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FLOOD HAZARD ANALYSIS IN THE OLIVETO RIVER BASIN

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EXTENDED ABSTRACT

Generalmente, un'alluvione è un allagamento temporaneo di aree che di solito non sono ricoperte d'acqua. Pertanto, le alluvioni possono causare ingenti danni al territorio, alle infrastrutture e agli insediamenti presenti, con conseguenze economiche, ambientali e sociali anche mortali. Le principali forzanti sono forti precipitazioni, ostruzioni dei ponti, rotture di dighe, cambiamenti dell'uso del suolo, pressione antropica, etc. In molti casi, queste forzanti vengono analizzate singolarmente, senza quindi un'analisi integrata di tutte le principali cause.

La valutazione del pericolo di alluvione, insieme alla definizione delle priorità in termini di obiettivi e misure, è la base per le fasi di valutazione e gestione del rischio di alluvione e la sua corretta valutazione deve ridurre la soggettività e considerare tutte le principali forzanti. Da questo punto di vista, le tecniche di telerilevamento ed i sistemi informativi geografici (GIS), insieme alla modellazione idrologico-idraulica accoppiata, sono state ampiamente utilizzate per fornire gli strumenti per effettuare una valutazione del rischio di alluvione. Tra i modelli idrologici e idraulici, HEC-HMS e HEC-RAS sono ampiamente utilizzati in quanto molto affidabili e gratuiti.

L'articolo descrive un caso di studio sulla valutazione della pericolosità da alluvione nel bacino del torrente Oliveto attraverso un'analisi multi-hazard. In questa analisi sono stati presi in esame aspetti geomorfologici, sedimentologici, climatici, idrologici e idraulici, insieme all'individuazione delle criticità che possono aumentare la pericolosità idraulica, per identificare le aree soggette a potenziali allagamenti. Il bacino analizzato si trova in Calabria, una regione del sud Italia, all'imboccatura meridionale dello Stretto di Messina. Dal punto di vista amministrativo fa parte del comune di Motta San Giovanni, all'interno dell'area metropolitana di Reggio Calabria ed al suo interno sono presenti i centri abitati di Motta San Giovanni, nella parte collinare, e della sua frazione costiera Lazzaro in prossimità della foce. Quest'ultima parte è quella maggiormente antropizzata, con insediamenti residenziali, turistici, industriali e commerciali e con due ponti, uno stradale lungo la SS106 e l'altro ferroviario lungo la linea Reggio Calabria-Metaponto. Dal punto di vista idrografico il torrente Oliveto è caratterizzato da un regime torrentizio, con prolungati periodi di secca e con piene spesso improvvise ed intense. Nella parte collinare sono presenti due invasi, Scillupia e Vena. Il primo invaso è naturale mentre il secondo è artificiale e sono collegati attraverso un canale quasi totalmente artificiale.

La metodologia di valutazione della pericolosità è stata articolata in sei fasi: (1) perimetrazione e caratterizzazione morfometrica del bacino, mediante QGIS (2) analisi delle caratteristiche geologiche, sedimentologiche e climatiche, (3) analisi storica delle precedenti alluvioni, (4) ispezioni in situ, (5) modellazione idrologica mediante HEC-HMS, (6) modellazione idraulica mediante HEC-RAS. Le ispezioni in situ hanno evidenziato numerose criticità localizzate in varie parti del bacino: frane attive, alcune delle quali in sinistra idraulica dello Scillupia e del canale di collegamento col Vena, degrado del conglomerato bituminoso dello sbarramento del Vena, presenza di rocce di grandi dimensioni, presenza di folta vegetazione nel tratto vallivo, forte curvatura dell'alveo a ridosso del ponte stradale, presenza di varchi arginali a ridosso del centro abitato.

L'analisi effettuata evidenzia l'insorgenza di condizioni di pericolosità già per eventi non eccezionali, caratterizzati da un tempo di ritorno pari a 50 anni, ed in assenza di dam break e di trasporto solido. La presenza di varchi arginali vicino alle aree antropizzate è un fattore che incrementa notevolmente la pericolosità, insieme all'insorgenza di eventuali fenomeni di dam break e trasporto solido, soprattutto se di notevole dimensione. Pertanto, il principale aspetto evidenziato dall'articolo è che un'analisi di pericolosità da alluvione effettuata considerando un'unica forzante può sottostimare sensibilmente la pericolosità. Inoltre, un altro importante aspetto evidenziato dall'articolo è che un'analisi effettuata a scala locale e non a scala di bacino può essere caratterizzata da risultati fuorvianti. Infine, lo sviluppo di tecniche accurate di valutazione della pericolosità da alluvione può agevolare legislatori e decisori nella corretta valutazione della pericolosità e dei potenziali effetti di interventi e misure di mitigazione della pericolosità, soprattutto in ambienti complessi caratterizzati da numerose forzanti come in questo caso studio.

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ABSTRACT

Generally, a flood is a temporary flooding of areas that usually are not covered with water. The main driving factors are heavy rainfall, bridge obstructions, dam break, land use change, anthropogenic pressure etc. In many cases, individual driving factors are analyzed without an integrated analysis of all the main driving factors. The paper describes a case study on the flood hazard assessment in the Oliveto River basin through a multi-hazard analysis. In this analysis geomorphological, sedimentological, climatic, hydrological, and hydraulic aspects, together with the identification of criticalities that can increase the hydraulic hazard, were analyzed to identify areas subject to potential flooding. The paper mainly highlighted that a flood hazard analysis, carried out by considering only a single driving factor, can underestimate the hazard. Furthermore, the paper shows how that the analyses on a local scale and not on a basin scale can lead to partial or misleading results. Indeed, the analysis highlighted the possibility of hazard conditions just for non-exceptional events, characterized by a 50-year return period, in absence of dam break and sediment transport. The hazard conditions increase due to the openings in the levees near man-made areas and it can be further increased if a dam break occurs or if the discharge is not only water but also includes sediments and blocks.

Keywords: *flood hazard, bridge obstruction, hydrological and hydraulic modeling; dam break, levees openings*

INTRODUCTION

Generally, a flood is a temporary flooding of areas that usually are not covered with water. Thus, floods can cause considerable damage to the territory, the infrastructures, and the settlements present, with economic, environmental, and societal consequences, even fatal (Tingsanchali, 2012; Doocy *et alii*, 2013; Aceto *et alii*, 2016; Petit-Boix *et alii*, 2017).

