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Mapping direct and indirect fluvial hazard in the Middle Calore River valley (southern Italy)

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INTRODUCTION

Fluvial environment is characterized by delicate equilibriums, constantly threatened by human disturbances. An incorrect management of such environment can increase hazard and associated risks. In recent years, and especially in the second half of the last century, many rivers underwent substantial geomorphological changes (Liebault and Piegay, 2002; Rinaldi, 2003; Surian and Rinaldi, 2003, Surian et al., 2009; Perşoiu and Rădoane, 2011). These changes mainly consisted of channel narrowing and riverbed degradation and were mostly related to human interventions. They had consequences also in terms of fluvial hazard and associated risks, as they produced new geomorphological landsurfaces, hanging few meters above the water level and often cultivated or anthropized, which were subject to over-flooding during flood events (Allamano et al., 2009). Floods are constantly and directly associated to the fluvial dynamics; thus, this kind of hazard is to be considered as a form of *direct* fluvial hazard. The landsurfaces produced by channel narrowing and riverbed degradation are always bordered downslope by steep fluvial scarps. These latter are subject to undercutting processes, that increase the probability of landslides to occur. Differently from floods, landslides are not constantly associated with fluvial dynamics, so the related hazard cannot be considered as a direct fluvial hazard. However, in this particular case, landslides are induced by a typical fluvial process, i.e. undercutting. Thus, the hazard associated to this particular kind of landslides can be considered as a form of *indirect* fluvial hazard.

The probability of a given landsurface to be overflooded during a particular flood event is unquestionably controlled by the increase of the water level during the event, but also by the nature and the elevation of the landsurface above the riverbed (Domeneghetti et al., 2013; Mazzorana et al., 2013). Thus, a geomorphological approach can provide useful data in the framework of flood hazard assessment. Similarly, the hazard associated with landslides induced by undercutting along the fluvial scarps is affected by the frequency and intensity of undercutting processes. Fluvial scarps that directly border the active channel are constantly subject to undercutting. Thus, the landslide hazard will be here higher. Also in this case, data derived from detailed geomorphological survey are fundamental in assessing hazard and risk. GIS are extremely useful to process, quantify and graphically represent data and results derived from geomorphological analysis (Diakakis, 2011).

In this note, the results of a detailed geomorphological analysis were processed in GIS environment to map both landsurfaces with different degrees of flood hazard, on a relative scale, and fluvial scarps with different hazard associated to undercutting-induced landslides. These data have been interpreted in the framework of the degree and type of anthropization of the landscape to produce corresponding relative risk maps. The method was applied to a

7.7 km^2-wide sector of the middle Calore River alluvial plain (southern Italy) (Fig. 1). In the second half of the last century, this river underwent remarkable geomorphological changes, which greatly affected the morphology of the alluvial plain (Magliulo et al., 2013). In particular, a mean narrowing up to 66% and an incision generally ranging from 2 to 4 meters took place and concurred to transform the channel morphology from transitional to single-tread.

