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Natural Hazards and Earth System Sciences
Discussions

A spatial multicriteria prioritizing approach for geo-hydrological risk mitigation planning in small and densely urbanized Mediterranean basins

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Abstract

Landslides and floods, particularly flash floods, occurred currently in many Mediterranean catchments as a consequence of heavy rainfall events, causing damages and sometimes casualties. The high hazard is often associated to intense urbanization in particular along the coastline where streams are habitually culverted. The necessary risk mitigation strategies should be applied at catchment scale, considering the concurrent landslides and flood events and would need to be accurately planned in order to optimize the available economic resources.

In the present work 21 small catchments in a high hazard area have been assessed and compared through three sets of parameters: one describing the morphometric-morphological features related to flood and landslide hazard, another describing the degree of urbanization and of anthropogenic modifications at catchment scale and the last related to the elements that are exposed to risk. The aim of the research is to constitute a priority scale among the small catchments, applying the multicriteria analysis technique to the descriptive parameters and giving a support tool for decision makers, supporting a strong scheduling of long-time planning interventions at catchment scale.

This approach could be applied in similar context, even at sub-catchment scale, after identifying a suitable set of descriptive parameters depending on the active geomorphological processes and the kind of anthropogenic modification, obtaining the optimization of economic resources.

1 Introduction

Floods and landslides are very common in many areas of the Mediterranean basin due to particular characteristics of geology, geomorphology and climate that can induce a high geo-hydrological hazard (Canuti et al., 2001; Guzzetti and Tonelli, 2004; Luino, 2005; Luino and Turconi, 2017).

Among these processes, flash floods are the most dangerous for the short development time that often do not allow the population to protect itself. They occur following very

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intense and localized rainfall events and their ground effects have been underlined by many authors (Roth et al., 1996; Massacand et al., 1998; Delrieu et al., 2006; Amengual et al, 2007; Gaume et al., 2008; Marchi et al., 2009; Barthlott and Kirshbaum, 2013). Spread shallow landslides and debris flow often occurs and their effects are superimposed and may locally magnify flooding, in particular in urban/suburban areas (Borga et al., 2014). Small catchments have a fast response to those events, reacting with large discharge of water and debris to the usually densely urbanized floodplain (Pasche et al., 2008). Many coastal Mediterranean areas are particularly liable to this kind of hazard: the general climatic context, with the interface between cold air masses and the sea, a steep territory and a complex geomorphologic and geologic context are the main natural factors. Small catchments have a fast response to those events, reacting with large discharge of water and debris to the usually densely urbanized floodplain (Pasche et al., 2008). Many coastal Mediterranean areas are particularly liable to this kind of hazard (Gaume et al., 2008): the general climatic context, with the interface between cold air masses and the sea, a steep territory and a complex geomorphologic and geologic context are the main natural factors.

In such hazardous context the high vulnerability that characterizes most of the urbanization determines the elevate risk, while the intense anthropogenic modification of large portion of catchments and hydrographical networks tends to amplify the effects (Llasat et al., 2014; Nirupama et al., 2006): impervious surfaces increase the surface run-off and decrease the time of concentration (Shuster et al., 2007), while strictly constrained and often culverted streambeds, frequently have inadequate discharge capacity (Moramarco et al., 2005; Faccini et al., 2016).

Anthropogenic modifications are interesting most of the coastal floodplain with a strong soil consumption and with the widespread narrowing of the streambed that has favored most of the flood prone areas (Faccini et al. 2015, Faccini et al. 2016). Furthermore, the modifications are often interesting even the hinterland: besides the urban sprawl and the fragmentation caused by infrastructures, in some areas the ancient man-made terraces realized for agricultural practice and actually largely abandoned, constitute an increasing factor of geomorphological hazard (Brancucci and Paliaga, 2006; Tarolli et al., 2014; Paliaga, 2016). In the recent years many evidences have been arising in Italy: large areas of Liguria (Brandolini et al., 2017; Cevasco et al., 2017) and Toscana (Bazzoffi and Gardin, 2011) are interested by terraces instability that may turn in source of geomorphologic hazard. In the Mediterranean region many areas present similar occurrence of terraces with analogous problems: the French Côte d'Azur, the Mediterranean and insular Spain and Greece (Tarolli et al., 2014) are some example. In the recent years some disastrous events involved terraced slopes: in 2011, during the Cinque Terre flood (Liguria, northern Italy) (Brandolini et al., 2017; Luino and Turconi, 2017), many terraces collapsed and the subsequent debris filled villages at a height of about 3 m, and in 2014, in the Leivi village during the Chiavari flood (Liguria) a terraced slope collapsed destroying a house and causing 2 fatalities (Faccini et al., 2017; Luino and Turconi, 2017).

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Every year in Italy many casualties and significant damages, both to private and public sectors, are caused by floods, landslides and debris flow: the 2017 periodic CNR-IRPI report (CNR, 2018) on Italian population landslides and floods threat, evidences 1789 casualties and 317.526 homeless in the period 1967-2016, with all the regions affected. Liguria, despite its small surface, is between the most affected region scoring the third place in the mortality index calculated on both landslide and flood events.

Risk mitigation strategies are more and more urgent but largely disregarded, unapplied or only partially pursued: few resources are allocated and, commonly, are used only for emergency actions while a long-term planning and scheduling should be crucial to obtain significant results (Prenger-Berninghoff et al., 2014). In the recent years, in Italy, some large structural works have been started to mitigate the worst flooding risk situations, but without following a broad approach at catchment scale. The most important is the floodway channel for the Bisagno stream in Genoa (Liguria), but similar project or culvert adjusting are ongoing in smaller neighboring streams. This approach allows to mitigate just a part of the risk, ignoring slope instability processes and related contribution to solid transport into hydrographical network.

In Liguria, and especially in the Genoa metropolitan area, the high geo-hydrological risk is related to intense urbanization, to the geomorphological asset and to heavy rainfall that is generally intense in autumn (Silvestro et al. 2012) and that appears to be increasing in intensity (Faccini et al., 2015; Aquaotta et al., 2017). Apart the structural interventions in the larger Bisagno catchment, even the smaller ones in the Genoa metropolitan area are considered at high risk from the local environmental agency (ARPAL) and request mitigation works to be planned and scheduled.

