Abstract code: AP2

Geo-hydrological risk and change in rainfall regime: an example from the 4th October 2010 event in Molinassi and Chiaravagna catchments (Genova, Italy)

F. Faccini[1], M. Firpo[1], F. Luino[2], M. Piccazzo[1], A. Sacchini[1], L.Turconi[2]

[1] DiSTAV, Università degli Studi di Genova, Italia
[2] CNR-IRPI, Torino, Italia

Corresponding author details:
Francesco FACCINI
E-mail: *faccini@unige.it*
DiSTAV, Università degli Studi di Genova
Corso Europa 26 – 16132 Genova
++39 010 3538039

Keywords:
Flash floods, Climatic Change, Shallow Landslides, Urban Development, Basin Master Plan, Liguria

INTRODUCTION

In 2010 October 4th, a flash flood interested the western area of the Genoa City focusing on the populous neighborhood called Sestri Ponente (Fig. 1). The phenomenon occurred few hours after a similar event that hit the holiday town of Varazze, ten kilometers West.
During the Sestri Ponente event short and intense rainfalls among the highest among the past ones were recorded. Such events in the Mediterranean area and in Liguria are becoming more frequent with consequent increased geo-hydrological risk. The event from the meteorological point of view has been studied: rainfall intensities are compared with those of other events that have affected the Liguria between the twentieth and twenty-first century, even in the light of recent climatic changes. In this research are described the effects of this event (floods and shallow landslides) and their relating damage.
The geomorphological aspects are very important in the assessing of the catchment response to the pulses generated by intense rainfall in terms of landslides and flash floods.
The comparison among different historical maps about land-use has allowed us to evaluate the effect of the man-made factor on the basin evolution: the uncontrolled urbanization has become a contributory cause of the increased geo-hydrological risk conditions, raising important questions about the most appropriate method to reduce risks.

DISASTER EVENT ANALYSIS

In 2010 October 4th, at 00 a.m. a disturbance associated with a deep trough centered near the Biscaglia Gulf approached the Western Mediterranean Sea. An anticyclonic block in the Middle Mediterranean area, leading African air with 15°C at 850 hPa between Corsica and Sardinia, stopped this baroclyne system (Fig. 2). Together with warm temperature of the sea, these are the typical meteorological conditions triggering heavy rainfalls in Liguria (Bossolasco et al., 1971). The southern intense humid hot flow, in the warm sector of the perturbation, develops strong thunderstorm activity around the sea-land border, accentuated by the orographic effect of the Alpine-Apenninic chain (Fig. 3). Around 6 a.m. a supercell system stroke Varazze with rainfall of almost 100 mm/1h and about 220 mm over 3 hs.

