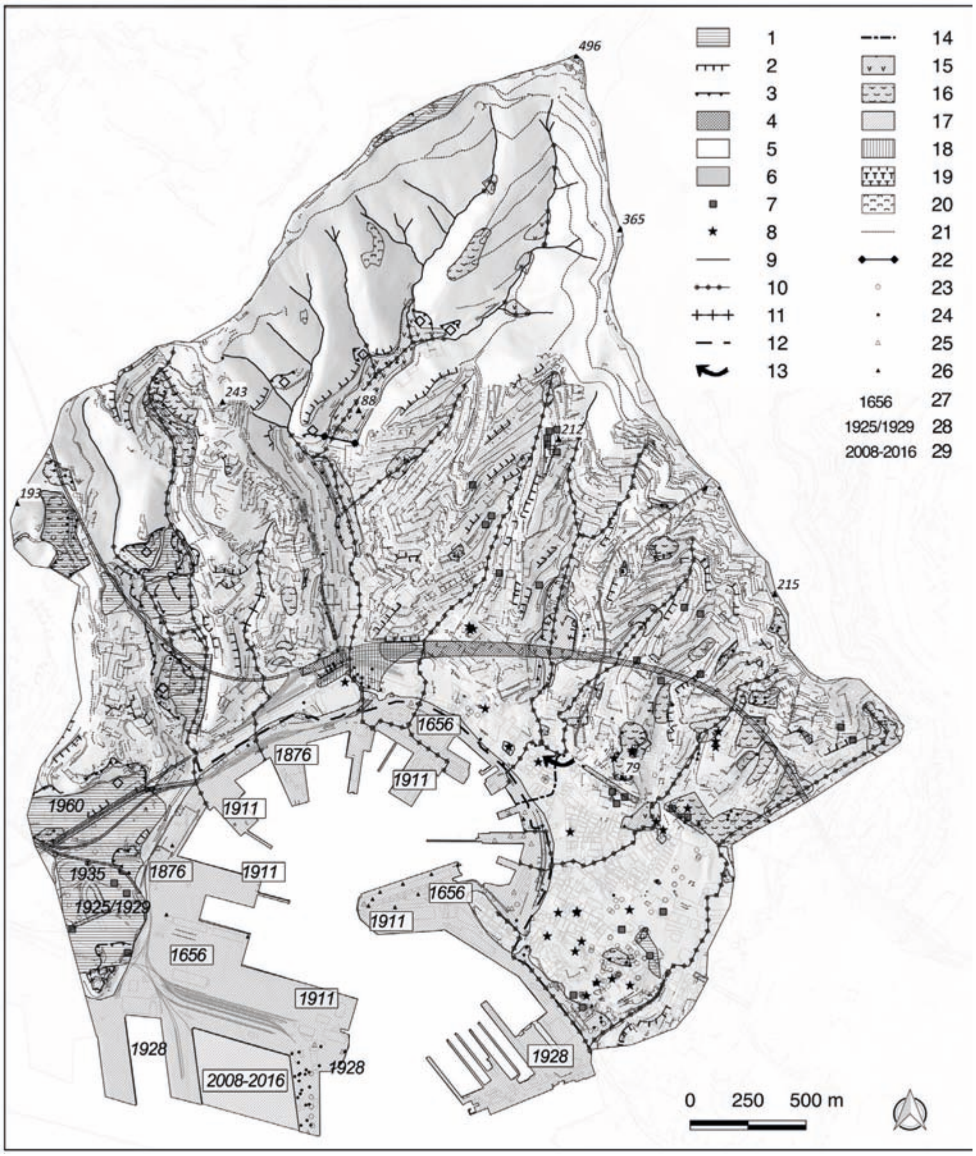

FIG. 5 - Man-made landforms map of Genoa historical amphitheatre. Legend - Erosional landform: 1) excavation area due to quarry activity and road, railway and building work; 2) edge of quarry scarp; 3) edge of scarp due to road, railway and building work; 4) railway tunnel; 5) road tunnel; 6) lift tunnel; 7) underground war shelter; 8) underground cistern; 9) poorly modified and/or natural riverbed; 10) culverted stream; 11) concrete riverbed; 12) eaves channel; 13) riverbed diversion; 14) abandoned channel. Accumulation landforms: 15) filling material on valley bottom; 16) filling material on slope; 17) filling material at sea - reclamation area; 18) railway embankment; 19) cultivated/good state of consevation agricultural terraces; 20) abandoned/destroyed agricultural terraces; 21) retaining wall; 22) dam. Thickness (th) of filling materials by boreholes: 23) th < 2.5 m; 24) 2.5 < th < 5 m; 25) 5 < th < 10 m; 26) th > 10 m. Morphochronological data of the most relevant modifications: 27) year of morphogenetic event; 28) time span of morphogenetic event; 29) years of multiple morphogenetic events.

Since the Middle Ages, the drainage network has been strongly modified with significant changes to the longitudinal profile of the streams (weirs and artificial step/falls), mainly by the construction of underground stone channels (figs. 7 and 8).