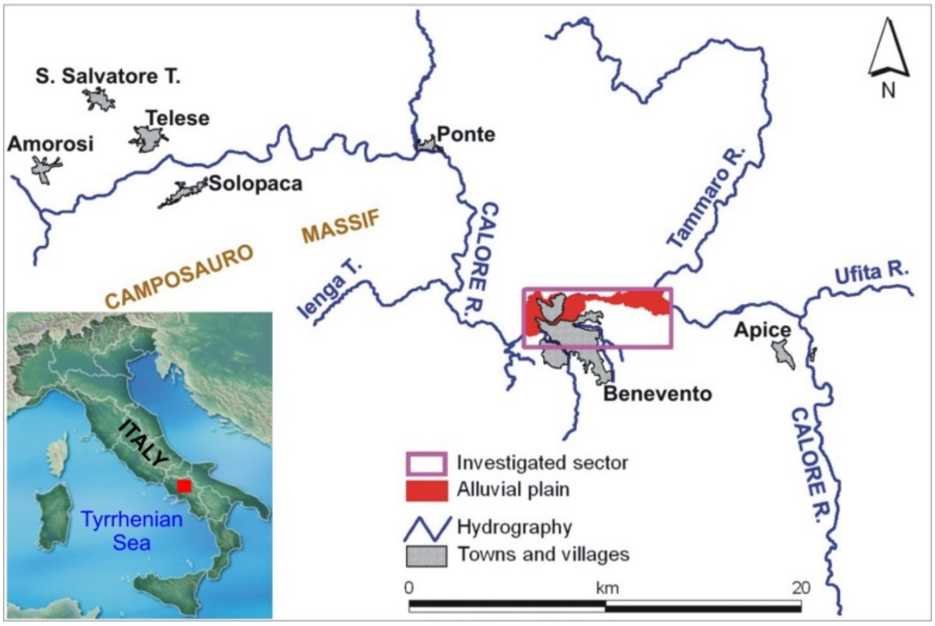

Fig. 1 – Location map of the study area

MATERIALS AND METHODS

The first step of this study was the compilation of a GIS-based geomorphological map of the study area (Valente and Magliulo, 2012; Fig. 2A) by processing data collected using classical techniques of geomorphological analysis. In particular, the results derived from the analysis of (i) 1:10,000-scale color orthophotos, (ii) vectorial topographic maps digitized from 1:10,000 raster maps with contour interval of 10 m, (iii) 1:25,000-scale topographic maps, and (iv) 1:34,000-scale black-and-white aerial photographs, were checked and/or integrated with those collected from a detailed field survey and introduced into the ArcGis 9.3 software. An “Anthropization Map” (Fig. 2B) was also produced by introducing into the GIS software the results of the visual interpretation of the orthophotos.

The flood hazard (direct fluvial hazard; Fig. 3A) was considered the highest (i.e. “very high” or “high”), on a relative scale, in depressed areas (e.g., abandoned channels, lateral incisions, etc.) and on landforms occurring within the active channel (e.g., fluvial bars and islands). Decreasing levels of flood hazard were considered with increasing altitude of the landsurfaces above the water level. To assess the risk, intersection procedures, in GIS environment, between the flood hazard map (Fig. 3A) and the anthropization map were carried out. The flood risk (Fig. 3B) was considered “null” on every un-anthropized landsurface, independently from the degree (class) of hazard. On anthropized landsurfaces, the degree of risk was defined by increasing the degree (class) of relative hazard by one. In this preliminary phase of the study, the type of anthropization (e.g., urbanized or agricultural areas), was not taken into account.

The hazard associated to undercutting-induced landsliding of fluvial scarps (indirect fluvial hazard; Fig. 3C) was assessed taking into account the frequency and the intensity of the undercutting caused by river flowing. Thus, the hazard, on a relative scale, was considered the highest for those scarps directly bordering the active channel, as the undercutting is here continuous. For scarps not directly bordering the active channel, the hazard was assessed taking into account the flood hazard of the landsurface located immediately downslope (Fig. 3A). In fact, undercutting processes affect these scarps only when the underlying landsurface is completely overflooded. To assess the indirect fluvial risk (Fig. 3D), the anthropization of the landsurface located upslope to a given scarp was taken into account by intersecting, in GIS environment, the indirect fluvial hazard map (Fig. 3C) with the anthropization map. The indirect fluvial risk was always considered “null” if the landsurface was not anthropized. On the contrary, when the area upslope to the scarp was urbanized and/or cultivated, the risk was assessed by increasing by one the degree (class) of indirect fluvial hazard.