The aim of the research is to propose a support tool to decision makers in order to plan and schedule long-term interventions at catchment scale. A group of 21 small catchments in the middle of the zone more liable to heavy rainfall (Cassola et al., 2016) have been analyzed, comparing three sets of descriptive parameters. The comparison has been performed with spatial multicriteria analysis using a total of 19 parameters and obtaining a priority scale between the 21 catchments. Spatial multicriteria approach has been applied by many authors in flood risk and in natural hazard management (Gamper et al., 2006; de Brito et al., 2006), mostly to identify specific areas prone to instability or to compare catchments through morphometric parameters (Benzougagh et al., 2017). In the present work the Authors applied those techniques considering a broader set of parameters, trying to address the peculiarity of small urban catchments in a mountainous territory. The rank obtained with the method application could be used to evaluate the catchments that need more urgent actions in order to mitigate future eventual damages and casualties, considering that past extreme rainfall events hit bordering ones but, in the future, could replicate their effects.

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2 Material and method

2.1 Geomorphological and geological settings

The studied area is one of the more critical in terms of geo-hydrological risk in Italy and in the Mediterranean basin. It is located in the central part of Liguria region, northern Italy (fig.1): 21 catchments with a surface area comprised between 1.3 and 27.5 km^2 have been analyzed. Five of them, numbered 11,13, 14 and 15 in fig. 1, are sub-catchments of the two major ones that cross Genoa city: the Bisagno and Polcevera catchments. All the others flow directly into the Ligurian sea.

The area is densely populated, 2,429 inhab/km^2 in the whole Genoa administration unit (ISTAT, 2012) and has been strongly urbanized starting from the beginning of the 20th century (Faccini et al., 2016). Land use (fig. 1) clearly shows the strong dualism between the urban area, mainly concentrated in the lower catchments close to the sea, and the middle and upper mountainous catchments that preserve natural features with meadows and woods. Some catchments have been strongly modified by urbanization: in particular n° 8, 9, 10, 12, 15 and 16. In the upper portion of n° 10 is present, since more than 50 years, the city dump and, in the central portion, some limestone quarries.

The catchments are mainly elongated and oriented orthogonally to the coast line and reach maximum altitudes comprised between 491 and 1189 m a.s.l. (tab. 1). Only n°1, 3 and 4 present a less elongated feature. The strong steepness of the slopes and a substantial lack of coastal floodplain is a distinctive feature of all the area: gradient is high in all the catchments and particularly in n° 3 and 21 (fig. 2). The only relatively extended floodplains are present in catchments n° 8, 9, 10, 14 and 16.

The catchments present substantial homogeneous lithological features if considered in three groups fig. 3): the western one (from n° 1 to 7) are prevalently ophiolitic and metamorphic; the eastern (from n° 11 to 21) are essentially sedimentary, while the central ones (from n° 8 to 10) present both the lithology. This structure corresponds to the limit between, respectively, Alpine and Apennine structural units, with the Sestri-Voltaggio unit limit.

Hydrographical networks are generally well developed (tab. 1), but present a higher density in the western catchments, due to the more impervious substrate. Main streams are generally short, coherently with the small dimensions of the catchments. Almost all the final stretches of the main streams have been culverted due to the dense urbanization: the only exceptions are n° 3, 11 and 19. In fig. 1 culvert in the final 1 km stretches are shown. Data of the floods that hit the catchments in the period 1950-2016 (Guzzetti et al., 1994; Luino and Turconi, 2017) are reported in fig. 4 and demonstrate the high geo-hydrological risk in the area. Some recent events resulted particularly dramatic: 1 casualty in n° 10 in 2010 and 6 casualties in n° 15 in 2011.

Landslides are widespread along most of the catchments (fig. 5) and particularly in n° 3, 4, 5, 6, 7, 14 and 21. Most of the processes are superficial and, despite the small dimension, sometimes may produce high local damages, interacting with infrastructures

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and urban area. In occasion of flash floods that hit the area (i.e. in 2010, 2011, 2014 and 2015) high solid transport, supplied by superficial landslides, occluded partially or totally some culverts, contributing significantly to the streams overflow. In the area are present even some large DSGSD and an ancient landslide dam in n° 14.

Anthropogenic modification has interested even the not urbanized area: in the past, due to the high gradient and to the need of subsistence agricultural practices, slopes were widely modified by man-made terraces (fig. 6). The structures are largely abandoned and affected by instability and erosion, increasing the geo-hydrological hazard (Brancucci and Paliaga, 2006; Tarolli et al., 2014; Paliaga, 2016). Recent events in the Cinque Terre (2011) and in Leivi (Genoa metropolitan area, 2014) show the dramatic effects related to the presence of terraces and of their partial or total abandon (Cevasco et al., 2017; Giordan et al. 2017): widespread damages in the first, and 2 casualties in the latter. Terraces are widespread prevalently in n° 3, 4, 6, 11, 14, 15, 16, 17 and 18 where gradient and aspect are more favorable.

2.2 Climate and Meteorological context

Climate is humid-mild with a short dry summer season (Sacchini et al., 2012; Acquaotta et al., 2017), with annual mean rainfall between 1,100 and 1,300 mm and 16 °C annual mean temperature, registered in the 1945-2015 period. Despite these mean values, the impact of intense extreme events characterized the area, due to the Mediterranean cyclones that periodically spring and intensify from south of the Alps over the Gulf of Genoa in the Ligurian Sea (Saéz de Càmara et al., 2011). This phenomenon is enhanced by the interaction between the general air mass circulation and the orography, characterized by high gradient slopes and the short distance of the mountains from the sea: the severe thermodynamic contrast between hot humid Mediterranean and colder continental air masses generate this configuration in the autumn-winter and spring periods (Anagnostopoulou et al., 2006), producing heavy rainfall (Sacchini et al., 2012).

At the end of the summer and autumn, when the thermodynamic contrast is higher, thunderstorm convective systems and sometimes super-cells are triggered (Silvestro et al., 2012, 2016) and perturbations canalized through the valley, facilitated by their orientation. Precipitations are then accentuated by the orographic effect. During recent heavy rainfall events the maximum intensity registered was 180 mm/h in 2011 and 140 mm/h, respectively close and into catchment n° 15. During the 1970 flood event that hit Genoa area causing damages and 44 casualties, were registered intensities over 200 mm/6h and over 500 mm/24h (Faccini et al. 2016).