The main driving factors are heavy rainfall, bridge obstructions, dam break, land use change, anthropogenic pressure etc. (Delenne *et alii*, 2012; Xiao *et alii*, 2017; Woldensenbet *et alii*, 2018; Versaci *et alii*, 2018; Cowles *et alii*, 2019; Canale et alii, 2020; Bombino *et alii*, 2022; Foti *et alii*, 2022). In many cases, individual driving factors are analyzed without an integrated analysis of all the main driving factors (Perosa *et alii*, 2022).

The assessment of the flood hazard is the basis for the flood risk assessment and management phases, together with the prioritization of objectives and measures, and a correct assessment must reduce subjectivity and consider all these factors (Chen *et alii*, 2011; Sicilia *et alii*, 2013; Neale & Weir, 2015; Kourgialas & Karatzas, 2017; Scionti *et alii*, 2018; Toosi *et alii*, 2019; Rezende *et alii*, 2020; Barbaro *et alii*, 2021; Blazquez *et alii*, 2021; Serra-Llobet *et alii*, 2022).

From this point of view, remote sensing, and geographic information system (GIS) techniques have been widely used (Tehrany *et alii*, 2013; Grimaldi *et alii*, 2016; Zhang *et alii*, 2019; La Salandra *et alii*, 2022), together with coupled hydrological-hydraulic modelling (Grimaldi *et alii*, 2018; Ahmadisharaf & Kalyanapu, 2019; Nogherotto *et alii*, 2019), and provide a tool to carry out a flood hazard assessment. Among the hydrological and hydraulic models, HEC-HMS and HEC-RAS are widely used as they are very reliable and free (Oleyiblo & Li, 2010; Halwatura & Najim, 2013; Tharur *et alii*, 2017; Abdessamed & Abderrazak, 2019; Cowles *et alii*, 2019).

The paper describes a case study on the flood hazard assessment in the Oliveto River basin through a multi-hazard analysis. In this analysis geomorphological, sedimentological, climatic, hydrological, and hydraulic aspects, together with the identification of criticalities that can increase the hydraulic hazard, were analyzed to identify areas subject to potential flooding.

SITE DESCRIPTION

The Oliveto River basin is in the Calabria region (southern Italy), at the southern mouth of the Strait of Messina (Fig. 1). The basin is entirely part of the municipal territory of Motta San Giovanni, in the metropolitan area of Reggio Calabria. In this basin the agricultural areas are much larger than the anthropized areas. In fact, within the basin there are only two inhabited centers, Motta San Giovanni in the hilly part and its fraction Lazzaro, in the coastal part, plus some small minor hamlets for an anthropized area of less than 0.5 km^2, while the basin has an area of about 14 km^2. The Oliveto River is located a few hundred meters from Motta San Giovanni, with a difference in height of more than 50 m, while its mouth is in Lazzaro, in a heavily man-made area with residential and tourist settlements, industrial and commercial sheds, and two bridges of two important infrastructures, the highway 106 and the Reggio Calabria-Metaponto railway line. Furthermore, in

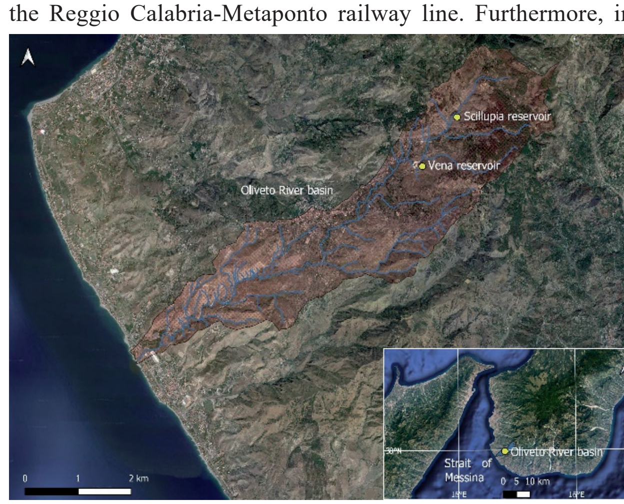

Fig. 1 - Study area location

the basin there is a dense road network, both in the anthropized part and along the slopes.

The Oliveto River, like many other Calabrian rivers, has a torrential and irregular regime, characterized by extensive dry periods with frequent sudden flood events, generated by short and intense rainfalls (Terranova *et alii*, 2009). The main tributaries of the Oliveto River are the San Basilio and the Fosso Rocca of San Giovanni, while in the hilly part of the basin, upstream of Motta San Giovanni, there are two reservoirs called Scillupia and Vena (Figs. 2-3).

The Scillupia is a natural reservoir located at an elevation of about 700 m and bounded by an earth dam. The Vena is an artificial reservoir located at an elevation of about 630 m. Its morphometry was evaluated through bathymetric surveys and both reservoirs have a maximum depth of about 7 m, a surface of about 10000 m^2 and a volume of about 50000 m^3. The reservoirs are connected by an artificial channel, with a total length of about 1 km which in the last 70 m becomes a natural channel.

Fig. 2 - Scillupia reservoir

Fig. 3 - Vena reservoir

METHODOLOGY

The flood hazard assessment in the Oliveto River basin is divided into the following phases:

1. perimeter and morphometric characterization of the basin;
2. geological, sedimentological, and climatic analysis;
3. historical analysis of flood events;
4. on-site inspections;
5. hydrological modelling;
6. hydraulic modelling.

The perimeter and morphometric characterization of the Oliveto River basin was carried out using QGIS starting from the DTM with square mesh of 5 m available in the OpenData section of the Calabrian Geoportal (http://geoportale.regione.calabria.it/).

The area, perimeter, orientation, main stream length, total stream length, maximum and average heights, average slope, Gravelius index, hypsometric integral, Curve Number (CN) and time of concentration were calculated. The estimation of the last parameter was made using the formulas of Giandotti (1934), Kirpich (1940) and NRCS (1997). About the CN estimation, the input data are the shapefiles of land cover and of Lithological Map. The first data are from the Corine Land Cover project fourth level relates to the years 2018 and freely available on the government agency website "*Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA)*" (https://www.isprambiente.gov.it/it/attivita/suolo-e-territorio/copertura-del-suolo/corine-land-cover). The second data are available in the OpenData section of the Calabrian Geoportal (http://geoportale.regione.calabria.it/opendata). A value of CN (Williams *et alii*, 2012) was associated with each land use category of the Corine Land Cover fourth level and with each lithological class. The average values of CN were calculated as a weighted average of the values of each land use category and of each lithological class, with weight equal to the area of each category and class.