All the streams were culverted, either completely (Torbido, Sant'Anna, S.Ugo) or largely (Dinegro, S. Teodoro, Lagaccio, Carbonara). Their final stretch is always culverted and along the seafront, by the original pre-harbour coastline, a drain channel receives wastewaters. For the whole catchment surface of 8.5 km^2 the total length of the streams is c. 24 km of which 16.6 km (70% of the original drainage network) is constituted by culverts (fig. 8).

The case of Rio S. Gerolamo (once called Vallechiara) is a very significant example of 'anthropic stream capture': the stream was diverted into Rio Carbonara (the ancient Rio S. Sabina). In the 12th century these were open-air streams for their whole length; following the thirteenth-century urban expansion, the final stretch of Rio S. Gerolamo was diverted into Rio Carbonara at Porta Sant'Agnese. The abandoned stretch was covered and used for the wastewaters of the area. In the 16th century, following the building of the church of Annunziata, both the streams were completely culverted.

Slope modifications

Archival information and multi-temporal cartographical and photographical comparison allowed the mapping of anthropic slope modifications due to excavation and filling. The regional database of boreholes drilled in the urban area was particularly important for the identification and detailed mapping of landfill areas. Data from c. 1000 boreholes were collected of which 202 show thickness between 2.5 and 5 m, 133 between 5 and 10 m and 35 are >

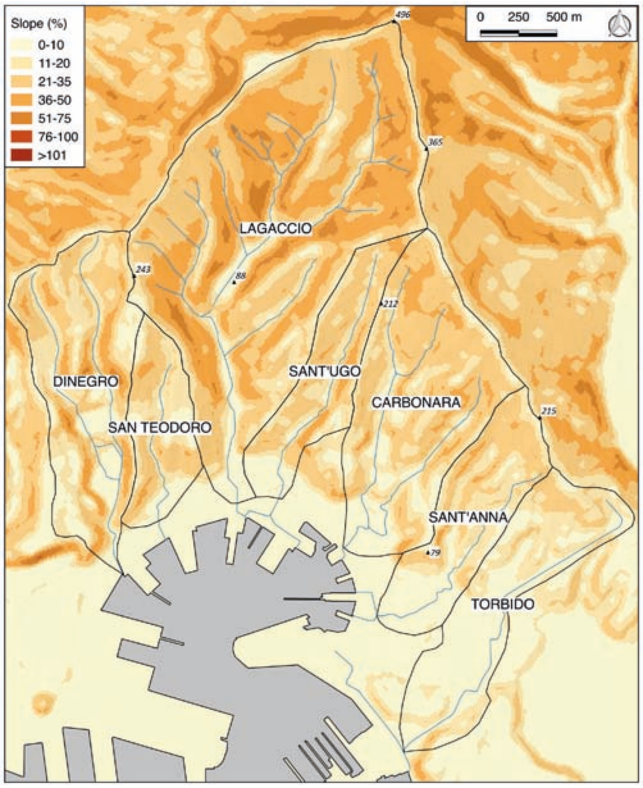

FIG. 6 - Slope map of the historical amphitheatre of Genoa city.