2.3 Research methodology

In order to support the decision process in planning mitigation strategies of geo-hydrological risk, a comparing tool has been developed. The problem of relating heterogeneous physical quantities has been faced using the spatial multicriteria analysis

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techniques (S-MCA), commonly used as a support in decision making procedures, but applied even in natural hazard management (Gamper et al., 2006). The basic idea is to use a tool developed to compare heterogeneous physical quantities in order to obtain a sustainability scale between different alternatives and using it to perform a priority scale of attention for the small catchments in term of geo-hydrological risk. The methodology considers parameters as gain or cost, depending on the influence they have in terms of sustainability: in the present study all the parameters have been considered as gain, except one, the concentration time, because of their contributing effect to risk.

Considering the peculiarity of the studied area three sets of describing parameters at catchment scale have been selected: the first related to the natural features connected to geo-hydrological, the second to the human alteration and the third to the exposure at risk, according to the flood directive 2007/60/EC. The flow chart of the prioritizing process is shown in fig. 7 and the selected parameters are as follows:

- Set 1 (environmental factors-natural evolution – tab.2):
  - Drainage density: it is related to the flood potential (Patton and Baker, 1976).
  - Mean slope: it is related to the time of concentration in the catchment.
  - Melton ratio: has been used as a potential indicator of susceptibility to generate debris flow (Aversa et al., 2016).
  - Ruggedness number: is related to flash flood potential and high erosion rate (Patton and Baker, 1976).
  - Hypsometric integral: it is correlated to the stage of geomorphic development of the catchment, is an indicator of the erosional stage and is related to several geometric and hydrological properties such as flood plain area and potential surface storage (Rogelis and Werner, 2014).
  - Landslides: total surface in percentage respect to the catchment surface, excluding DSGSD.
  - Mean bifurcation ratio, obtained as the average value of the Rb for all stream orders: high values are correlated to flash flooding potential (Howard, 1990; Rakesh et al., 2000).
  - Times of concentration: the calculation has been performed with Pasini, Ventura, Pezzoli, Kirpich and NRCS-SCS formulae (tab.3); the mean value has been chosen. For NRCS-SCS application a prior CN evaluation has been assessed through land use data.
  - Floodable surface (200 years return period) as the surface in percentage respect to the total catchment surface.
- Set 2 (environmental factors-anthropogenic impact):
  - Soil consumption in percentage of the total catchment surface
  - Culvert: percentage of the last km of the main stream.
  - Terraces total surface in percentage respect to the catchment surface.
- Set 3 (social factors):
  - Percentage of the area exposed to risk level R1.

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- Percentage of the area exposed to risk level R2.
- Percentage of the area exposed to risk level R3.
- Percentage of the area exposed to risk level R1.
- Number of punctual elements exposed to risk level R2.
- Number of punctual elements exposed to risk level R4.

Considering the percentage on the catchment surface for the floodable area (set 1) and for the area exposed to risk level R1-R4 (set 3) is similar to weighting with the catchment extension. Surface area, then, is implicitly part of the process of computation.
No punctual elements in the classes R1 and R3 are present in the studied catchments.
The descriptive parameters have been collected in a geodatabase related to catchments geometry in order to allow the application of S-MCA, performed through the geo-UmbriaSUIT plugin available in Quantum GIS software. The software performs a TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) multicriteria method (Huang and Yoong, 1981).
To perform calculation of the parameters for the 21 catchments the following data, realized by the regional authority, have been used:

- 5 m DEM model, realized in 2007.
- Land use in scale 1:10000, realized in 2015.
- Landslides inventory from IFFI project, updated in 2017.
- Hydrographical network and culvert data from CTR 1:5000, 2007.
- Floods data from the AVI archive (Guzzetti et al., 1994) and from the database of events in the period 2005-2016 (Luino and Turconi, 2017).
- Aerial photographies, shooted in 2014.

A survey of the whole area has been performed in order to control the real and current conditions of the catchments and to evaluate the ongoing mitigation works that actually regards catchments n° 9, 10 and 16 with the stabilization of landslides, and n° 10 and 15 with structural works to the streambed final stretch. The overflow channel realization is part of the larger project for the Bisagno stream. A project for structural works in the streams are actually at the design stage for catchment n° 9.

3 Results

The geodatabase, collected through the calculation of the 19 parameters and shown in table 4 and 5, evidences a certain variability of values. In table 6 the time of concentration values obtained with the different formulae are shown.
For the set 1 parameters, drainage density, being affected by the bedrock and permeability, evidences higher values for the catchments from n°1 to 8, while mean slope is always high apart, relatively, for the smaller catchments n° 9, 17 and 18. Melton ratio is particularly high for catchments n° 19 and 20; ruggedness number presents high values

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for n° 3 and 7. Hypsometric index is always high due to the similar morphological asset of the catchments. Landslides surface, in percentage of the catchment surface, shows a large variability with the maximum values in catchments n° 3, 4, 5 and 6. Mean bifurcation ratio is low only for catchment n° 9. Time of concentration values are always short, due to the small dimensions of catchments and morphometric features; n° 5, 9, 17, 18, 19 and 20 have values shorter than 30 min. The higher number of flood events, more than 17, interested catchments n° 4, 10 and 16, while floodable areas shows a significant high value for catchment n° 9.

For set 2 parameters, soil consumption is always high and superior to 20%, at catchment scale, in n° 4, 5, 8, 9, 10, 12, 17 and 18; n° 9 reaches a value of about 50%. The final km culverted percentage for the main stream is over 30%, that means a 300 m long culvert, for n° 8, 9, 12, 15 and 21 with 100% for n° 12 and 21. Terraces are spread on more than the 20% of the surface in catchments n° 4, 6, 14, 15, 17 and 18.

Set 3 parameters describe the elements exposed at risk: catchments n° 8, 9 and 16 appears as the ones in the worst condition.

The analysis of data in the geodatabase evidences how catchment n° 9 often emerges for critical values, followed by n° 6, 8 and 17. But leaving a qualitative approach for the quantitative one that is obtained by the application of the S-MCA techniques, some more meaningful results may be obtained. The first application of the method has been performed without assuming different weights at *priori* to the describing parameters; even the same relative importance has been assumed for environmental factors (set 1 and 2) and for the social ones (set 3).The values obtained by the calculation have been ordered in 5 classes, being the number 1 the more critical, or the one that requests a higher level of attention for the risk mitigation strategies. Results are shown in figure 8, while table 7 provides the score values obtained using all the parameters (priority scale A), only the anthropogenic origin ones (priority scale B) and only the natural origin ones (priority scale C) for the environmental factors. A further calculation has been performed assuming proportional weights to the social factors, that is giving a major importance to the higher risk level respect to the lower ones. The results are collected in fig. 9 and in table7 and constitute the priority scale D.