The geological features were assessed by on-site inspections and by analysis of the shapefiles of Geological and Lithological Map available in the open data section of the Calabrian Geoportal (http://geoportale.regione.calabria.it/opendata). The sedimentological features were assessed through laboratory analysis of sediment samples. The climatic features were assessed analysing the data available in the Historical Data section of the Calabrian Multi-Risk Functional Center (http://www.cfd.calabria.it/).

The historical analysis of flood events was carried out analysing the "Historically flooded areas in Calabria" database of the National Research Council – Research Institute for Hydrogeological Protection of Cosenza. This database contains events of hydrogeological instability which occurred in Calabria in the last few centuries. For each event, information on date and damage are available.

The fourth phase concerned on-site inspections to verify the state of conservation of the structures and whether there are any further criticalities that could increase the hydraulic hazard.

The hydrological modelling of the Oliveto River basin was carried out using the HEC-HMS version 4.6.1 software to evaluate the peak runoff with different return period, and to evaluate the dam break conditions of the reservoirs. Runoff is calculated based on the Soil Conservation Service Curve Number (SCS-CN) method (Usda Natural Resource Conservation Service, 1986). This is an empirical, event-based method widely used due to its conceptual simplicity and easy of coding (Hawkins *et alii*, 2009; Sajikumar & Remya, 2015; Li *et alii*, 2017). As return period were considered 50, 200 and 500 years, according to the current legislation of the Calabria region, to analyse rare and exceptional events, and 2, 5, 10 and 20 years to analyse frequent events. Preliminarily, the rainfall events with a fixed return period were estimated by applying the Two Component Extreme Value (TCEV) distribution (Stediger 1983; Fiorentino *et alii*, 1987; Versace *et alii*, 1989; Rossi & Villani 1992) and the Gumbel distribution (1958). The rainfall data were estimated from the rainfall time series available in the Historical Data section of the Calabrian Multi-Risk Functional Centre (http://www.cfd.calabria.it/). The good fit of the rainfall data to the hypothesized distribution was evaluated by Pearson's chi-squared test. In this modelling, 115 simulations were carried out to consider several conditions: absence and presence of the reservoirs, with and without dam break, frequent, rare, and exceptional events. In addition, dam break was evaluated hypothesizing the breakage of only the Scillupia or the Vena reservoir and hypothesizing the breakage of both reservoirs. Moreover, various geometric and temporal configurations of the dam break were hypothesized. In detail, an Overtop Breach of width equal to the width of the spillway, of variable height (1.5, 3 and 6 m, corresponding, in both reservoirs, to superficial, intermediate, and deep breakage) and of variable duration (0.5, 2 and 10 hours, corresponding to almost instantaneous, intermediate, and slow breakage) was hypothesized.

The hydraulic modelling was carried out with HEC-RAS version 5.0.7 software. The geometry was reconstructed by merging the DTM with square mesh of 5 m with a high-resolution DTM obtained through a topographic survey. The roughness was assessed in terms of Manning coefficient by on-site inspections according to the Chow table (1988). The modelled part extends for about 1200 m upstream starting from the mouth, is divided into 37 cross sections and includes two bridges, one highway and one railway. The modelling was carried out using the runoff values obtained with the hydrological modelling.

RESULTS

The results are presented following the five phases of the methodology mentioned above.

The morphometric characterization of the Oliveto River basin, shown in Fig. 1, highlighted that the basin has area of 13.7 km^2, perimeter of 23.6 km, orientation from North-East to South-West, main stream length of 11 km, total stream length of 46 km, maximum height of about 900 m, average height of about 540 m, average slope of about 25%, Gravelius index of about 2.3, which is characteristic of strongly elongated basins, hypsometric integral of about 0.6, which is characteristic of basins at the end of the erosion phase approaching to the equilibrium phase, and time of concentration of about 2.5 hour.

The geological analysis highlighted that the Oliveto River basin is mainly made up of hills that represent the south-western offshoots of the Aspromonte massif, sloping down towards the Ionian coast (Fig. 4).

Fig. 4 - Typical geological formation of the Oliveto River basin

Analysing the outcropping rocks from the oldest to the most recent, a crystalline-metamorphic basement is observed, which is divided into two units. The first unit is called Aspromonte Unit and is made up of rocks of medium-high grade metamorphic origin, such as gneiss, paragneiss and biotitic schists, with crystalline limestone and rare granite bodies. These are very compact and erosion-resistant rocks, with low permeability. The second unit is called Upper Phillade Unit and is made up of philladic schists with muscovite and biotite, and of low-grade metamorphic rocks. Their resistance to erosion is medium and their permeability is medium low.

The sedimentary clastic formations of the Tertiary age (especially of the Miocene) and the Pliocene, Pleistocene and Holocene soils overlap this basement. The former formation consists of variously cemented clays and sands, of chaotic and polychrome clays, of sandstones and silty clays and of sands and conglomerates and are very erodible and not very permeable, except for sands and conglomerates. The latter soils are erodible and permeable and consist of soft sandstones and silty clays, of terraced sandy-conglomeratic deposits of marine origin, of terraced conglomeratic deposits of reddish colour of fluvial origin, of slope and landslide deposits of a predominantly sandy-silty nature containing gravels , pebbles and other coarse detrital elements, of terraced alluvial deposits of a gravelly-sandy nature and of current and recent floods and coastal deposits of pebbly and gravelly-sandy granulometry.

Furthermore, the study area is one of the areas with the greatest seismic hazard in Italy and Europe due to the slow geological uplift process of the Aspromonte. In fact, numerous earthquakes of strong intensity have occurred, primarily those of 1783 and 1908. Furthermore, the lifting process is also evident from the notable incision of the streams, especially in the intermediate parts of the basin, with the formation of almost vertical slopes in correspondence with lithotypes more resistant to erosion. From these slopes it is possible to generate landslide phenomena of the collapse type, with large blocks (in the order of cubic meters) that can be transported downstream during flood events (Fig. 5).

Fig. 5 - Detail of large blocks present in numerous slopes of the Oliveto River basin

To evaluate the sediment characteristics, six samples were taken along the valley part of the Oliveto River and then analysed in the laboratory. This samples have density values between 2298 kg/m^3 and 2570 kg/m^3 and have the following average composition: pebbles (10 cm – 2 cm), with percentages between 40 and 10%; gravel (2 cm – 2 mm), with percentages between 40 and 12%; sand (2 mm – 0.62 mm), with percentages between 38 and 69%; silt and clay (less than 0.062 mm), with percentages between 16 and 6%. So, the Oliveto River is characterized by sediments with a predominantly sandy-gravelly-pebbly matrix with silt and clay, where elements (rocks and blocks) of a few cubic meters are immersed.