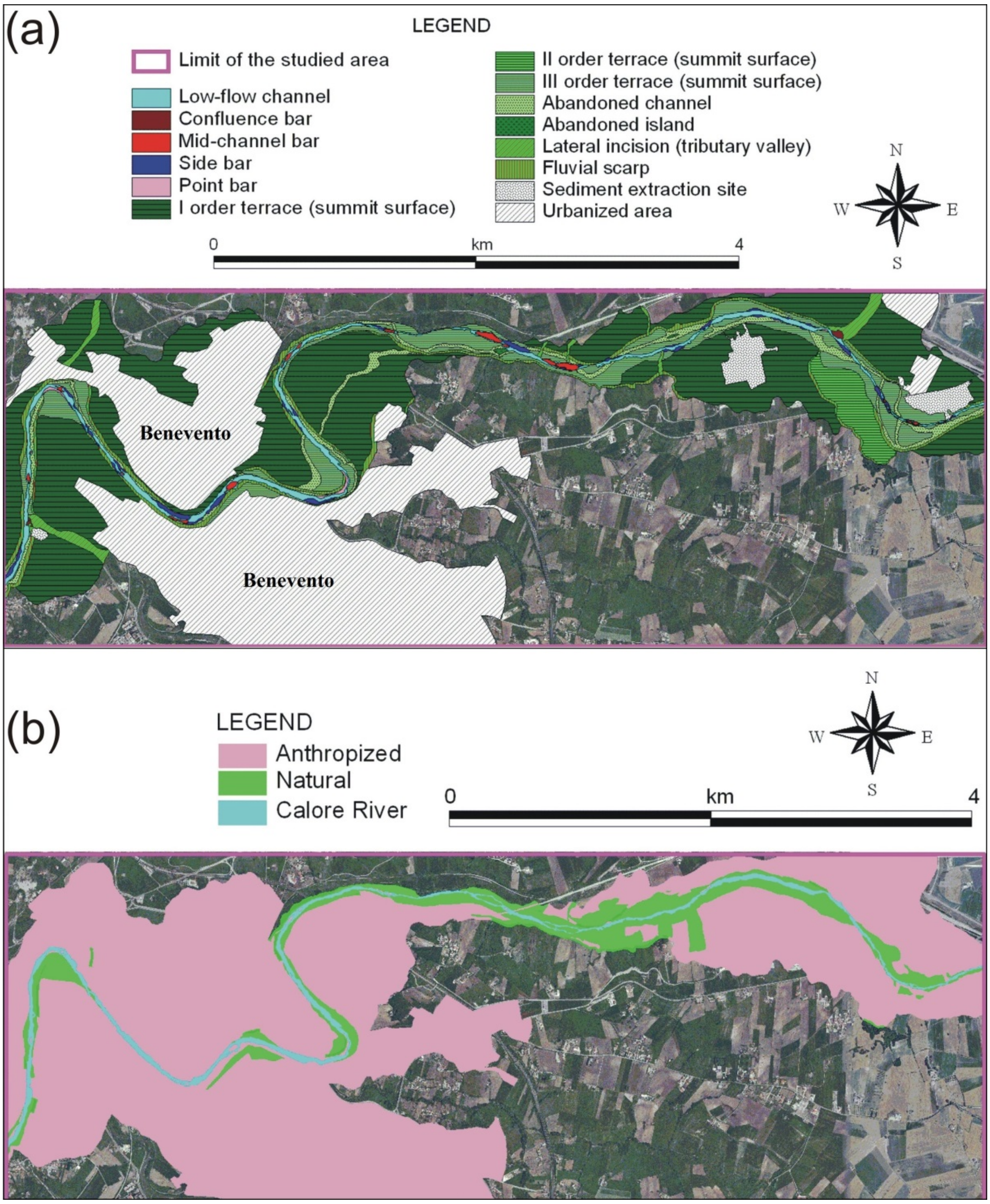

Fig. 2 – (A) GIS-based geomorphological map of the recent alluvial plain of the Calore River in the study area (from: Valente and Magliulo, 2012). (B) Anthropization map of the study area.

RESULTS

The geomorphological analysis highlighted the occurrence, in the study area, of various fluvial landforms, including three orders of river terraces (Valente and Magliulo, 2012). As stated above, highest degrees of flood hazard (i.e., “very high” and “high”) were assigned to the most depressed landforms and/or to those located very close or within the active channel, such as fluvial bars and islands, lateral incisions and abandoned channels. The lower terrace (III order) hangs ~2 meters above the mean water level. Thus, a “moderate-high” flood hazard was assumed. “Moderate-low” and “low” flood hazards were assigned to the II and I order terraces, respectively. In general, landsurfaces characterized by “low” flood hazard strongly predominated, as they occupied 74.7% of the studied area (Fig. 3A and 4A).