4 Discussion

The results of the application of the S-MCA technique to the 21 small catchments represent an attempt to give a decision support tool to plan and manage investments for works aimed at mitigating geo-hydrological risk in an area hardly hit by floods, flash floods and landslides in the past, as addressed by many authors (De Brito et al., 2016). Ranking alternatives in flood and risk mitigation strategies have been largely implemented and addressed to decision makers, using different S-MCA techniques. The need of optimizing economic resources and to mitigate risk is essential in critical situation with high inhabitants' density, strong anthropogenic modifications and characterized by

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a high hazard. Besides, flash flood events are strongly localized and in the recent years hit prevalently some catchments (tab. 4): n° 4, 10 and 16 present the higher numbers, even if the more critical events happened in n° 8, 9, 10 and 15. Considering that all the studied area is characterized by high hazard for the possible hit of super-cell systems and presents high hazard even for the peculiar geomorphological features, the question is what could happen if a localized and intense event would hit every catchment. For this reason, and for the highly inadequate actual situation, it seems necessary to assess a priority scale that take into account both natural features of the catchments and the anthropogenic modifications that enhanced the risk level in order to obtain a priority scale on a quantitative base.

The priority scale A obtained evidences the critical situation of catchment n° 9 that emerged even at a qualitative analysis level, with n° 3 and 8 in the second rank and n° 1 in the third that were more difficult to recognize. These results suggest that, possibly, the higher attention in planning resources for risk mitigation works at catchments scale should be paid to these higher-level ranks catchments. A detail study for the punctual activities would be essential, considering the necessity of eventual enlargement of embankments and culverts, for example, but even acting along the slopes with stabilization of landslides and reduction of diffuse erosion with an integrated approach.

Priority scale B and C have been obtained considering, respectively, only the anthropogenic parameters and only the natural ones, in order to evidence the different eventual influence of the two sets. Considering the scale C the natural tendency of catchments to geo-hydrological risk emerges a bit differently and, examining the scale A, a possible influence of anthropogenic modifications arise more clearly. Effectively catchments n° 8 and 9 have been particularly interested by human activities: the soil consumption is high, as high is the percentage of the final km culverted streambed. We can deduce that human interventions enhanced the most critical situations, while in other context the effect has been lower, even if always in the increasing direction.

The situation changes a little assuming a different weight to the social parameters, that is considering of proportional major importance the higher exposition to risk: the priority scale always sees catchments n° 3, 8 and 9 at the higher ranks, giving a further confirmation of how critical their situation is. At the opposite side of the priority scale, catchments n° 12, 18, 19, 20 and 21 are always stable in the lower rank, meaning a possible lower level of attention, in respect to the other ones. For example, the Fereggiano catchment (n° 15) critical situation is well known even at international level: the heavy rainfall in 2011 caused 6 casualties and many damages. Despite that it ranks at the 4th level in the priority scale. It does not mean that its risk level is not high, but that it has been hit by a heavy rainfall that caused a devastating consequence. If such an event would hit one of the other studied catchment, like n° 9 for example, the effect would be, probably, similar or even worst. At the same time the D scale shows that catchments in the lower rank position are almost the half in respect to the ones at the same position in scale A.

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Considering the high-risk level of the whole area the rank in the scale must be considered as an additional information: it does not mean that no mitigation work should be performed in catchments at the lower rank position, but only that the other ones should be considered more urgent.

Another consideration regards limitations in the approach related to peculiar situations that dos not emerge from the comparison: in Geirato catchment (n° 14) is present a large landslide dam that is a potential source of high hazard, not limited to the catchment itself but possibly to the main Bisagno one. This limitation could be overcome adding a parameter for punctual peculiar situations, but it has not been considered in the present work.

Finally, mitigation works would have a direct influence in the priority scale method: besides the stabilization of landslides, the structural interventions on streams would have the effect of modifying and reducing the extension of floodable areas and then even of the areas exposed at risk. In this way the methodology could be used even to simulate the effects of some structural important and expensive works on the overall rank in the priority scale. This information could be included in the cost/benefit analysis.

5 Conclusion

Mitigation strategies for geo-hydrological risk request a catchment scale approach that results particularly crucial in a composite context where hazard related to natural features concur together with high anthropogenic modification of the territory and high vulnerability (Pasche et al., 2008). More in general prevention of geo-hydrological risk requests a decision-making process that is complex, affected by uncertainty (Akter and Simonovic, 2005; Kenyon, 2007) and often with limited economic resources at disposition.

Besides, an area characterized by many small catchments is complex to manage and a strong programming and planning is essential. The proposed method for prioritize planning for risk mitigation works at catchment scale could be used as a support tool to quantitatively address economic resources that usually are limited and request a strong optimization (Gamper et al., 2006). The approach could be even used in different context at sub-catchment scale to point out the more critical situations and basing the comparison on different sets of parameters depending on the active processes in the area. The procedure may be adapted and modified with weighting of selected parameters in order to give major importance to the ones considered more crucial. Another adjustment of the method is possible considering the relative importance to the environmental set of parameters in respect to the social ones: depending on the value that we would assign to the different aspects of the evaluation, different weight may be assumed.

The application of the methodology in a high-risk area allowed to obtain a priority scale that is actually partially confirmed by the structural intervention that local authority is operating: some are in design phase and some are in construction. The critical situation of catchment n° 9 is actually being approached and the solution has been found in some

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important design for the adjustment of the culvert and of stream embankments; besides an overflow channel is going to be realized in the Bisagno catchment, involving even the Fereggiano one (n° 15). These works are largely expensive but are now essential to reduce risk in a situation where the anthropogenic modification almost saturated all the available spaces in the floodplain, like happened in all the small catchments examined in the present study. The risk mitigation would require a holistic approach at catchment scale, considering all the processes acting, their mutual relationships and trying to address all the problems, considering that what happens along the slopes influences even the lower portion of the catchment itself (Blöschl et al., 2013; Samuels et al., 2006). Moreover, the cost of intervention along the slopes is usually significantly less economically impacting than the structural works are.