From the climatic point of view, the study area is of Mediterranean warm temperature (according to the Koppen classification), with both mild autumns and winters and both long and dry springs and summers. Most important climatic factors are the orographic conditions, with the Aspromonte massif that blocks the humid currents coming from the south-westerly direction, and the presence of the Strait of Messina. The combination of these factors can cause intense convective rainfall events, that are often concentrated between September and December, when the sea temperature is still high. The characterization of the pluviometry was carried out starting from the data of the rain gauges of Motta San Giovanni and of Motta San Giovanni Allai. The first gauge is located at 480 m height, the annual average rainfall is about 720 mm, with an average of 66 rainy days. The wettest months being October, November, December, and January, all with an average rainfall above 100 mm. In the summer months, the average rainfall does not exceed 10 mm, with an average of one rainy day per month. The second gauge is located at 890 m height, the annual average rainfall is about 990 mm, with an average of 89 rainy days. The wettest month is November, with an average rainfall of 185 mm and in the months of September, October, December, January, and March the average rainfall exceeds 100 mm while from April to August it is less than 50 mm.

Analysis of the historical flood database showed that in the study area, six events occurred from 1930 to today, and in three of them damage to highway and railway bridges occurred, especially during the flood of 1953.

The on-site inspections carried out highlighted that along the slopes there are numerous erosive processes due to landslides and surface runoff water. These processes are caused by high slope angles, with values up to 60-70° in correspondence with compact and erosion-resistant rocks such as gneiss and sandstones. Some of these active landslides are visible to the hydrographic left of the Scillupia reservoir that could involve both the reservoir and the artificial channel connected to the Vena reservoir (Fig. 6).

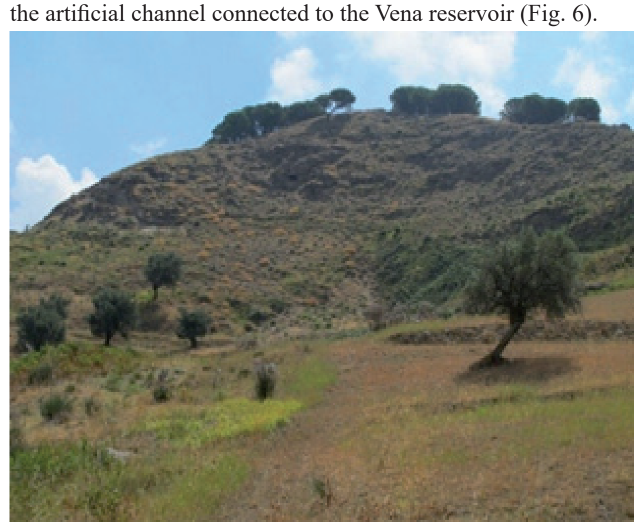

Fig. 6 - Active landslides near the Scillupia reservoir

In addition, there are some cracks in the bituminous conglomerate on the top of the dam of the Scillupia reservoir (Fig. 7).

Upstream of the highway bridge there are rocks and dense

Fig. 7 - Cracks in the bituminous conglomerate on the top of the dam of the Scillupia reservoir

Fig. 8 - Sudden change of river direction upstream of the highway bridge

vegetation, and the river suddenly changes direction near the bridge itself (Fig. 8). Below the bridge the river section is partially obstructed due to vegetation and aggradation (Fig. 9). Downstream of the highway bridge there are several openings in the levees near anthropized areas (Fig. 10), and a concrete slab, which protects the foundation of the railway bridge pile but caused an increase in the riverbed height (Fig. 11).

The results of the hydrological modeling show that the runoff values calculated with the TCEV distribution are significantly higher than those calculated with the Gumbel distribution, with increments between 50 and 80%. About the dam break, the worse condition is instantaneous deep breakage, which causes a double discharge compared to the one obtained without

Fig. 9 - Partial obstruction of the river section below the highway bridge due to vegetation and aggradation

Fig. 10 - Levees openings downstream of the highway bridge near anthropized areas.

Fig. 11 - Concrete slab near the railway bridge pile

breakage. Also, both the intermediate and the slow breakage cause negligible runoff increments due to the lamination effects that occur in the basin itself. In addition, it highlighted that the breaking of the Scillupia alone causes negligible runoff increments due to the lamination effects induced by the underlying Vena reservoir while the simultaneous breaking of the two reservoirs causes negligible increases compared to the breaking of the only Vena reservoir.

The results of the hydraulic modeling in absence of dam break (Figs. 12-16) show that frequent events, with a return period of 2 and 10 years, do not cause flooding. With a return period of 50 years, in the flat area upstream of the highway bridge and in the area between the two bridges, there are some flooding areas. Instead, with a return period of 200 years, the flooding areas extends from the flat area upstream the highway bridge to the mouth. These results show a potential flooding hazard in the terminal part of the Oliveto River just for non-exceptional events, characterized by a 50-year return period.