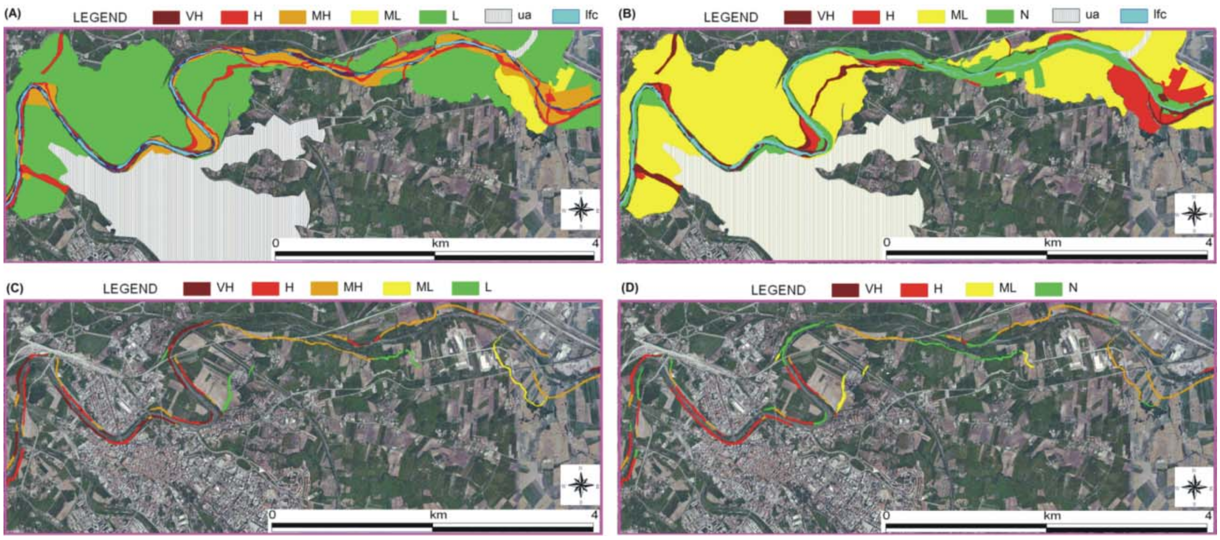

Fig. 3 – (A) Flood hazard map. (B) Flood risk map. (C) Undercutting-induced landslides hazard map (indirect fluvial hazard). (D) Undercutting-induced landslides risk map (indirect fluvial risk). LEGEND – VH: very high; H: high; MH: moderate-high; ML: moderate-low; L: low; N: null; ua: uninvestigated area; lfc: low-flow channel.

The anthropization of most of the landsurfaces characterized by “low” flood hazard determined conditions of “moderate-low” risk, which affected 73.1% of the study area (Fig. 4B). The northern part of the town of Benevento is entirely located on a wide I order terrace (Fig. 2A), characterized by “low” relative flood hazard; however, the intense urbanization of this geomorphological landsurface determined here a “moderate-low” relative flood risk (Fig. 3B).

The geomorphological analysis also showed the occurrence of 24 fluvial erosional scarps (Fig. 2A), shaped in alluvial, loose or poorly-cemented deposits. These deposits mainly consisted of loose sands and silts along the currently active scarps, while the oldest scarps resulted mainly shaped in poorly-cemented gravels and sands. These scarps resulted to be affected by different degrees of relative hazard and risk (Fig. 3). The undercutting-induced landslide hazard (Fig. 4C) resulted, on a relative scale, mainly “moderate-high”, as it characterized 34.8% of the total length of the scarps, and, subordinately, “high” (29.5%) and “very high” (21.6%). The intense anthropization of most of the landsurfaces bordering these scarps determined conditions of “high” and “very high” risk along the 36.0% and 34.8% of the scarps, respectively (Fig. 4D). Obviously, the highest relative indirect fluvial risk was assessed along the fluvial erosional scarps occurring within the town of Benevento.

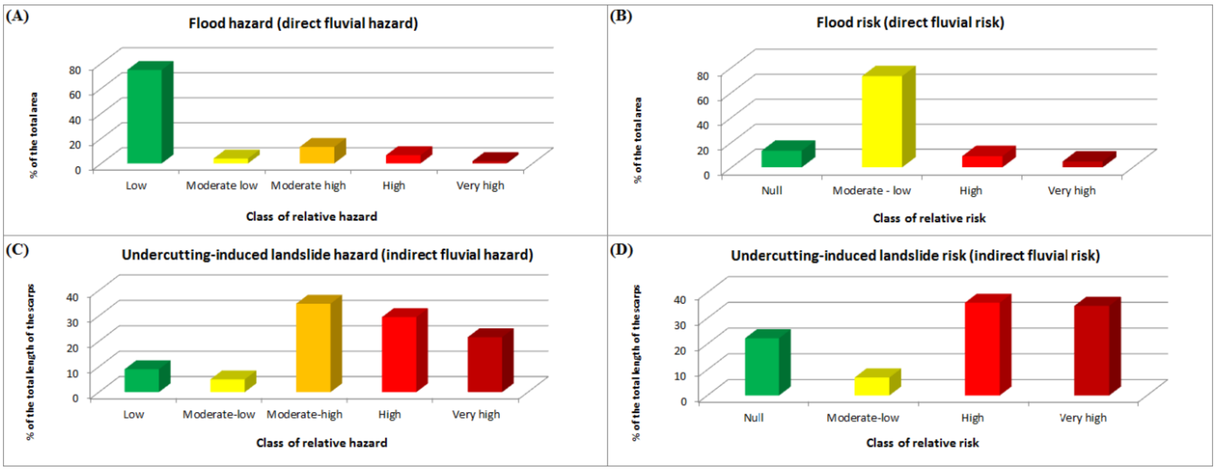

Fig. 4 – Frequency histograms of the different hazard and risk classes in the study area. See text for details.

CONCLUSIONS

This preliminary study allowed recognizing and mapping geomorphological landsurfaces and features affected by different degrees of direct and indirect fluvial hazard and risk, on a relative scale, by using a detailed, classical, GIS-aided geomorphological approach. Notwithstanding the research should be completed with quantitative data about the water levels during the floods, the vulnerability and the cost, and notwithstanding robust statistical approaches could integrate the proposed approach, this study represents a first but fundamental step for a correct assessment of the fluvial hazard and risk in an anthropized area.

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