The cost of interventions has not been considered in the present study as the aim of the work was to compare the small catchments and realize a priority scale of attention to address planning on risk basis but could be included in the methodology and perhaps developed in a subsequent phase. Its role would be at the same level of environmental and social factors and a weight could be assigned to balance between the three. Such evaluation could be done after a preliminary assessment of the interventions in all the comparing catchments; the application of the method in such a case could address more precisely the investment of economic resources.

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Figure 1: Land use of the studied catchments (ref. to table 1). A: urban area; B: meadows; C: cultivations; D: woods; E: rocks and areas hit by fire.

Figure 2: Gradient in the studied catchments.

Figure 3: Simplified lithology of the studied catchments.

Figure 4: The hydrographical network with main streams culverted last stretch of the studied catchments; the light blue circles are proportional to the number of floods in the catchments in the period 1900-2016 (Guzzetti, 1994; Luino and Turconi, 2017).

Figure 5: Landslides in the studied catchments discriminated by activity status (IFFI database, 2017 update).

Figure 6: Man made terraces in the studied catchments.

Figure 7: The flow chart for the prioritizing method: the spatial multicriteria analysis allows to compare 3 sets of un-homogeneous parameters to realize a classification of the catchments that can be used as a decision support system in risk mitigation planning.

Figure 8: The priority scale obtained using all the parameters, excluding DSGSD for the calculation of landslides.

Figure 9: The priority scale obtained using all the parameters, excluding DSGSD for the calculation of landslides and weighting the social factors.

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646 **Table 1:** The main morphometric features of the studied catchments.

Stream name	Catchment number	Area (km^2)	Hydrographical network length (m)	Main stream length (m)	Mean altitude (m)	Minimum altitude (m)	Maximum altitude (m)
T. LERONE	1	21,1	79150	8274	510	0	1189
T. CANTARENA	2	4,5	22573	4289	444	0	922
T. CERUSA	3	23,1	142921	7946	506	0	1177
T. LEIRA	4	27,5	144486	6249	410	0	1001
T. BRANEGA	5	4,7	26733	3339	290	0	859
T. FOCE	6	3,5	18629	3354	191	0	598
T. VARENNA	7	22,3	140566	10393	461	0	995
R. MOLINASSI	8	1,8	9246	3707	222	0	545
R. CANTARENA	9	1,9	5621	2443	131	0	435
R. CHIARAVAGNA	10	10,7	60531	6838	272	0	658
T. TORBELLA	11	5,0	21644	3946	232	14	635
R. LAGACCIO	12	3,4	7866	2773	199	0	493
T. VELINO	13	3,2	12439	3034	236	18	543
T. GEIRATO	14	7,8	27863	4368	296	47	779
T. MOLINETTO	15	4,7	17197	4239	216	10	564
T. STURLA	16	13,3	54024	6995	316	0	845
R. PRIARUGGIA	17	1,5	3745	2680	145	0	491
R. CASTAGNA	18	1,4	5672	2652	165	0	540
R. BAGNARA	19	1,6	6816	2645	293	0	823
R. S. PIETRO	20	1,3	5940	2597	279	0	724
T. NERVI	21	9,0	51201	6166	391	0	846

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650 **Table 2:** The morphometric parameters formulae used.

Morphometric parameter	**Formulae**
Drainage density	$D_d = \frac{\sum L}{S}$
Melton ratio	$(H_M - H_{Mm})/(S)$ ½
Ruggedness number	$Rn = D_d * (H_M - H_m)$
Hypsometric integral	$Hi = \frac{(H - H_m}{(H_M - H_m)}$
Bifurcation ratio	$Rb = \frac{N_u}{N_{u+1}}$
Catchment surface	S
Stream length	L
Strahler order	u
Main stream length	L_m
Main stream gradient	i
Mean elevation	H
Main stream difference in height	d
Maximum elevation	H_M
Minimum elevation	H_m
Medium elevation	H
Mean gradient of the slopes	y

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654 **Table 3:** Time of concentration formulae used.

Time of concentration	Formulae
Pasini	$t_c = 0.108 * \frac{(A * L_m)^{1/3}}{i^{1/2}}$
Ventura	$t_c = 0.127 * (S/i)$ ½
Pezzoli	$t_c = 0.055 * \frac{L_m}{i^{1/2}}$
Kirpich	$t_c = 0.095 * \frac{{L_m}^{1.155}}{d^{0.385}}$
NRCS-SCS	$t_c = 0.57 * \frac{L_m^{0.8} * (X+1)^{0.7}}{y^{1/2}}$ $X = \frac{1000}{CN} - 10$ *CN*= curve number

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658 **Table 4:** The geodatabase with the chosen criteria related to geo-hydrological hazard. The *a* through *j* parameters are related to natural features, while the *k* through *m* are determined by anthropogenic
660 modifications.

	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*
Catchment number	**Dd (km^{-1})**	**Mean gradient (%)**	**Mi**	**Rn**	**Hi**	**Landslide (%)**	**Rb mean**	**Time of concentration (')**	**Floods number**	**Floodable area 200 y (%)**	**Soil consumption (%)**	**Culvert last km (%)**	**Terraces (%)**
1	3,75	56,5	0,26	4,45	0,43	0,2	0,28	82,64	2	0,3	10,9	5,1	12,1
2	4,96	55,9	0,43	4,58	0,48	0,4	0,25	36,15	0	0,6	17,1	25,0	14,1
3	6,19	60,4	0,25	7,29	0,43	6,6	0,31	81,34	1	0,7	7,4	7,4	19,2
4	5,25	62,1	0,19	5,26	0,41	4,3	0,32	73,37	20	0,2	20,7	10,5	20,1
5	5,71	46,1	0,40	4,90	0,34	6,5	0,24	29,53	3	0,6	27,8	9,0	9,9
6	5,34	45,4	0,32	3,19	0,32	4,9	0,26	35,29	4	0,5	9,5	22,2	40,3
7	6,30	56,0	0,21	6,27	0,46	0,6	0,30	110,08	6	0,3	16,9	11,4	9,6
8	5,06	47,2	0,40	2,76	0,41	0,0	0,21	33,80	2	3,4	20,4	45,9	18,8
9	3,01	31,8	0,32	1,31	0,30	0,0	0,07	27,16	4	10,6	49,4	34,4	6,6
10	5,65	49,4	0,20	3,72	0,41	0,1	0,29	77,65	17	2,7	23,4	17,6	5,3
11	4,33	46,3	0,28	2,69	0,35	0,8	0,29	39,58	1	1,9	13,6	0,0	18,0
12	2,33	45,1	0,27	1,15	0,40	0,0	0,31	34,43	0	0,1	36,3	100,0	0,0
13	3,84	55,0	0,29	2,02	0,42	2,8	0,31	35,75	1	1,8	7,3	35,7	5,6
14	3,58	49,9	0,26	2,62	0,34	0,2	0,37	50,12	2	0,6	7,7	11,8	29,2
15	3,68	48,2	0,26	2,04	0,37	0,0	0,30	55,11	4	3,4	19,0	80,4	26,8
16	4,05	50,6	0,23	3,42	0,37	0,0	0,32	85,44	10	2,0	13,8	9,8	16,7
17	2,58	32,6	0,41	1,27	0,30	0,0	0,13	26,56	0	0,5	34,0	17,2	32,3
18	4,04	38,6	0,46	2,18	0,31	0,0	0,39	26,06	0	0,0	22,3	3,6	32,3
19	4,35	50,8	0,66	3,58	0,36	1,3	0,22	19,56	0	0,1	15,1	10,7	14,6
20	4,47	55,3	0,63	3,23	0,39	0,0	0,32	20,38	0	0,0	8,6	18,2	12,8
21	5,66	65,8	0,28	4,79	0,46	0,7	0,29	65,20	7	0,4	3,3	100,0	11,5