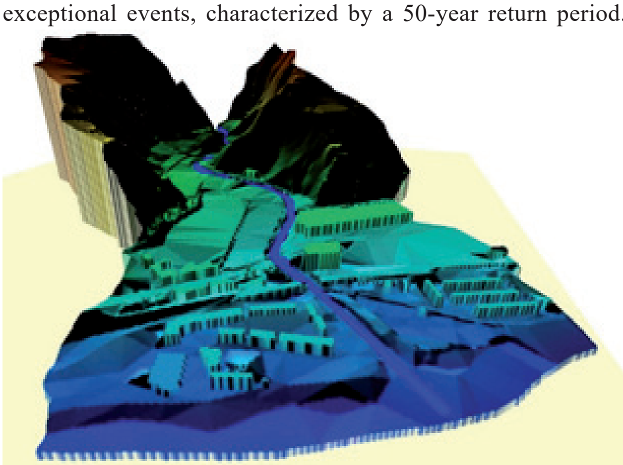

Fig. 12 - High-resolution DTM obtained through a topographic survey

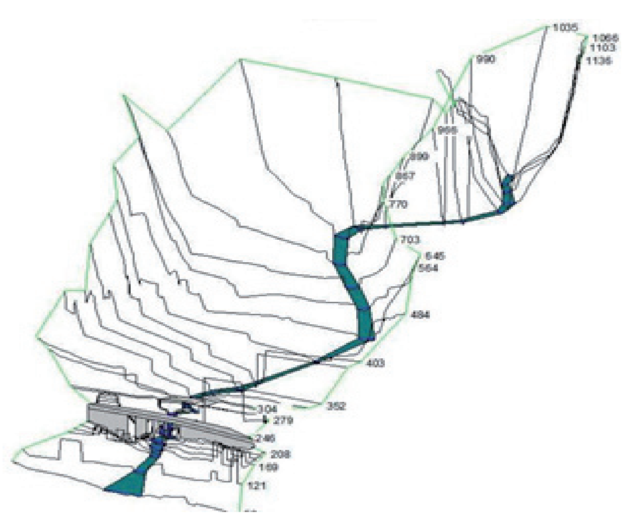

Fig. 13 - Flooded areas with return period of 2 years

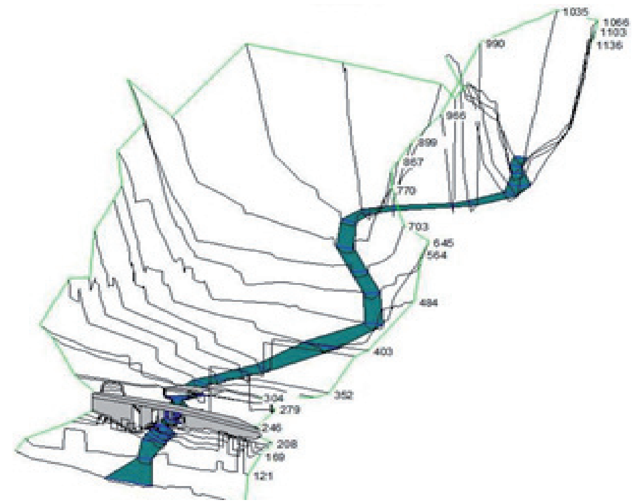

Fig. 13 - Flooded areas with return period of 10 years

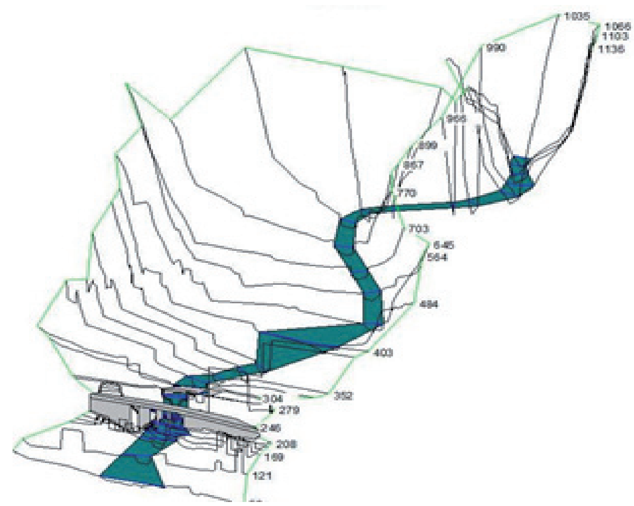

Fig. 14 - Flooded areas with return period of 50 years

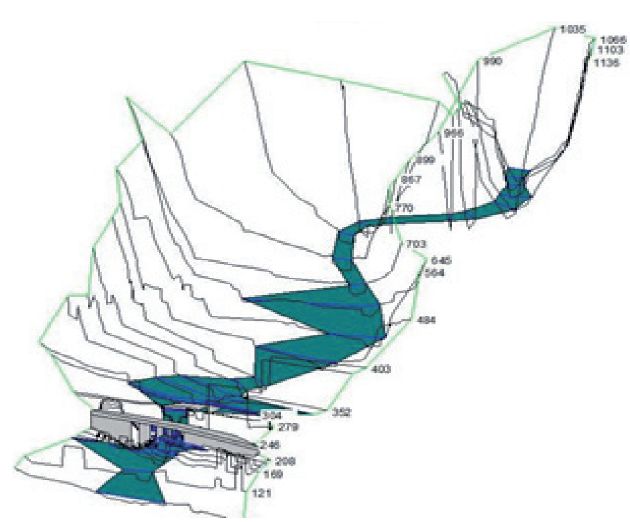

Fig. 15 - Flooded areas with return period of 200 years

The flooding hazard increases due to the openings in the levees near man-made areas and it can be further increased if a dam break occurs or if the runoff is not only liquid but also includes sediments and blocks.

DISCUSSION

This paper, through a case study in the Oliveto River basin in southern Italy, shows how the flood hazard analysis of a river is a complex process that should involve various driving factors and issues (geomorphological, sedimentological, climatic, hydrological, hydraulic, etc.).

The paper mainly highlighted that a flood hazard analysis, carried out by considering only a single driving factor, can underestimate the hazard.

Furthermore, the paper shows how that the analyses on a local scale and not on a basin scale can lead to partial or misleading results.

Indeed, many analyses mainly focus on the runoff generated by precipitation driving factor, neglecting the other factors. In this case study, hydraulic modelling has shown that for frequent events, characterized by return period of less than 50 years, there are no flood areas. On the other hand, for events characterized by return period of 50 years, modest floods are possible in the river sections downstream of the highway bridge, while for rare events characterized by return period of 200 years the possible floodable areas are much more extensive. However, the analysed basin, like many other Calabrian basins called "fiumare" (Sorriso-Valvo & Terranova, 2006; Sabato & Tropeano, 2014), is characterized by torrential and irregular hydrological regime, with extensive dry periods and frequent sudden flood, caused by short and intense rainfall, and is characterized by sediments with a predominantly sandy-gravelly-pebbly matrix with silt and clay, where elements (rocks and blocks) of a few cubic meters are immersed. In addition, from various slopes of this basin it is possible to generate landslide phenomena of the collapse type, with large blocks (in the order of cubic meters) that can be transported downstream during flood events. This combination of hydrological and granulometric characteristics causes high sediment transport which can accumulate in the valley part of the basin, where there are also anthropized areas, vegetation, and open levees. Generally, these conditions can cause over-flood phenomena (Foti *et alii*, 2020) and accumulation of sediments and vegetation close to bridges (Panici *et alii*, 2020). In this case study, the major hydraulic critical issues were observed near the highway bridge, where the river section is partially blocked by sediments and vegetation. Under these conditions, a possible flood with a modest return period, but characterized by high transport of sediments, rocks, and vegetation widely present upstream of the bridge, could obstruct the bridge itself. Another condition that increases the possible flooding hazard is related to the two reservoirs in the hilly part of the basin whose possible dam break would cause significant runoff increases. In addition, near the Scillupia reservoir there is an active landslide and they have been observed cracks in the bituminous conglomerate of the dam.

In summary, this analysis was carried out at the basin scale using high-resolution DTM and coupled hydraulic and hydrological modelling. The coupled use of these models is widely used (Aggett & Wilson, 2009; Zhang *et alii*, 2022). This analysis showed that the greatest flood hazard occurs at the highway bridge, near a man-made area, so the flood risk is also high. This result is consistent with numerous studies, where bridges, dams and nearby areas are often characterized by high flood hazard and risk (Briaud *et alii*, 2014; Mathews & Hardman, 2015; Hung & Yau, 2017; Lamb *et alii*, 2017; Koks *et alii*, 2019; Scozzese *et alii*, 2019; Ahamed *et alii*, 2020; Argyroudis & Mitoulis, 2021; Canale *et alii*, 2021).

However, the analyzes of flood hazard are often carried out on a large scale and in large basins and the level of detail and the number of driving factors analyzed are proportional to the basin size (Fan *et alii* 2016; Perosa *et alii*, 2022). On the other hand, there are few studies carried out in small basins such as Oliveto and characterized by a high level of detail as done in this paper.

CONCLUSIONS

This paper, through a case study in the Oliveto River basin in southern Italy, shows how the flood hazard analysis of a river is a complex process that should involve different issues (geomorphological, sedimentological, climatic, hydrological, hydraulic, etc.). From this point of view, developing accurate flood hazard assessment techniques can assist lawmakers and decision makers to assess the potential hazard and to evaluate the potential impacts of specific management strategies to minimize damages and mortalities, especially in complex environments where there are various types of hazard factors.

Furthermore, this paper shows that the analyses on a local scale and not on a basin scale can lead to partial or misleading results. An example of this would be the analysis of the valley part of the Oliveto River without considering aggradation near the highway bridge, due to transport of sediment, vegetation and rocks, and a dam break of the two hilly reservoirs.

REFERENCES

Abdessamed D. & Abderrazak B. (2019) - *Coupling HEC-RAS and HEC-HMS in rainfall–runoff modeling and evaluating floodplain inundation maps in arid environments: case study of Ain Sefra city, Ksour Mountain. SW of Algeria*. Environ. Earth Sci., **78**: 586. Doi: 10.1007/s12665-019-8604-6.

Aceto L., Caloiero T., Pasqua A.A. & Petrucci O. (2016) - *Analysis of damaging hydrogeological events in a Mediterranean region (Calabria).* Journal of Hydrology, **541**(A): 510-522. Doi: 10.1016/j.jhydrol.2015.12.041

Ahamed T, Duan Jg & Jo H. (2020) - *Flood-fragility analysis of instream bridges–consideration of flow hydraulics, geotechnical uncertainties, and variable scour depth.* Struct Infrastruct Eng. Doi: 10.1080/15732479.2020.1815226Ahmadisharaf E. & Kalyanapu A.J. (2019) - *A coupled probabilistic hydrologic and hydraulic modelling framework to investigate the uncertainty of flood loss estimates.* J. Flood Risk Manag., **12**. Doi: 10.1111/jfr3.12536

Aggett G.R. & Wilson J.P. (2009) - *Creating and coupling a high-resolution DTM with a 1-D hydraulic model in a GIS for scenario-based assessment of avulsion hazard in a gravel-bed river*. Geomorphology, **113**(1-2): 21-34. Doi: 10.1016/j.geomorph.2009.06.034

Argyroudis S.A. & Mitoulis S.A. (2021) - *Vulnerability of bridges to individual and multiple hazards-floods and earthquakes.* Reliability engineering & system safety, **210**: 107564. Doi: 10.1016/j.ress.2021.107564

Barbaro G., Miguez M.G., De Sousa M.M., Ribeiro Da Cruz Franco A.B., De Magalhães P.M.C., Foti G., Valadao M.R. & Occhiuto I. (2021) - *Innovations in Best Practices: Approaches to Managing Urban Areas and Reducing Flood Risk in Reggio Calabria (Italy)*. Sustainability, **13**(6): 3463. Doi: 10.3390/su13063463

Blázquez L., García J.A. & Bodoque J.M. (2021) - *Stakeholder analysis: Mapping the river networks for integrated flood risk management.* Environmental Science & Policy, **124**: 506-516. Doi: 10.1016/j.envsci.2021.07.024

Bombino G., Barbaro G., D'agostino D., Denisi P., Foti G., Labate A. & Zimbone S.M. (2022) - *Shoreline change and coastal erosion: The role of check dams. First indications from a case study in Calabria, southern Italy.* Catena, **217**: 106494. Doi: 10.1016/j.catena.2022.106494

Briaud J. L. (2015) - *Scour depth at bridges: method including soil properties. I: maximum scour depth prediction*. J Geotech Geoenviron Eng, **41**(2). Doi: 10.1061/(Asce)Gt.1943-5606.0001222.

Canale C., Barbaro G., Foti G., Petrucci O., Besio G. & Barillà G.C. (2021) - *Bruzzano river mouth damage due to meteorological events.* International Journal of River Basin Management, 1-17. Doi: 10.1080/15715124.2021.1901725

Canale C., Barbaro G., Petrucci O., Fiamma V., Foti G., Barilla G.C., Puntorieri P., Minniti F. & Bruzzaniti, L. (2020) - *Analysis of floods and storms: Concurrent conditions.* Italian journal of engineering geology and environment, 23-29. Doi: 10.4408/IJEGE.2020-01.S-03

Chen Y.R., Yeh C.H. & Yu B. (2011) - *Integrated application of the analytic hierarchy process and the geographic information system for flood risk assessment and flood plain management in Taiwan.* Nat. Hazards, **59**: 1261-1276. DOI: 10.1007/s11069-011-9831-7

Chow V.T., Maidment, D.R. & Mays, L.W., (1988) - *Applied Hydrology.* McGraw Hill Book

Cowles A., Willson C. & Twilley R. (2019) - *Effects of Land-Use Change (1938–2018) on Surface Runoff and Flooding in the Amite River Basin, Louisiana, USA Using Coupled 1D/2D HEC-RAS–HEC-HMS Hydrological Modeling*. AGU 2019 Fall Meeting. AGU, San Francisco, CA, USA.