10 m. The most significant thickness was observed in two different morphological situations: the most common cases were found along the main bottom valleys, for a total

FIG. 7 - Underground drainage network in the historical center of Genoa: A) Rio Carbonara; B) Rio Sant'Ugo; C) Piazza Corvetto; D) Palazzo San Giorgio (photos by C. Leoni, after Bixio & *alii*, 2017)

surface of c. 24 ha and along the slopes, associated with the most significant roads and buildings, for a total area of c. 12 ha. In many cases the stratigraphy showed underground voids > 1 m in height due to old cisterns or culverts and parts of the ancient city walls.

The filling of the valley of Lagaccio is particularly significant. The place derives its name from the presence of a little dam built in the 17th century to irrigate the gardens of the Doria Palace. Following the progressive landfill of the lake, in the 1970s the Rio Lagaccio was culverted and some sport facilities were built on the site. A similar situation is found along the lower sector of Rio Carbonara Valley, where in 1652 a 8 ha wide and > 25 m deep landfill area was created to allow the construction of the very large charitable hospital called the *Albergo dei Poveri*.

Many significant excavation areas were also identified through on-site observation: the most frequent examples are connected to historical quarry scarps for the extraction of stone materials (marly limestones) and to cut slopes for the construction of buildings and roads (Cimmino & *alii*, 2004).

The most important example of slope excavation in the city is in the Promontory of San Benigno; it took place in the early 20th century to facilitate communications to the Western Riviera. The area had also been affected by quarrying activities in the previous century. The excavation progressively destroyed the promontory, where the relict of old marine terraces, at 100 m asl, was recognisable. The remains of this promontory, represented by an isolated rock outcrop, is still observable within the port area, where the "Lanterna di Genova" stands. The Lanterna, built in the 16th century, is the second tallest lighthouse in Europe just after that of Île Vierge in Brittany.

Coastline modification

Coastal embankments for land reclamation and the development of the harbour represent one of the most significant morphological modifications. The expansion of the harbour towards the sea and the building of piers and breakwaters have been mapped and chronologically reconstructed through the analysis of cartographical and archival material (harbour plans and bathymetry maps) and the drilling surveys by the Genoa Port Authority (fig. 5).

Alongside the expansion of the city, new sea embankments protected an additional 2.3 km^2 with filling thickness up to 20 m, closing almost completely the ancient port bay.

The first sea embankments date back to the Middle Ages with the growing power of the Republic of Genoa; however, the extension of the coastline became significant in the 19th century. In the first half of the century the first important sectors of the port are completed; by the end of the century and at the beginning of the 20th century the port reached its current shape with the building of port basins like Calata Stefano Canzio, Calata Bettolo, Ponte Rubattino, Calata Giaccone, Ponte San Giorgio and Calata Sanitá which are largely still active today.

The material for the embankments was extracted from quarries such as the Chiappella quarry in the Promontory