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664 **Table 5:** The geodatabase with the evaluation of the surfaces (%) and punctual elements at risk in the studied catchments, according to the EU Flood Directive 2007/60/CE.

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Catchment number	R1 risk area (%)	R2 risk area (%)	R3 risk area (%)	R4 risk area (%)	R2 risk elements	R4 risk elements
1	0,19	0,02	0,00	0,16	0	0
2	0,14	0,61	0,02	0,48	1	0
3	0,16	0,18	0,04	0,53	6	0
4	0,08	0,18	0,00	0,14	2	1
5	0,04	0,41	0,01	0,38	1	1
6	0,07	1,03	0,00	0,45	0	0
7	0,13	0,37	0,00	0,17	1	0
8	0,20	2,30	0,00	3,21	0	2
9	0,02	0,24	0,00	10,54	0	13
10	0,07	0,57	0,04	2,61	0	3
11	0,08	0,70	0,08	1,73	0	0
12	0,00	0,00	0,00	0,14	0	0
13	0,01	0,60	0,73	1,05	0	0
14	0,08	0,97	0,02	0,52	1	1
15	0,00	0,28	0,05	3,30	0	2
16	0,27	0,64	0,06	1,70	0	0
17	0,11	0,15	0,02	0,50	0	0
18	0,00	0,00	0,00	0,00	0	0
19	0,00	0,05	0,00	0,11	0	0
20	0,00	0,01	0,00	0,02	0	0
21	0,02	0,09	0,01	0,35	0	0

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670 **Table 6:** Time of concentration for the studied catchments: 5 methodologies have been used and the mean value has been chosen as representative in table 4.

Catchment number	Pasini (m)	Ventura (m)	Pezzoli (m)	Kirpich (m)	NRCS-SCS (m)	Mean value (m)
1	109,0	105,5	82,1	47,0	69,6	82,6
2	43,8	40,9	35,5	24,7	35,8	36,1
3	108,8	108,3	77,5	45,0	67,1	81,3
4	103,6	115,1	59,3	36,6	52,3	73,4
5	34,7	35,3	23,6	18,0	36,1	29,5
6	43,7	42,4	32,9	23,3	34,2	35,3
7	145,3	131,6	125,2	65,1	83,2	110,1
8	38,2	32,2	38,2	26,1	34,3	33,8
9	33,9	32,9	25,5	19,1	24,4	27,2
10	102,4	94,3	85,2	48,4	58,0	77,6
11	49,9	48,7	37,1	25,5	36,6	39,6
12	46,9	48,2	31,4	22,5	23,2	34,4
13	46,1	45,6	33,3	23,5	30,3	35,8
14	66,1	67,1	45,4	29,8	42,2	50,1
15	75,1	70,6	59,9	36,9	33,0	55,1
16	117,2	111,1	92,0	51,4	55,5	85,4
17	32,1	29,0	27,9	20,5	23,4	26,6
18	30,5	27,5	26,6	19,8	25,9	26,1
19	21,2	19,4	17,7	14,5	25,0	19,6
20	22,0	19,8	19,3	15,4	25,4	20,4
21	84,5	78,3	69,4	41,3	52,5	65,2

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674 **Table 7:** The priority scales - A: using all the parameters; B: using parameters *k, l* and *m* (ref. Tab. 2); C: using parameters *a* through *j* (Tab. 2); D: using all the parameters and weighting the social ones (tab 3).

676

Catchment number	Priority scale A	Priority scale B	Priority scale C	Priority scale D
1	5	5	4	4
2	4	4	4	3
3	2	3	1	1
4	4	4	3	3
5	4	5	3	3
6	4	4	3	3
7	5	5	4	4
8	2	2	2	1
9	1	1	2	2
10	4	4	4	4
11	5	4	4	4
12	5	4	5	5
13	3	3	2	3
14	4	4	4	4
15	4	3	4	4
16	4	4	4	3
17	5	4	5	4
18	5	5	5	5
19	5	5	4	5
20	5	5	5	5
21	5	4	5	5