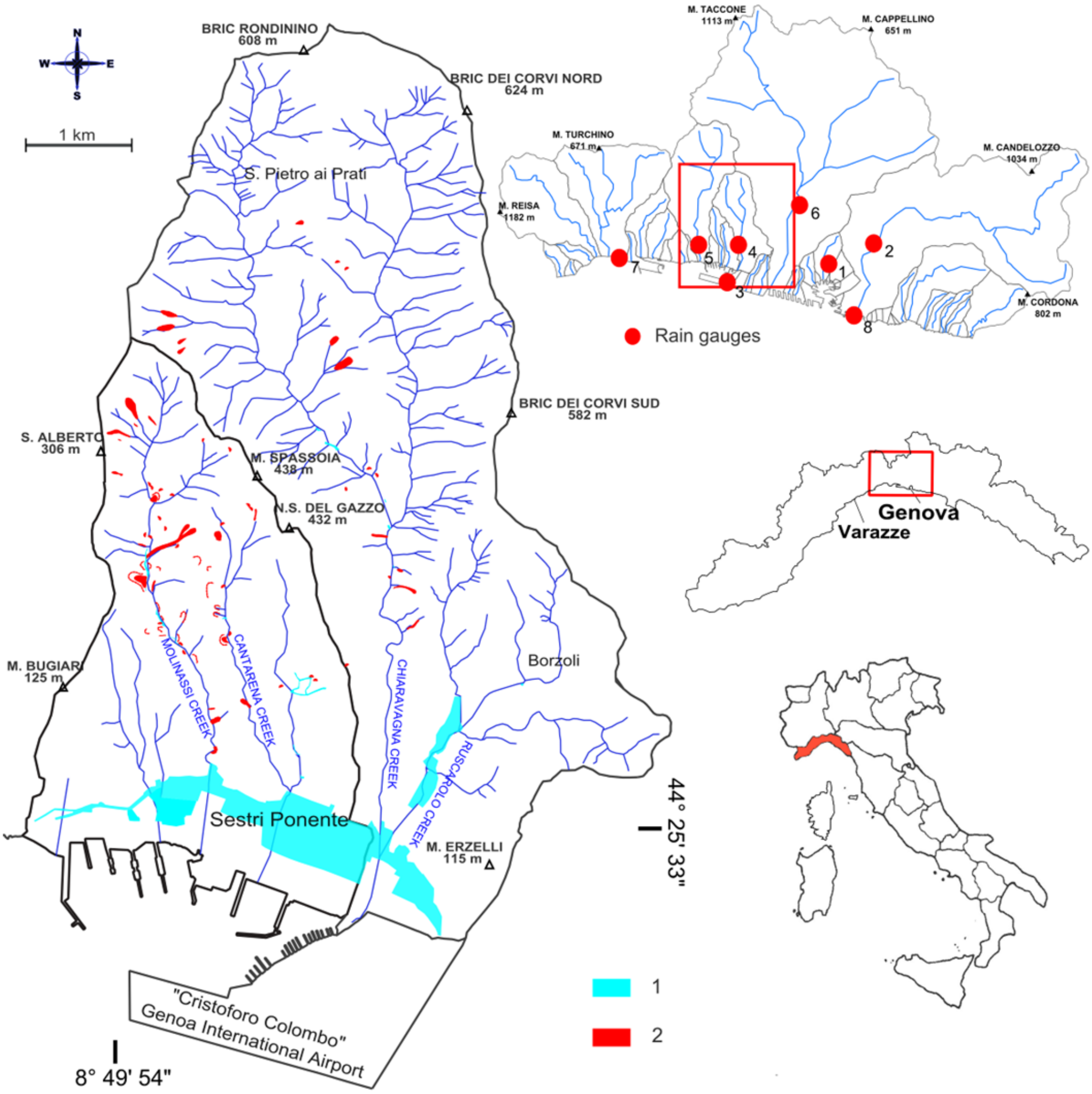

Fig. 1 - Catchment area of the Genoa-Sestri Ponente streams: flooded area (1) and shallow landslides (2) concerning the event of 4th October 2010. Top right: geographic sketch map of Genoan catchments and rain-gauges used in the research (1: University; 2: Pontecarrega; 3: Sestri Ponente; 4: Mt. Gazzo; 5: Pegli; 6: Bolzaneto; 7: Madonna delle Grazie; 8: Foce).

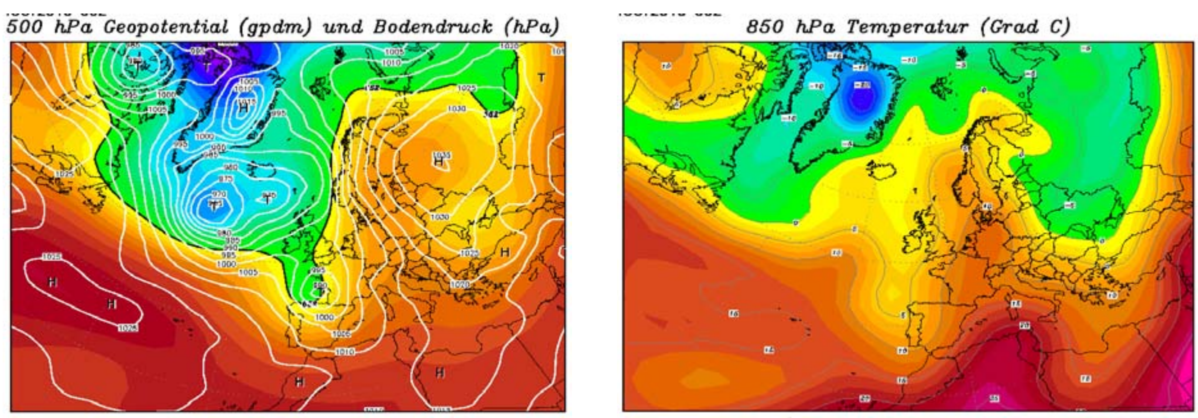

Fig. 2 - Meteorological conditions on 4th October 2010: geopotential height at 500 hPa and sea level pressure at 00 GMT (left) and temperature at 850 hPa at 00 GMT (right).

Between 9 and 12 a.m. the same system regenerated and stroke Sestri Ponente, about 20 km East, with a rainfall peak of 124 mm/1h and total 411 mm/12hs (Sacchini et al., 2011). All streams flooded urban areas and a lot of shallow landslides collapsed causing heavy damage (Fig. 4). During the former Genoan floods, in 1970, 1992 and 1993 maximum 120 mm/1h, 80 mm/1h and 96 mm/1h rainfalls, and 446 mm/6hs, 250 mm/6hs, 284 mm/6hs were recorded (Russo & Sacchini, 1994).
Water levels in the streams increased in a short time: the Varenna stream in Pegli, where there is the nearest water level indicator, reached a peak of 2.62 m with an increase of 2.08 m in an hour. Molinassi and Chiaravagna creeks inundated the areas close their riverbeds and Sestri Ponente.
The rain-gauges in the Sestri Ponente surrounding areas measured a peak of 90 mm/1h and a cumulated rainfall of 380 mm/12 hs (Pegli) and 73 mm/1h and 295/12 hs (Bolzaneto), while the Foce rain gauges at the Bisagno stream outlet recorded a peak of 40 mm/1h and a cumulated rainfall of 100 mm/12 hs (Fig. 5).
The Genoa area has often been characterized by flood events due to climatic and morphological conditions. However it appears the frequency of the events has intensified in more recent times. Analyzing the historical trend of the rainfall, temperature in Genoa University (located in the historical center) and Sestri Ponente weather stations is possible to notice a significative climatic trends (Fig. 6) while other studies in the historical meteorological station of Genoa University showed an important increase in the rainfall rate (Faccini et al., 2014).
At Sestri Ponente, in particular, having a data set of about 50 years, it is possible to observe a sensible decrease in annual precipitation which corresponds an increase of the trend in air temperature.
Historical documents can allow to reconstruct the past floods: the analysis has identified some major floods linked to strong meteorological events at Sestri Ponente. They occurred in 1900, 1906, 1911, 1929, 1945, 1951, 1970, 1977, 1993 and the last episode in 2010.

THE EFFECTS ON THE GROUND

Liguria features steep Alpine and Apenninic slopes with the watershed at a distance of 5-30 km from the sea, very short streams and a brief concentration times. They swirl across urban areas in their ending stretches. In addition, geological complexity and particular atmospheric circulation lead to a high flood hazard, above all between September and November, when the Ligurian Sea is warmer. In particular, the event of October 4th, 2010, struck two basins related to the sea belonging to Sestri Ponente (Fig. 1): the Chiaravagna creek (10 km^2) and the small basin of the Molinassi creek (2 km^2): on the their slopes many shallow landslides were triggered.
Approximately over than 100 critical of shallow landslides were reported in the Molinassi and Chiaravagna catchments. They were mainly concentrated in the middle and lower basin sectors. Two-thirds of the cases were rock falls, slides, debris flows and complex processes (slide-debris flow and fall-debris flow) and had a mean thickness of less than two metres. Most of the gravitational movements can be defined as debris slides and they were triggered along the side valleys of the streams. A victim occurred because of a landslide in a Panigaro quarry, located in the middle Chiaravagna valley.
Above all damage affected communication routes both for pedestrians and vehicles, buildings and the terraced slope tracts used for farming. The rainfall created rapid increases in the flood discharges with transport of material in suspension and floating shrubs and trees which were eroded along the scarps and unprotected embankments. Roads were flooded and the small villages on the adjacent hills were isolated. The mobilised debris flows rapidly channelled along riverbeds and lower areas, causing critical hydraulic conditions in the secondary hydrographic network, also because the culverts under roads were insufficiently dimensioned.