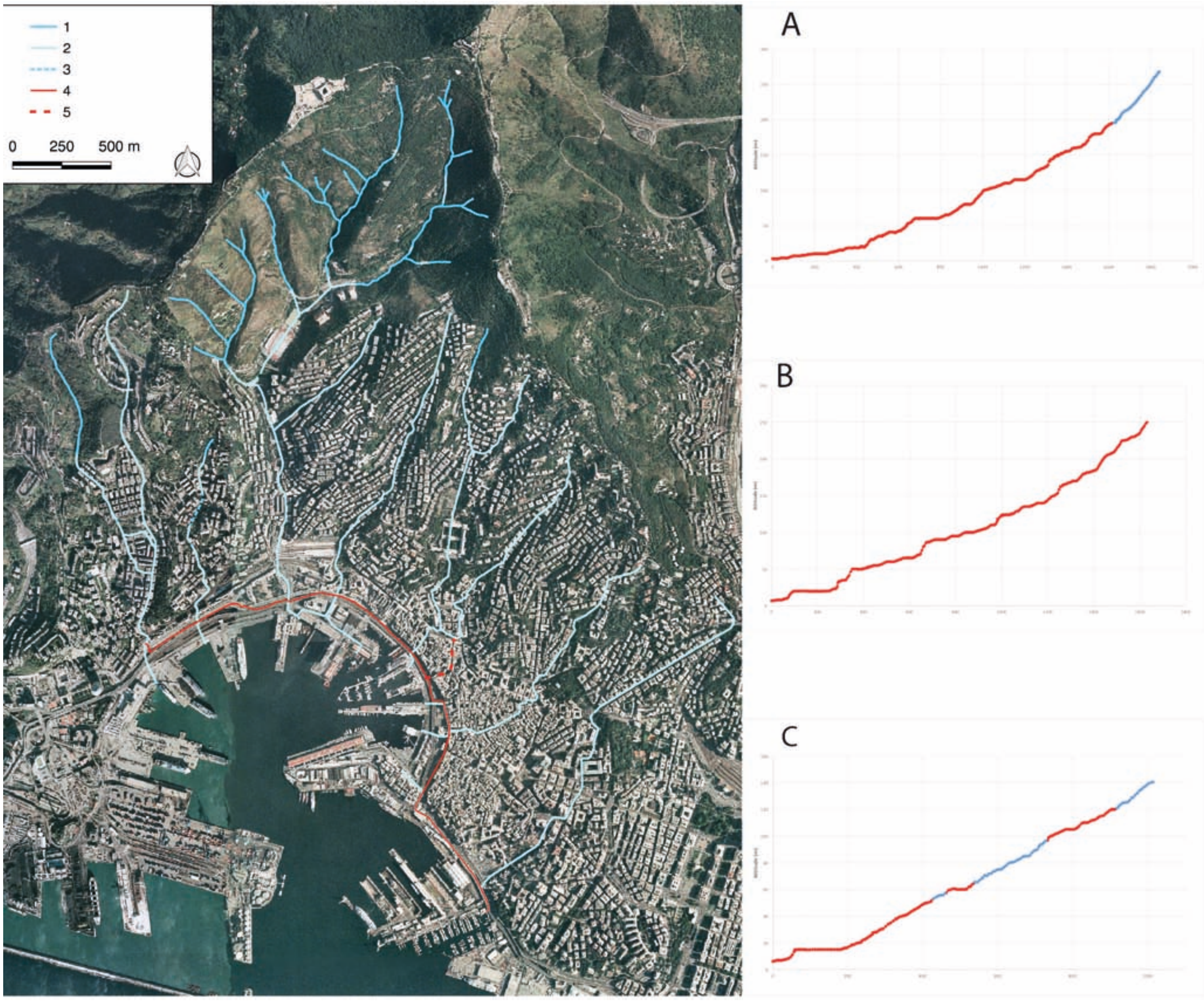

FIG. 8 - Present day situation of drainage network: 1) poorly modified and/or natural riverbed; 2) culverted stream; 3) concrete channel; 4) eaves channel; 5) abandoned channel. Longitudinal sections of Carbonara (A) San Teodoro (B) and Sant'Ugo (C) streams: red line shows artificial riverbed; blue line shows poorly modified and/or natural riverbed.

of the Lighthouse and other quarries along the coast. The extension of the breakwater (Diga Foranea) towards the west with the building of Molo Duca di Galliera is made up of marly limestone blocks from an historical quarry below Mortola hamlet and of the landslide blocks of the same lithology, found along the sea cliff foot between Camogli and Punta Chiappa in the western sector of the Portofino Promontory (Brandolini & *alii*, 2007b).

DISCUSSION AND CONCLUSIONS

In this paper a comprehensive map of the historical erosion and accumulation man-made landforms, occurred in Genoa historical centre, has been produced. The geomorphological classification of the Working Groups on "*Cartography*" and "*Urban Geomorphology*" of the Italian Association of Physical Geography and Geomorphology (AIGEO) has been applied.

Given the particular morphological features of the city centre, between seaside and hillside, the AIGEO classification was integrated with additional information and related symbols. They relate to the mapping of drainage network modifications, that has been categorized as 'poorly modified/"natural" streams, culverted streams, concrete riverbed and eaves channels' (Sala & Inbar, 1992). Due to their potential implications in terms of risk and impact, the mapping of underground cisterns and springs amongst the water-works was also considered appropriate. There were 29 underground cisterns linked to historical buildings, with volumes of about 1000-2000 m^3: as these are artificial cavities, sink-hole phenomena might occur. They are elements

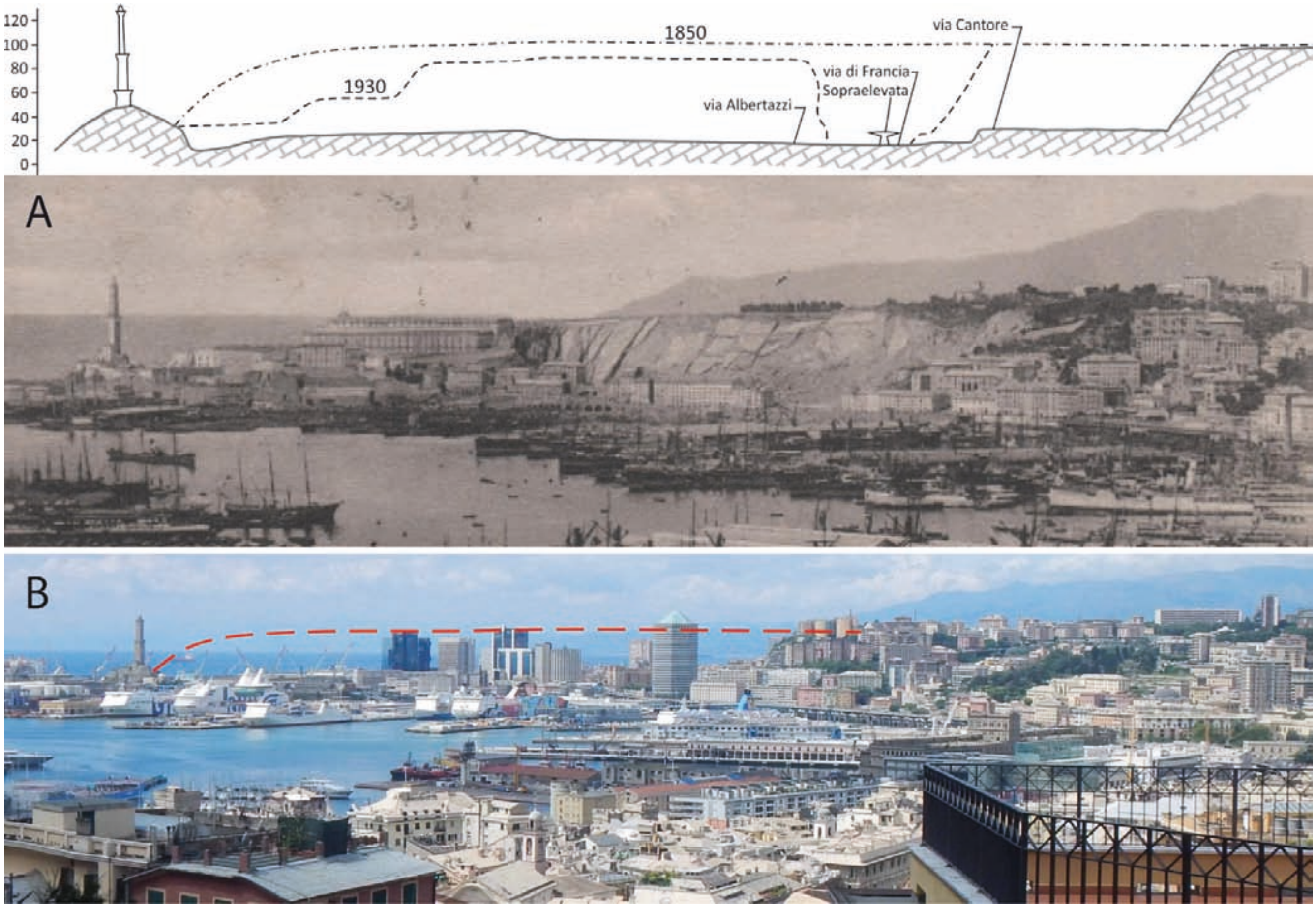

FIG. 9 - The cross-section shows the Promontory of San Benigno morphological modification due to different phases of excavation, carried out along the last two centuries for quarry activity and the expansion of the city's road to the west. The photo (A) of the beginning of 20th century still shows, before the demolition of the promontory, at c. 100 m asl, the remain of an old marine terraces surface. The dashed line in the present-day image (B) shows the former profile of the promontory.

of cultural heritage and in need of being preserved and protected from potential damage. In addition, they are useful reservoirs for flood lamination in urban environment.

Underground excavation landforms were also added (Brandolini & *alii*, 2007a; Chelli & Pappalardo, 2008); these are tunnels for public lifts, underground trains, railways and war shelters. The list of fillings in the draft classification (e.g. filling materials in ancient valley) was integrated with the other two categories: filling materials on slope to realize flat areas for roads, and parking and filling materials for the reclamation of harbour areas.

In Genoa the survey and detailed mapping of the various man-made landforms built over the original landscape revealed some potential geomorphological hazard scenarios (Brandolini & *alii*, 2008; 2018; Persichillo & *alii*, 2017). In particular the significant modifications of the drainage network, which today mainly consist of culverted streams, are particularly problematic. Their discharge sections are not currently adequate to contain the run-off of floods with a return period of 50 years (Città Metropolitana di Genova, 2016; Brandolini & *alii*, 2012, Faccini & *alii*, 2016). Another issue in this sense is the reduction of water infiltration due to the almost complete urbanisation of slopes.

Moreover culverted structures, of medieval origin, are mostly in poor conditions and often show structural failures due to lack of maintenance (Bixio et al., 2017). GIS mapping of the underground drainage network with roads and buildings layers revealed a high geo-hydrological risk (Cipolla & *alii*, 1999); this is due to the presence of more than 90 buildings, most of them with historical, cultural and artistic value (Lanza, 2003), standing on culverted streams or only less than 3 m from them. These buildings are at risk of collapse, sinking and flooding (the main risk probably is due to sinkhole phenomena) as happened during the floods of 2011 and 2014. Particularly significant examples are the historical buildings of Albergo dei Poveri along Rio Carbonara, Palazzo della Commenda di Pre along Rio Sant'Ugo and Palazzo San Giorgio, once headquarters of the Republic of Genoa, over Rio Sant'Anna (fig. 10).

Other significant issues include old quarry scarps, today affected by deep degradation, which in recent times were affected by slope instability triggered by short and intense rainfall events (Faccini & *alii*, 2015c; Cevasco & *alii*, 2013): these are mainly rock falls which caused damages

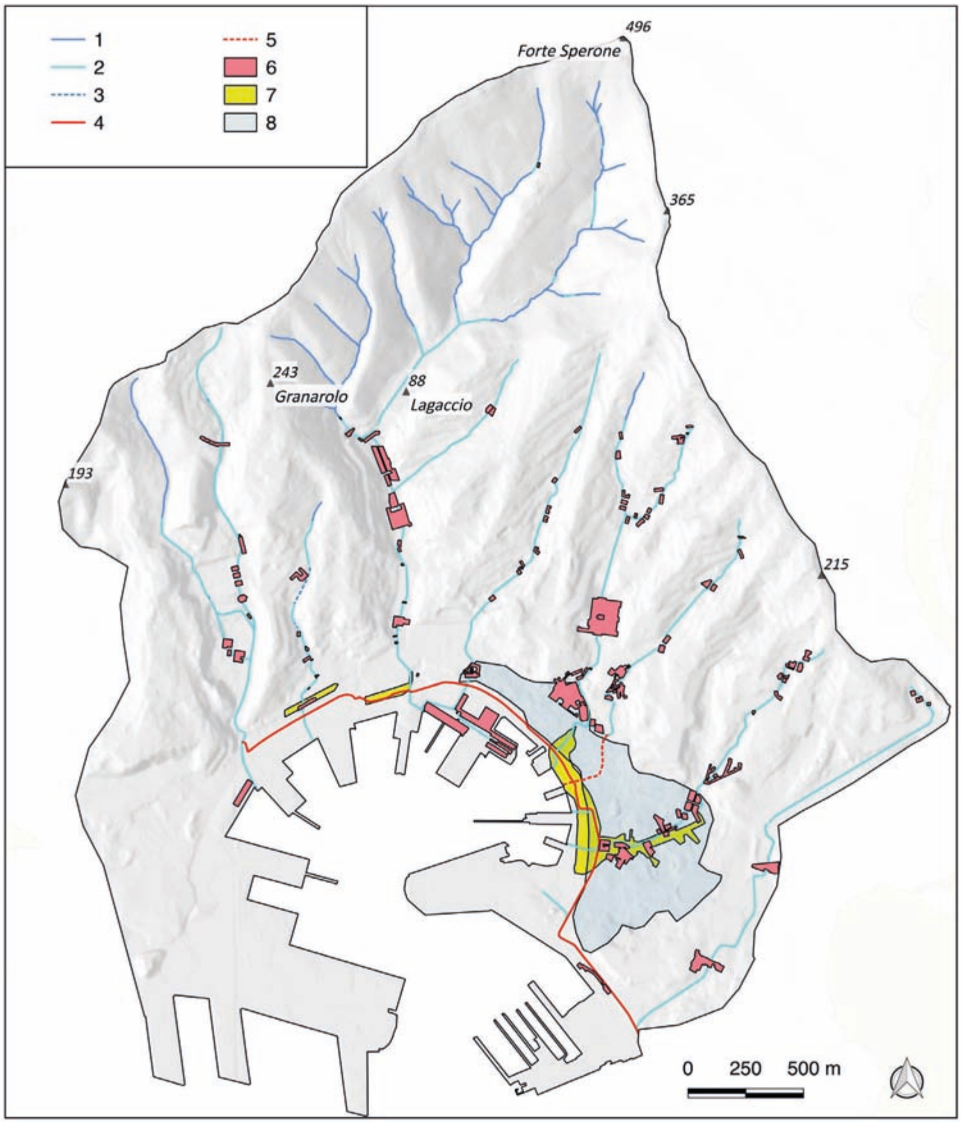

FIG. 10 - Geo-hydrological risk map of the historical amphitheatre of Genoa city. Legend: 1) poorly modified and/or natural riverbed; 2) culverted stream; 3) concrete channel; 4) eaves channel; 5) abandoned channel; 6) exposed buildings; 7) flooding area with recurrence time > 200 years ; 8) historical flooded area.

to structures and casualties, as in the emblematic case of via Digione in the catchment of Rio Dinegro (Peretti, 1969; Brandolini & *alii*, 2012) and other non-stabilized anthropic scarps like in via di Francia, by the rock cutting of the Promontory of Lanterna.

We believe that the application of the geomorphological classification being developed by the AIGEO, with the integrations introduced in this case-study, could contribute to a comprehensive urban geomorphological mapping in highly urbanised coastal contexts, featured by small catchments, steep slopes and intricate drainage patterns.

This study contributes to the assessment of the interaction between human interventions, slope instability hazard and flood events (Sacchini & *alii*, 2016; Faccini & *alii*, 2018). In order to support the identification and prioritization of risk-mitigation measures (Brandolini & Cevasco, 2015), today even more crucial due to the rainfall regime variations, this study intends to provide good insights into urban planning policies.

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