Priority scale
1
2
3
4
5

678

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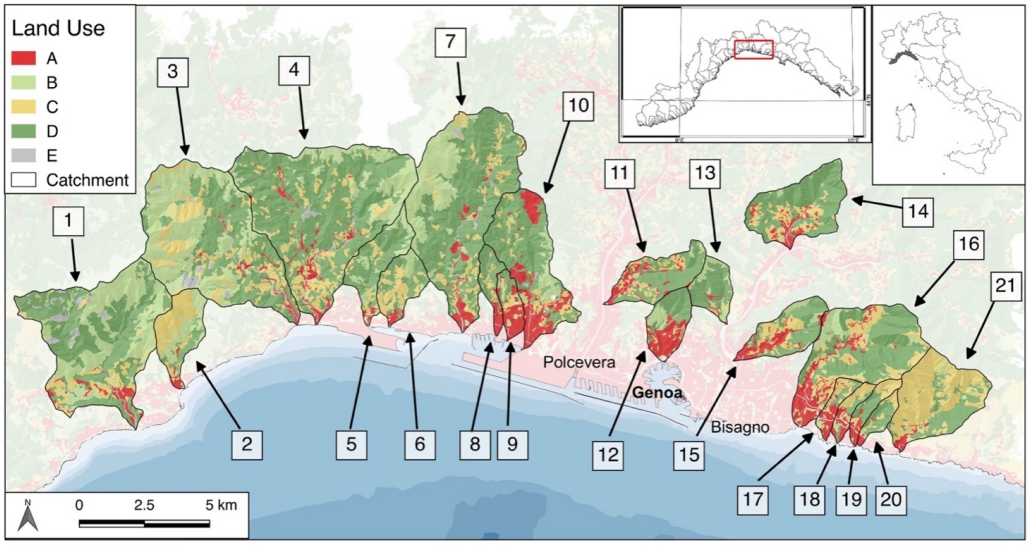

682 Figure1:

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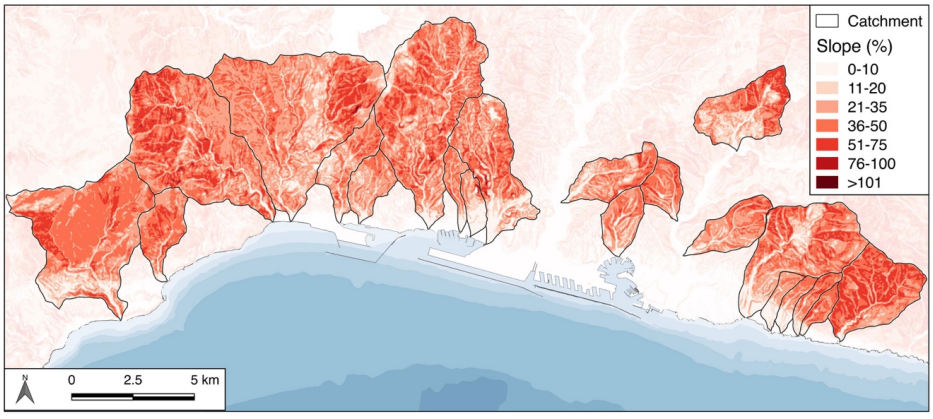

686 Figure 2:

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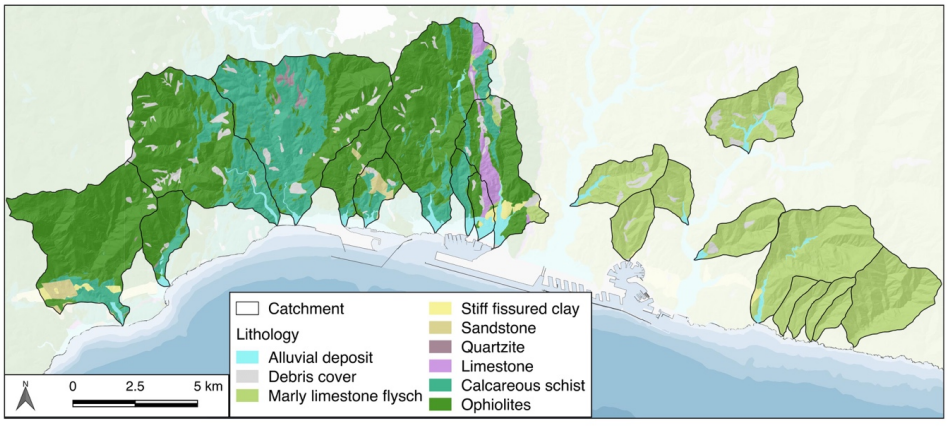

690 Figure3:

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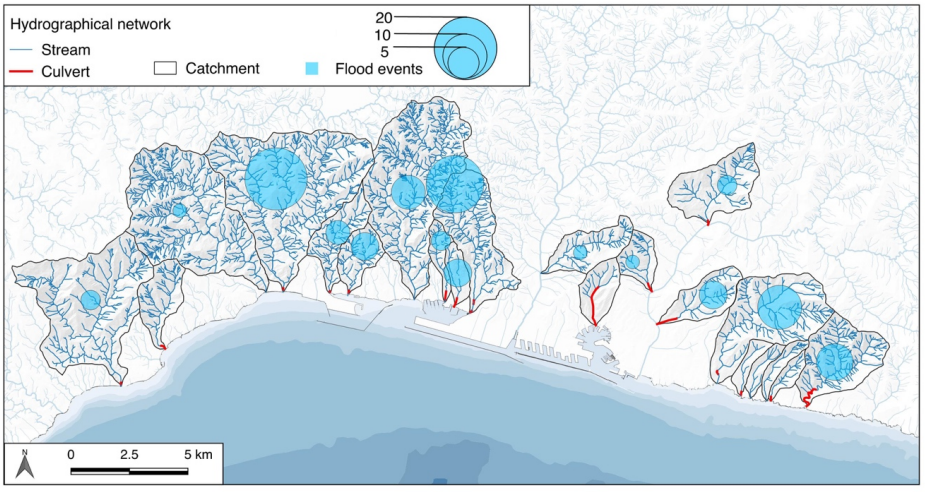

694 Figure 4:

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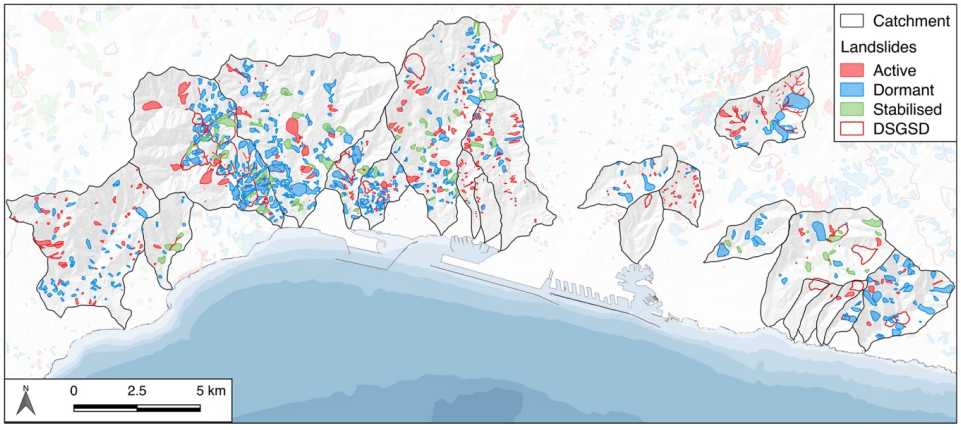