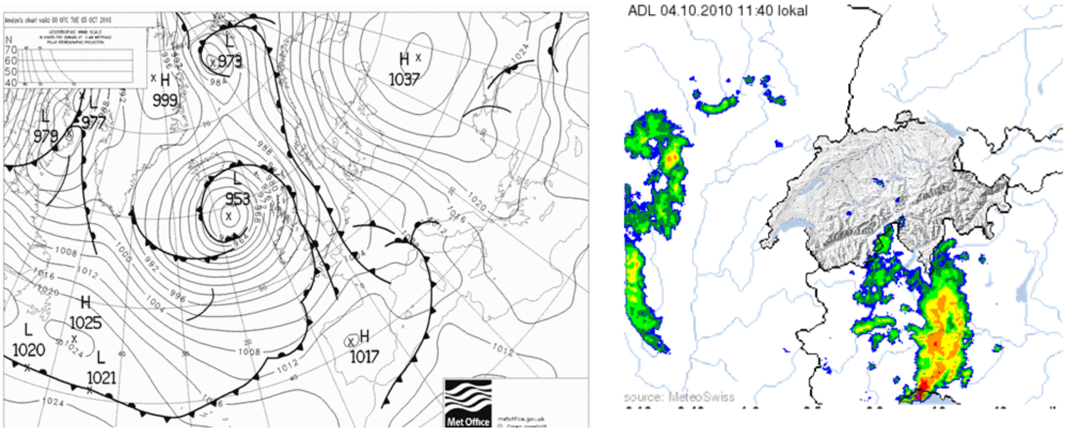

Fig. 3 - Meteorological conditions on 4th October 2010: sea level pressure and fronts at 24 GMT (left) and radar image at 10.40 GMT (right).

Fig. 4 – Ground effects of the 4th October 2010 event: the main street of Sestri Ponente flooded (left) and soil slips/debris flows around village in the Molinassi creek catchment (right).

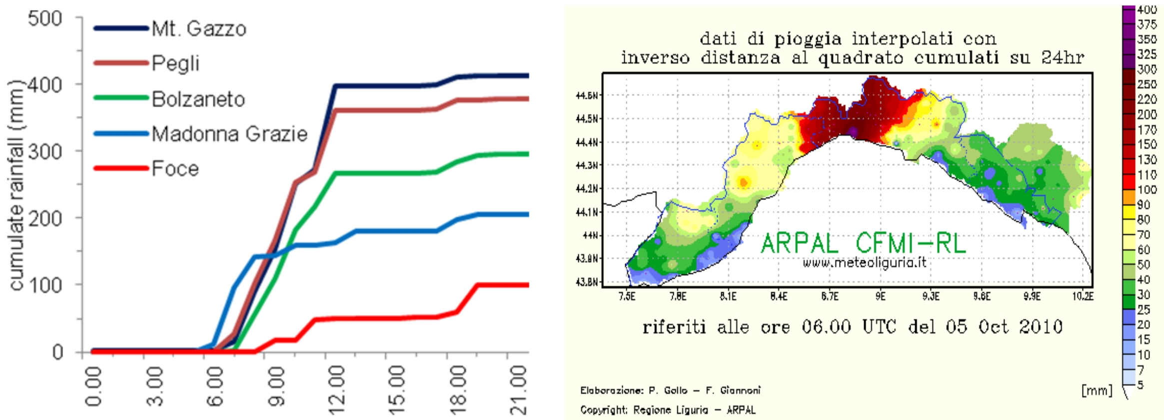

Fig. 5 – Cumulated rainfall recorded the 4th October 2010 at Sestri Ponente and surrounding area rain-gauges (left) and isoieth map (mm/24 hs) of the 04-10-2010 geo-hydrological event (right, from ARPAL 2011).

Artificial channels at the road intersections were rapidly obstructed, forming huge deposits; the Sestri Ponente flood-plain, between two streams, were flooded with water heights above street lever from 20 to 150 cm (Fig. 7). Damage to public infrastructures was estimated in more than 50 million euros. It's not possible to exclude the influence of a surcote effect by the sea in the inundation of the plain (ARPAL, 2011).

THE URBANIZATION OF THE PLAINS

The comparison of the historical maps shows some aspects of urbanization leading to an increase of the geo-hydrological risk (Fig. 8). In particular, it shows the change of land-use with the complete urbanization of flood-plains, the narrowing of the riverbeds and the channeling of streams crossing urban areas (nearly all of them totally or partially covered), the partial deviation of Ruscarolo creek in its final stretch: this creek is not reaching the sea near the original beach of Sestri Ponente, but it is channeled into the Chiaravagna creek. Historical notes of the ancient Maritime Republic of Genoa show that around XIst century the sea dampened the Chiaravagna valley through the little San Lorenzo Gulf and even a little harbour lied at the basis of the hills. In the XVIIth century the sea reached the Basilica of the Assunta, which was built on the seaside, that today it is about 1 km from the sea. These notes show that the area was affected by progradation of the alluvial plane in historical times. In addition to this natural trend other anthropogenic factors determined the increasing of the flood-plain: in the second half of the XIXth century the litoral railway was built and the plane was completely urbanized in the XXth century with productive and living units settlements; moreover the shipyards and the Genoa airport were also built (in the 60's), with the final separation of the suburb form the sea by means of cyclopic embankements and the forced curving of the streams.

DISCUSSION AND CONCLUSION

Most of the mapped landslides occurred on moderately steep slopes with gradients between 20% and 35%; more than half of the instabilities occurred on wooded slopes with mixed coppice and the remaining instabilities are triggered on farmed or abandoned terraced slopes. Regarding the geomorphology, most of the cases listed are represented by colluvial deposits of metric thickness. Notably, no criticality was observed in sectors with a very high geomorphical hazard identified in the Basin Master Plan (Provincia di Genova, 2013): they are constituted by large-scale landslides and mass movements that are not reactivated by events of short duration. More than 66% of the instabilities occurred on slopes that were classified of low or medium hazard. The events of 2010 greatly exceeded the thresholds for triggering landslides; they show an intensity ever recorded in relation to 1, 2, 3 hours of rainfall among the events that have caused geo-hydrological processes in the twentieth and twenty-first century (Faccini et al., 2012).
It is evident that those risks indicated in the Basin Master Plan should be updated by providing appropriate weights depending on the different geological, geomorphological and hydrological conditions. Climatic trends in Liguria increase the possibility of analysing intense precipitation events and triggering thresholds for geo-hydrological instabilities.
It is important to highlight that in Genoa area at least four major floods occurred during the 21st century. By pluvio-hydrometrical analysis for Mt. Gazzo and the Varenna stream it is worthy to notice that as soon as the inflection of the curve on pluviogram brand starts being marked, at the same time the river flood begins. Due to limited sizes of the affected area (not perfectly identified by previsions) and because of the suddenness of the event, the Civil Protection was not able to implement any plan of action during the occurrence (Brandolini et al., 2012). The weather nowcasting and real-time monitoring of the rain-gauge can provide information to civil protection with some ten minutes earlier the response of the watercourses.
This precious time can be used to alarm the population through a previous detailed and diffused information to save themselves.

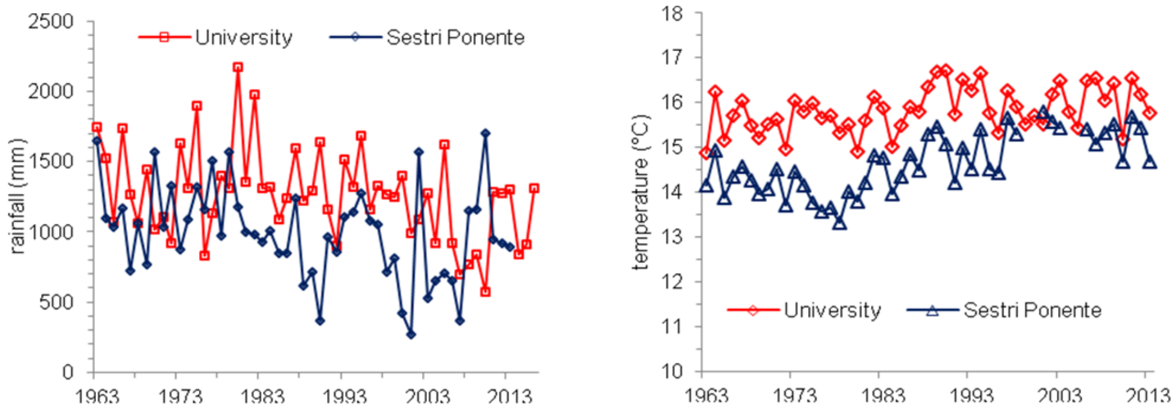

Fig. 6 – Annual rainfall (left) and mean annual temperature (right) of two Genoan rain-gauges in the 1963-2013 period.

Fig. 7 – Cantarena creek in mean discharge condition and during the 4th October 2010 event (images above), a narrow street in Sestri Ponente before and after the flood (bottom left), the demolished building on Chiaravagna creek before and after the flood event (bottom right).

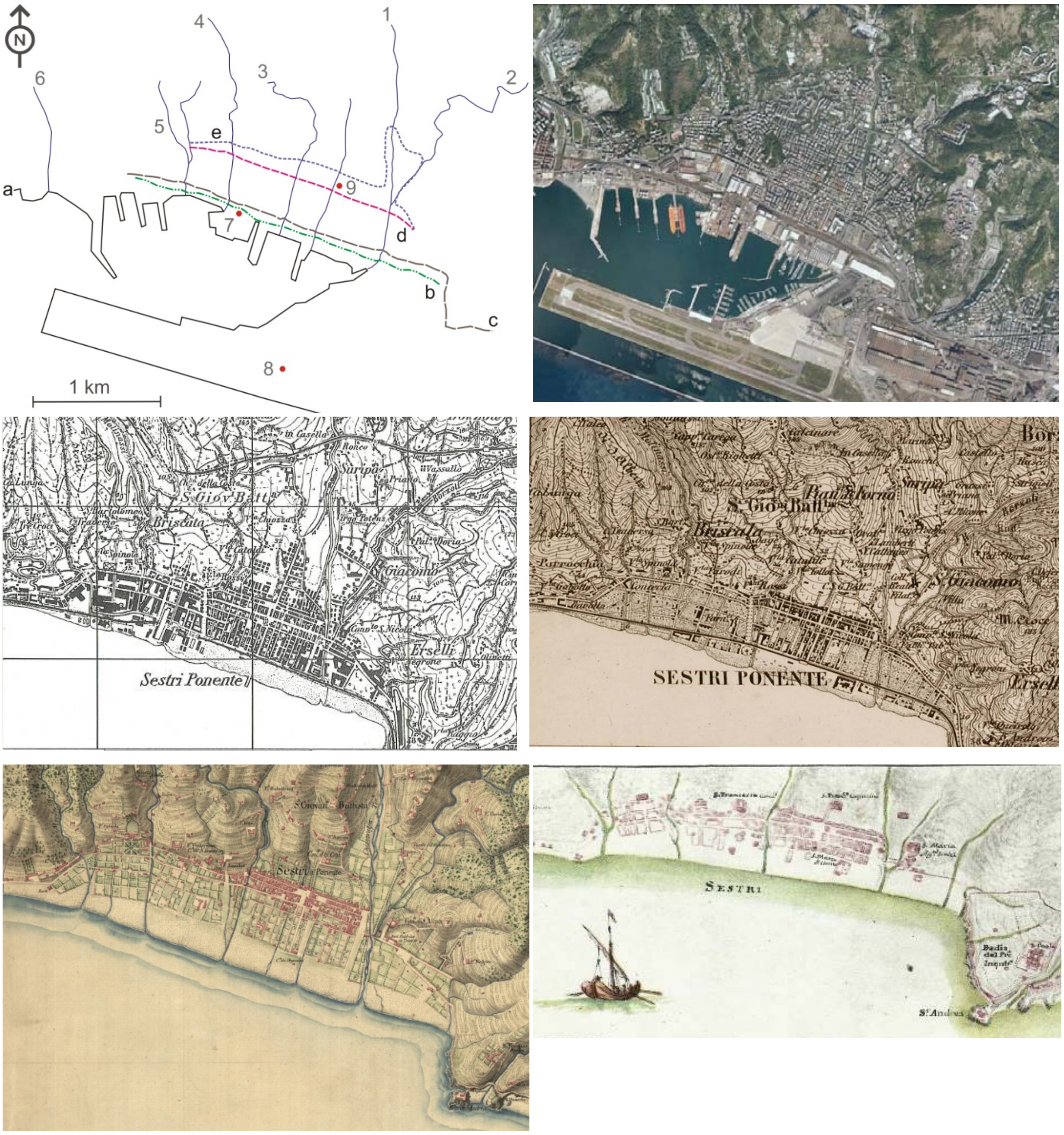

Fig. 8 – Historical maps comparison. Clockwise from upper left: historical coastline evolution (1: Chiaravagna creek; 2: Ruscarolo creek; 3: Cantarena creek; 4: Molinassi creek; 5: Marotto creek; 6: Varenna stream; 7: Shipyards; 8: Airport; 9: Basilica of the Assunta; a: actual coastline; b: shoreline at 1878-1936; c: shoreline at 1815-1825; d: shoreline at XVII century; e: shoreline at XI century), current aerial photograph (from Google Earth) of Sestri Ponente, map of 1878 (from IGMI archive, Tavoletta Sestri Ponente), map of XVIII century (from Matteo Vinzoni, Il Dominio della Serenissima Repubblica di Genova in terraferma), map of 1815-1823 (from IGMI Archive, Stati Sardi di Terraferma), map of 1940 (from IGMI archive, Tavoletta Sestri Ponente).

REFERENCES

Agenzia Regionale per la Protezione dell'Ambiente Ligure (ARPAL) 2011, 'Rapporto di evento meteo idrologico del 04/10/2010' (redatto da Onorato, L, Giannoni, F, Gollo, P, Turato B), [on line] available: *http://www.arpal.gov.it.*

Bossolasco, M, Cicconi, G, Dagnino, I & Flocchini, G 1971, 'Le cause meteorologiche dell'alluvione su Genova del 7-8 ottobre 1970', *Geofisica e Meteorologia*, vol. 20, pp. 122-132.

Brandolini, P, Cevasco, A, Firpo, M, Robbiano, A & Sacchini, A 2012, 'Geo-hydrological risk management for civil protection purposes in the urban area of Genova (Liguria, NW Italy)', *Natural Hazards and Earth System Sciences*, vol. 12, pp. 943-959.

Faccini, F, Robbiano, A & Sacchini, A 2012 'Geomorphic hazard and intense rainfall: the case study of the Recco Stream Catchment (Eastern Liguria, Italy)', *Natural Hazards and Earth System Sciences*, vol. 12, pp. 893-903.

Faccini, F, Luino, F, Sacchini A & Turconi, L 2014, 'Flash flood events and urban development in Genoa (Italy): lost in translation', in *Engineering Geology for Society and Territory: proceedings of XII IAEG Congress,* eds. G. Lollino et al., vol. 5, Springer International Publishing Switzerland, pp. 797-801.

Provincia di Genova 2013, 'Piano di bacino stralcio per la tutela dal rischio idrogeologico del Torrente Chiaravagna', Approvato con Delibera del Consiglio Provinciale n. 18 del 30/07/20, [on line]: *http://cartogis.provincia.genova.it/cartogis/pdb/chiaravagna.*

Russo, G & Sacchini, A 1994, 'Brief survey on recurrences of extreme rainfalls in Genoa, Italy', *Idojaras*, vol. 98, pp. 251–260.

Sacchini, A, Faccini, F, Firpo, M, Bozzano, S, Francioli, G & Robbiano, A 2011, 'Heavy rainfall triggering flash floods and shallow landslides: the case study of a Ligurian event (4th October 2010)', Abstract volume of *13th Plinius Conference on Mediterranean Storms,* Egu Topical Conference Series, Savona 7-9 September 2011, pp. 19-20.