Delenne C., Cappelaere B. & Guinot V. (2012) - *Uncertainty analysis of river flooding and dam failure risks using local sensitivity computations*. Reliability Engineering & System Safety, **107**: 171-183. Doi: 10.1016/j.ress.2012.04.007

Doocy S., Daniels A., Murray S. & Kirsch T.D. (2013). *The human impact of floods: a historical review of events 1980-2009 and systematic literature review.* PLoS Curr., **5**. Doi: 10.1371/currents.dis.f4deb457904936b07c09daa98ee8171a

Fan Y.R., Huang W.W., Huang G.H., Li Y.P., Huang K. & Li Z. (2016) - *Hydrologic risk analysis in the Yangtze River basin through coupling Gaussian mixtures into copulas.* Advances in Water Resources, **88**: 170-185. DOI: 10.1016/j.advwatres.2015.12.017

Foti G., Barbaro G., Manti A., Foti P., La Torre, A., Geria P.F., Puntorieri P. & Tramontana N. (2020) - *A methodology to evaluate the effects of river sediment withdrawal: The case study of the Amendolea River in southern Italy.* Aquatic Ecosystem Health & Management, **23**(4): 465-473. Doi: 10.1080/14634988.2020.1807248

Foti G., Bombino G., D'agostino D. & Barbaro G. (2022) - *The Effects of Anthropogenic Pressure on Rivers: A Case Study in the Metropolitan City of Reggio Calabria*. Remote Sensing, **14**(19): 478. Doi: 10.3390/rs14194781

Fiorentino M., Gabriele S., Rossi F. & Versace P. (1987) - *Hierarchical approach for regional flood frequency analysis*. Regional Flood Frequency Analysis, ed. V.P. Singh, Reidel, Dordrecht, The Netherlands, 35-49. Doi: 10.1007/978-94-009-3959-2_4

Giandotti M. (1934) - *Previsione delle piene e delle magre dei corsi d'acqua*. Memorie e studi idrografici, Servizio Idrografico Italiano (in Italian)

Grimaldi S., Li Y., Pauwels V.R.N. & Walker J.P. (2016) - *Remote sensing-derived water extent and level to constrain hydraulic flood forecasting models: opportunities and challenges*. Surv. Geophys., **37**: 977-1034. Doi: 10.1007/s10712-016-9378-y

Grimaldi S., Li Y., Walker J.P. & Pauwels V.R.N. (2018) - *Effective representation of river geometry in hydraulic Flood Forecast models.* Water Resour. Res., **54**(2): 1031-1057. Doi: 10.1002/2017wr021765

Gumbel E.J. (1958) - *Statistics of extremes*. Columbia University press, New York, USA.

Halwatura D. & Najim M. (2013) - *Application of the HEC-HMS model for runoff simulation in a tropical catchment*. Environ. Model. Software, **46**: 155-162. Doi: 10.1016/J.Envsoft.2013.03.006

Hawkins R.H., Ward T.J., Woodward D.E. & Van Mullem J.A. (2009) - *Curve Number Hydrology: State of the Practice.* ASCE Publications.

Hung C & Yau W. (2017) - *Vulnerability evaluation of scoured bridges under floods.* Eng Struct, **132**: 288-299. Doi: 10.1016/j.engstruct.2016.11.044

Kirpich Z. P. (1940) - *Time of concentration of small agricultural watersheds*. Civil Engineering, **10**(6): 362.

Koks E.E., Rozenberg J., Zorn C., Tariverdi M., Vousdoukas M., Fraser S.A., Hall J.W. & Hallegatte S. (2019) - *A global multi-hazard risk analysis of road and railway infrastructure assets*. Nat Commun, **10**(1): 2677. Doi: 10.1038/s41467-019-10442-3.

Kourgialas N.N. & Karatzas G.P. (2017). *A national scale flood hazard mapping methodology: the case of Greece – Protection and adaptation policy approaches.* Sci. Total Environ., **601-602**: 441-452. Doi: 10.1016/j.scitotenv.2017.05.197.

La Salandra M., Roseto R., Mele D., Dellino P. & Capolongo D. (2022) - *Probabilistic hydro-geomorphological hazard assessment based on UAV-derived high-resolution topographic data: The case of Basento river (Southern Italy).* Science of The Total Environment, **842**: 156736. Doi: 10.1016/j.scitotenv.2022.156736.

Lamb R., Aspinall W., Odbert H. & Wagener T. (2017) - *Vulnerability of bridges to scour: insights from an international expert elicitation workshop.* Nat Hazards Earth Syst Sci, **17**(8): 1393-1409. Doi: 10.5194/nhess-17-1393-2017.

Li S., Gitau M., Bosch D., Engel B.A., Zhang L. & Du Y. (2017) - *Development of a soil moisture - based distributed hydrologic model for determining hydrologically based critical source areas.* Hydrological Processes, **31**(20): 3543-3557. Doi: 10.1002/hyp.11276.

Mathews R. & Hardman M. (2017) - *Lessons learnt from the December 2015 flood event in Cumbria, UK.* Proc Instit Civil Eng-Forensic Eng, **170**(4):165-178. Doi: 10.1680/jfoen.17.00009.

Natural Resources Conservation Service (NRCS) (1997) - *Pondsplanning, design construction. Agriculture handbook.* United States Department of Agriculture (USDA).

Neale T. & Weir J.K. (2015) - *Navigating scientific uncertainty in wildfire and flood risk mitigation: a qualitative review.* Int. J. Disaster Risk Reduct., **13**: 255-265. Doi: 10.1016/j.ijdrr.2015.06.010.

Nogherotto R., Fantini A., Raffaele F., Di Sante F., Dottori F., Coppola E. & Giorgi F. (2019) - *An integrated hydrological and hydraulic modelling approach for the flood risk assessment over Po river basin.* Nat. Hazards Earth System Sci.Dis.: 1-22. Doi: 10.5194/nhess-2019-356

Oleyiblo J.O. & Li Z.J. (2010) - *Application of HEC-HMS for flood forecasting in Misai and Wan'an catchments in China.* Water Sci. Eng., 3, 14-22.

Panici D., Kripakaran P., Djordjevic S. & Dentith K. (2020) - *A practical method to assess risks from large wood debris accumulations at bridge piers*. Sci Total Environ, **728**: 138575. Doi: 10.1016/j.scitotenv.2020.138575

Perosa F., Seitz L.F., Zingraff-Hamed A. & Disse M. (2022) - *Flood risk management along German rivers–A review of multi-criteria analysis methods and decision-support systems.* Environmental Science & Policy, 135: 191-206. Doi: 10.1016/j.envsci.2022.05.004

Petit-Boix A.S.I., Rojas-Gutierrez E., Lorena A., Barbassa A.P., Josa A., Rieradevall J. & Gabarrell X. (2017) - *Floods and consequential life cycle assessment: integrating flood damage into the environmental assessment of stormwater Best Management Practices*. J. Clean. Prod., **162**: 601-608. Doi: 10.1016/j.jclepro.2017.06.047

Rezende O.M., De Franco A.B.R.D., De Oliveira A.K.B., Miranda F.M., Jacob A.C.P., De Sousa M.M. & Miguez M.G. (2020) - *Mapping the flood risk to Socioeconomic Recovery Capacity through a multicriteria index.* J. Clean. Prod., **255**. Doi: 10.1016/j.jclepro.2020.120251

Rossi F. & Villani P. (1992) - *Regional flood estimation methods.* Coping with Floods: 135-169. Doi: 10.1007/978-94-011-1098-3_8

Sabato L. & Tropeano M. (2014) - *Fiumara: a kind of high hazard river.* Physics and Chemistry of the Earth, **29**(10): 707-715. Doi: 10.1016/j.pce.2004.03.008

Sajikumar N. & Remya R.S. (2015) - *Impact of land cover and land use change on runoff characteristics*. Journal of Environmental Management, **161**: 460–468. Doi: 10.1016/j.jenvman.2014.12.041

Scozzese F., Ragni L., Tubaldi E. & Gara F. (2019) - *Modal properties variation and collapse assessment of masonry arch bridges under scour action.* Eng Struct, **199**: 109665. Doi: 10.1016/j.engstruct.2019.109665

Serra-Llobet A., J¨ahnig S.C., Geist J., Kondolf, G.M., Damm C., Scholz M., et al. (2022) - *Restoring Rivers and floodplains for habitat and flood risk reduction: experiences in multi-benefit floodplain management From California and Germany.* Front. Environ. Sci., **9**. Doi: 10.3389/fenvs.2021.778568.

Scionti F., Miguez M.G., Barbaro G., De Sousa M.M., Foti G. & Canale C. (2018) *Integrated methodology for urban flood risk mitigation in Cittanova (Italy).* Journal of Water Resources Planning and Management, **144**(10). Doi: 10.1061/(asce)wr.1943-5452.0000985.

Sicilia C.L., Foti G. & Campolo A. (2013) - *Protection and management of the Annunziata river mouth area (Italy)*. Journal of Air, Soil and Water Research, **6**: 107-113. DOI: 10.4137/aswr.s13143

Sorriso-Valvo M. & Terranova O. (2006) - *The Calabrian fiumara streams.* Zeitschrift für Geomorphologie, **143**: 109-125.

Stediger J. (1983) - *Estimating a regional flood frequency distribution.* Water Resources Research, **19**(5): 503-510. Doi: 10.1029/wr019i002p00503

Tehrany M.S., Pradhan B. & Jebur M.N. (2013) - *Spatial prediction of flood susceptible areas using rule based decision tree (DT) and a novel ensemble bivariate and multivariate statistical models in GIS.* J. Hydrol., **504**: 69-79. Doi: 10.1016/j.jhydrol.2013.09.034

Thakur B., Parajuli R., Kalra A., Ahmad S. & Gupta R. (2017) - *Coupling HEC-RAS and HEC-HMS in Precipitation Runoff Modelling and Evaluating Flood Plain Inundation Map*. World Environmental and Water Resources Congress: 240-251. Doi: 10.1061/9780784480625.022

Toosi A.S., Calbimonte G.H., Nouri H. & Alaghmand S. (2019) - *River basin-scale flood hazard assessment using a modified multi-criteria decision* *analysis approach: A case study*. Journal of hydrology, **574**: 660-671. Doi: 10.1016/j.jhydrol.2019.04.072

Tingsanchali T. (2012) - *Urban flood disaster management.* Procedia Eng., **32**: 25-37. Doi: 10.1016/j.proeng.2012.01.1233

United States Department Of Agriculture Usda (1986) - *Urban Hydrology for Small Watersheds:* Technical Release 55.

Versace P., Ferrari E., Fiorentino M., Gabriele S. & Rossi F. (1989) - *La valutazione delle piene in Calabria*. CNR-GNDCI, LINEA 1, CNR-IRPI. Cosenza: Geodata. (in Italian)

Versaci R., Minniti F., Foti G., Canale C. & Barillà G.C. (2018) - *River anthropization: Case studies in Reggio Calabria, Italy.* WIT Transactions on Ecology and the Environment, **217**: 903-912. Doi: 10.2495/SDP180761

Williams J.R., Kannan N., Wang X., Santhi C. & Arnold J.G. (2012) - *Evolution of the SCS runoff curve number method and its application to continuous runoff simulation*. Journal of Hydrologic Engineering, **17**(11): 1221-1229. Doi: 10.1061/(asce)he.1943-5584.0000529

Woldesenbet T.A., Elagib N.A., Ribbe L. & Heinrich J. (2018) - *Catchment response to climate and land use changes in the Upper Blue Nile sub-basins, Ethiopia.* Sci. Total Environ., **644**: 193-206. Doi: 10.1016/j.scitotenv.2018.06.198.

Xiao Y., Yi S. & Tang Z. (2017) - *Integrated flood hazard assessment based on spatial ordered weighted averaging method considering spatial heterogeneity of risk preference*. Sci. Total Environ., **599**: 1034. Doi: 10.1016/j.scitotenv.2017.04.218

Zhang K., Chao L., Wang Q., Huang, Y., Liu R., Hong Y., Tu Y., Qu W. & Ye J. (2019) - *Using multi-satellite microwave remote sensing observations for retrieval of daily surface soil moisture across China.* Water Sci. Eng., **12**(2): 85-97. Doi: 10.1016/j.wse.2019.06.001

Zhang K., Shalehy M.H., Ezaz G.T., Chakraborty A., Mohib K.M. & Liu L. (2022) - *An integrated flood risk assessment approach based on coupled hydrological-hydraulic modeling and bottom-up hazard vulnerability analysis.* Environmental Modelling & Software, **148**: 105279. Doi: 10.1016/j.envsoft.2021.105279.

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