696 Figure 5:

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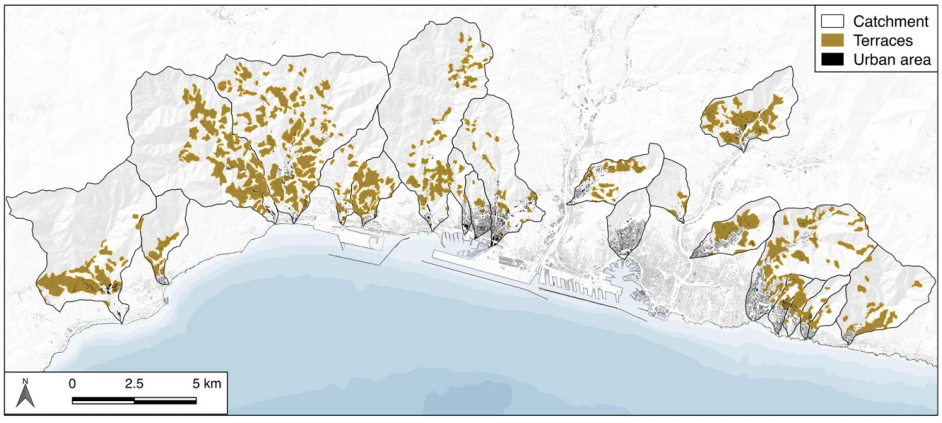

700 Figure 6:

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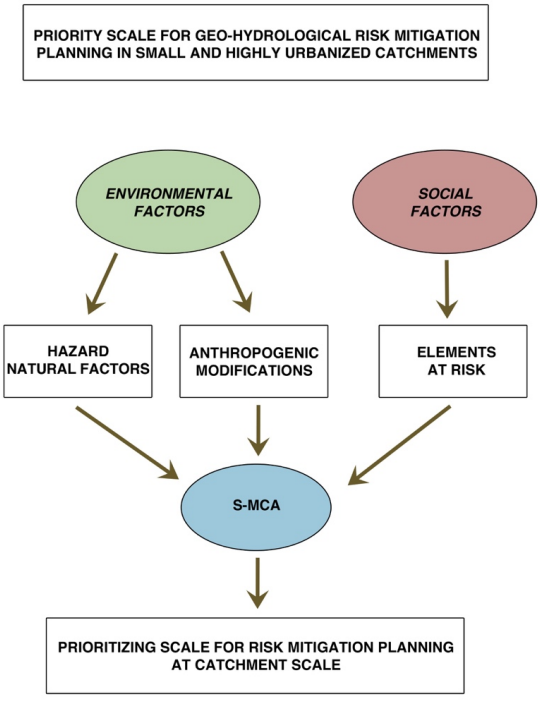

704 Figure 7:

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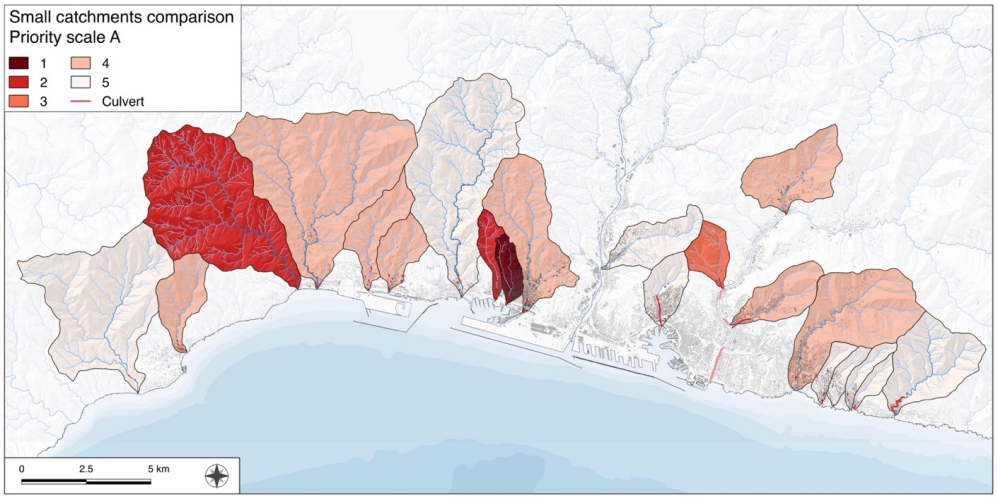

706 Figure 8:

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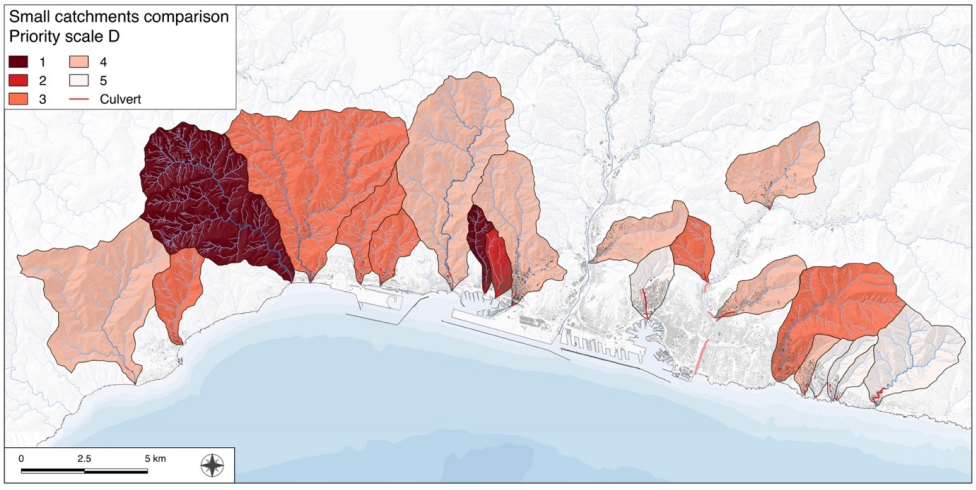

710 Figure 9: